



Government of India  
Bhabha Atomic Research Centre

# ANNUAL REPORT 2022



**BARC VISTA**



**Title:**

BARC VISTA: Annual Report 2022

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**Published by:**

Scientific Information Resource Division  
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Maharashtra, 400085 India  
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# Director's Message



Bhabha Atomic Research Centre (BARC) has always been a symbol of success and self-reliance, epitomizing the spirit of 'Atmanirbhar Bharat' and resonating with the celebration of 'Azadi ka Amrit Mahotsav' during the year 2022 to showcase the comprehensive achievements of BARC over the past 75 years since independence as well as the new heights to be attained in the coming 25 years.

BARC is a multidisciplinary research and development organization, which has been instrumental in the seeding and growth of numerous research programs, with direct applications to the nuclear sector, as well as spin-off benefits accruing to various other industries & sectors in the country and abroad. The centre is dedicated to pursuing activities pertaining to the nuclear fuel cycle and the use of radiation technology for societal applications. BARC, since its inception as the mother institute of DAE, has also been involved in R&D in Physical, Chemical, Biological and Material Sciences.

During the year 2022, some of the noteworthy contributions of BARC include the development of an artificial intelligence based system for carrying out inspection of PHWR fuel bundle end plate weld joints, technology for preparation of high purity low-carbon ferro-boron for making rare earth permanent magnets, Alkaline Water Electrolyzer technology for green hydrogen production, deployment of water purification units in 81 remote sites of India based on BARC-developed know-how and establishment of a new Radiation Medicine Research Centre in

Kolkata for providing state-of-art and affordable nuclear medicine services. In addition, more than 87 technologies have been transferred to entrepreneurs as part of a vibrant technology sharing initiative.

BARC continued to participate and contribute to multilateral programs aimed towards extending the frontiers of knowledge as well as towards the development of cutting-edge technologies. Development of human resources and propagation of a research culture are of equal importance in the growth and sustenance of an organization and both have received appropriate attention and importance in the programs of BARC.

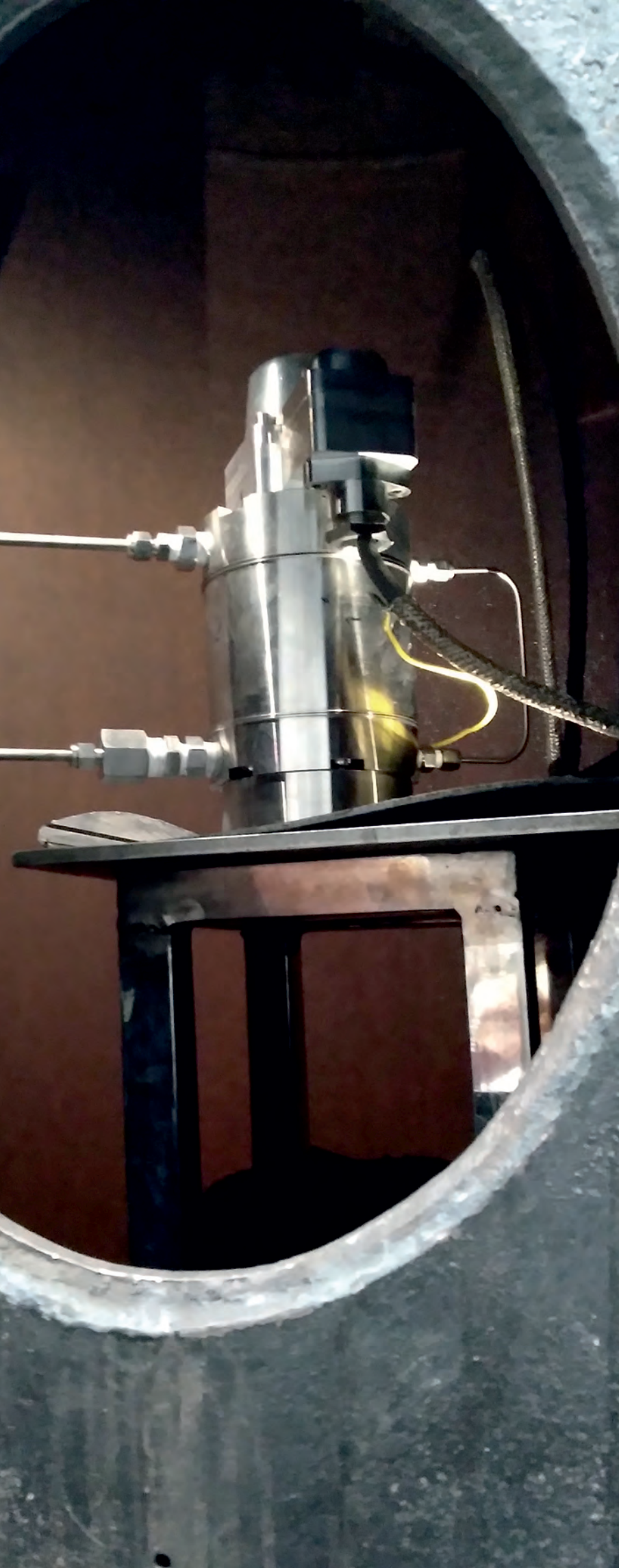
The BARC Vista-2022 will provide an account of the entire range of activities divided into 9 sections, including the introduction of two new segments viz., activities of BARC facilities in Visakhapatnam, and Safety and Security culture in BARC.

This document would certainly serve as a point of ready reference for anyone seeking information about the ongoing gamut of activities in BARC and on specific domains of the 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.

**Dr. Ajit Kumar Mohanty**

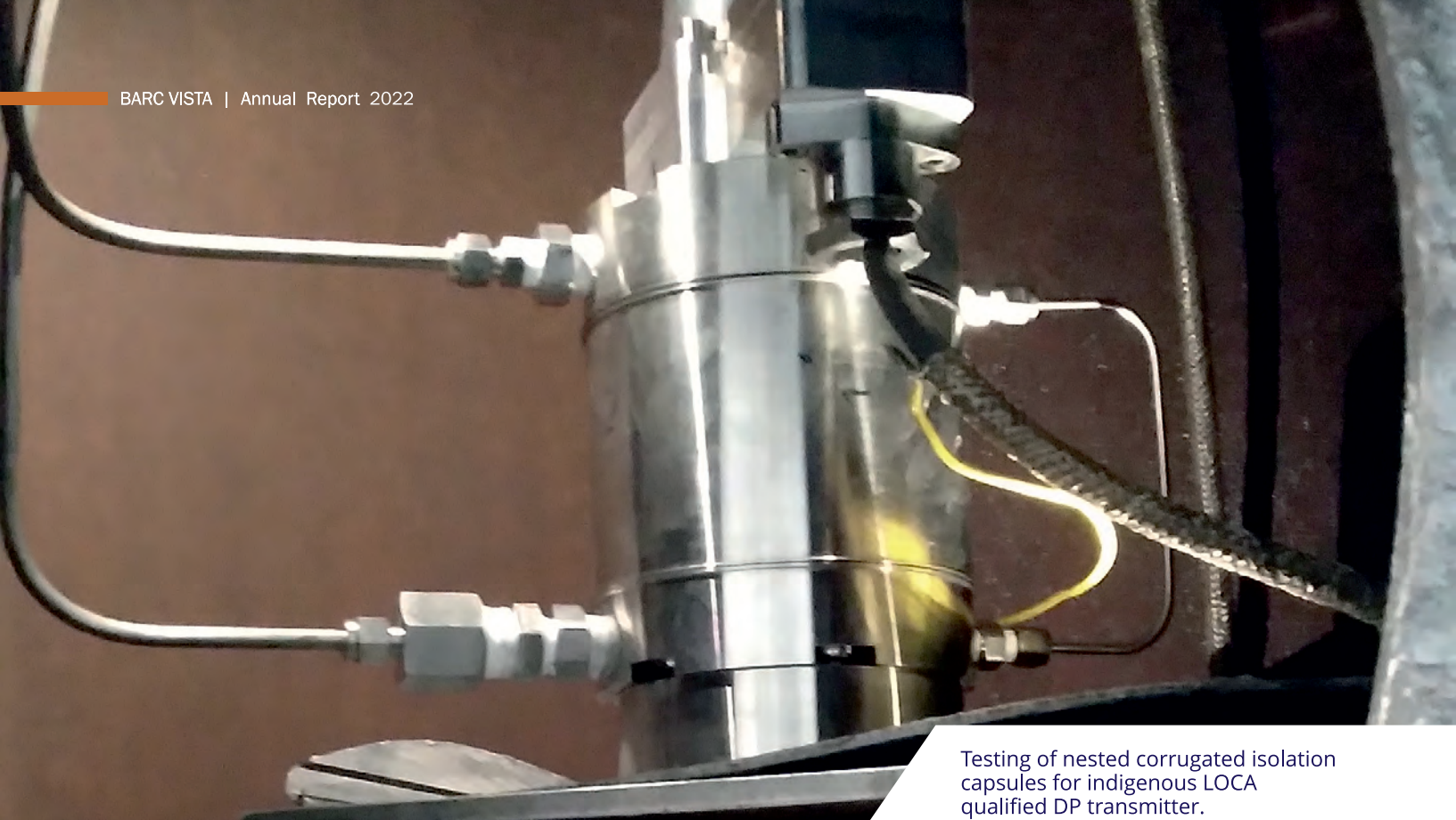


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# INDIAN NUCLEAR POWER PROGRAM

The centre 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.



Testing of nested corrugated isolation capsules for indigenous LOCA qualified DP transmitter.

# Indian Nuclear Power Program

## Development of Inspection Systems

### 700 MWe PHWR - Integrity Assessment of Calandria

To estimate the in-calandria retention time of core debris for 700 MWe Indian PHWR under a postulated severe accident scenario, the structural failure of calandria was assessed as per plastic instability, large inelastic strains and creep-stress rupture based criteria. It is observed that the calandria is well-equipped to retain the core debris for up to 42 hours before undergoing failure due to creep stress rupture in the weld region in the annular plate.

### In-service Inspection of Pressure Tubes

Two inspection heads were assembled, hydro-tested and calibrated for deployment during in-service inspection of pressure tubes of TAPS-3,



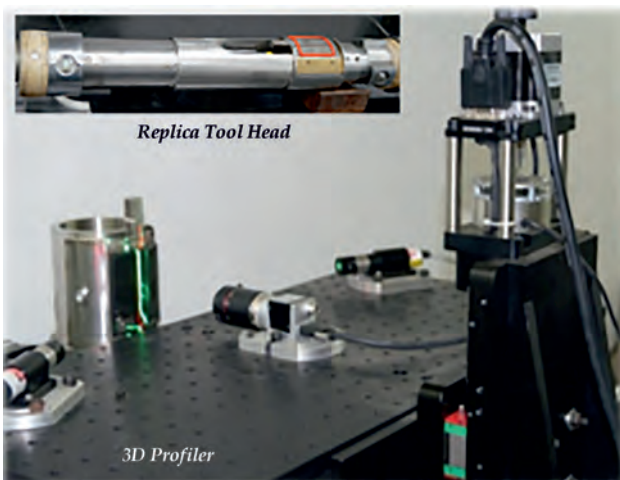
Inspection Head for 540 MWe PHWRs.

NAPS-2, KGS-4 and RAPS-2 units in different campaigns.

## Replication and Profile Measurement System for Pressure Tubes

A flaw replication and characterization system has been developed for assessment of surface flaw on the inner diameter of a 540 MWe PHWR pressure tube. The system consists of a Replica Tool and a 3D profiler, which is a laser-based flaw characterisation system. The Replica tool obtains a replica of the known flaw and the 3D profiler scans the replica to generate a 3D image of the flaw and measures its relevant dimensions.





Replica Tool and a 3D profiler.

### Wet Scraping Tool (WEST 220-Mark III)

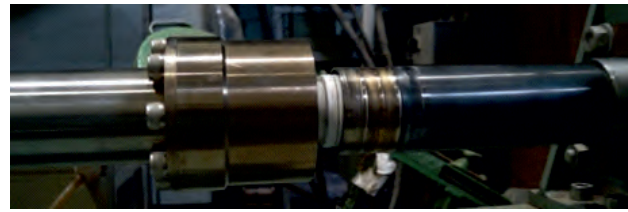
A Wet Scraping Tool has been developed to take metallic samples from the inside surface of operating pressure tubes for measuring hydrogen content build-up during service. Considering the irradiation induced radial creep of pressure tubes, a new version of tool has been developed to take scrap samples in 86.7 mm diameter pressure tubes. A prototype tool has been fabricated and tested.



WEST-220 Mark III Tool Head.

### Pressure Tube Rolled Joint Detachment System for 220 MWe PHWRs

The Pressure Tube Rolled Joint Detachment System (PTRJD-220), which works on the principle of thermal shock, has been developed for detachment of pressure tubes from the end fitting. A clean technology for detachment of rolled bonded mechanical joint, it is quite useful in a radioactive environment. Experimental trials have been conducted to optimize its operating parameters.



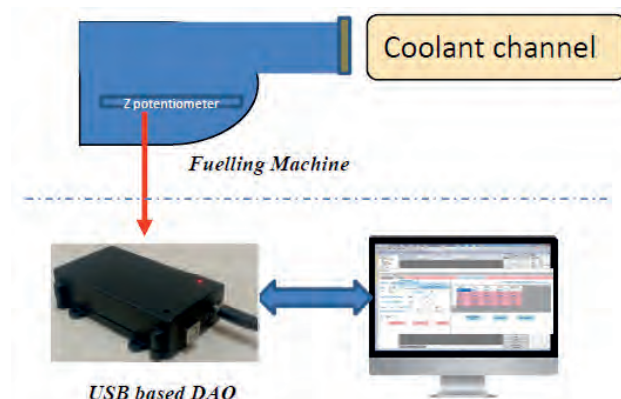
Detached pressure tube in full length PTRJD experimental setup.

### AI based Technique for Inspection of Fuel Bundle End Plate Weld

One of the steps involved in the production of 540 MWe PHWR fuel bundle is resistance welding of the end cap of fuel elements with the end plate. Assessment of the weld quality is carried out by visual inspection method, which is time consuming and causes visual fatigue to operators, thus increasing the risk of wrongful inspection. An artificial intelligence (AI) based inspection technique has been developed and integrated with the production line at NFC for active operator assistance. Synthetic data generation techniques have been used to balance the skewed dataset and have achieved a mean precision of 0.9918 and a mean recall of 0.9916.

### Axial Creep Measurement System for Coolant Channel of PHWR

The upgraded version of TMAC tool version 4.0 has been tested at KAPS-1&2. It is ready for deployment at all operating nuclear power plants. The new version is compatible with the current computer system and employs many operator friendly features.



Schematic Block Diagram of TMAC.

### Design Improvement in Wet Quarantine Plug for 540 MWe PHWR

Wet Quarantining of coolant channel is achieved by installing Wet Quarantine Plug (WQP) in the channel. BARC has modified the plug head of the WQP designed by NPCIL to achieve required flow characteristics and subsequently the WQP was qualified. Dimensions of outer diameter, labyrinth and pitch of the WQP were derived to suit the flow-pressure drop requirement and also to suit clearance requirement for its installation in channel using Fuelling Machine (FM). The WQP is qualified for reactor operating condition of pressure and temperature with desired flow rate range of 2-4 kg/s.



Setup for pull-test of Wet Quarantine Plug.

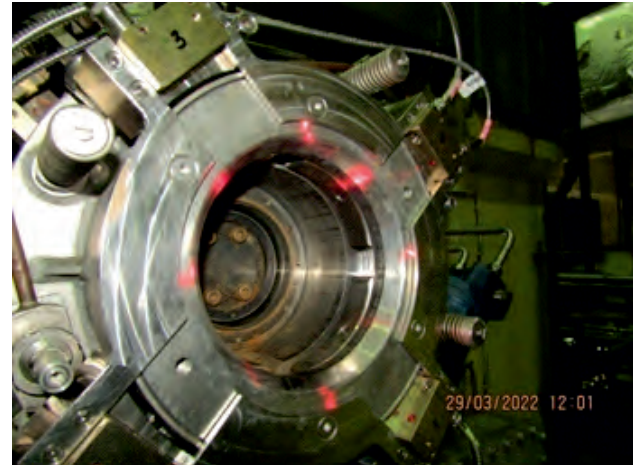
### Variation of Pull-out Strength of Rolled Joint of 540 MWe PHWR with Temperature

As a part of integrity assessment of the coolant channel assembly PHWR under severe accident conditions, the variation in pull-out strength of the rolled-joint between pressure tube and end-fitting with temperatures ranging from 300 K (RT) to 1073 K, has been evaluated using finite element (FE) simulation. It has been found that pull-out strength of the joint reduces drastically after the applied temperature exceeds 673 K. This outcome would help in ensuring safety of coolant channel assembly during severe accident scenario.

### Fuelling Machine Alignment System

For Pressurised Heavy Water Reactor (PHWR), precise alignment of the end fitting of the coolant channel with the fuelling machine head within a tolerance band is required during on-line refuelling. An optical triangulation based remote sensing tilt measurement system using fibre optic cable has

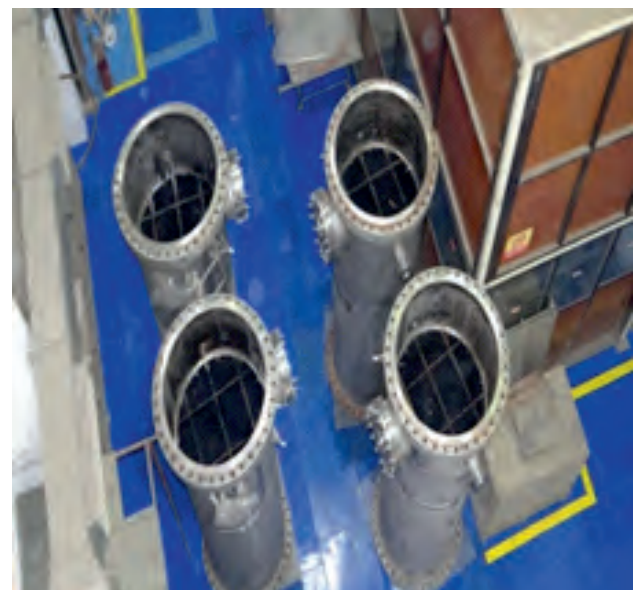
been designed for such alignment to cater to the requirements of power reactors operated by NPCIL. The non-contact tilt measurement sensors in quad sensor configuration are an all fibre solution to measure tilt in X&Y directions.



Fuelling machine alignment system developed in BARC to meet the requirement of NPCIL.

### Fabrication of Structured Packing for Upgrading Plants in PHWRs

Structured packings are used for vacuum distillation of heavy water used in PHWRs for upgrading the isotopic purity of deuterium in the moderator. One tower comprising 14 column sections for KAPS-4 Upgrading Plant towers has been fabricated and shifted to NPCIL site. The surface activation of

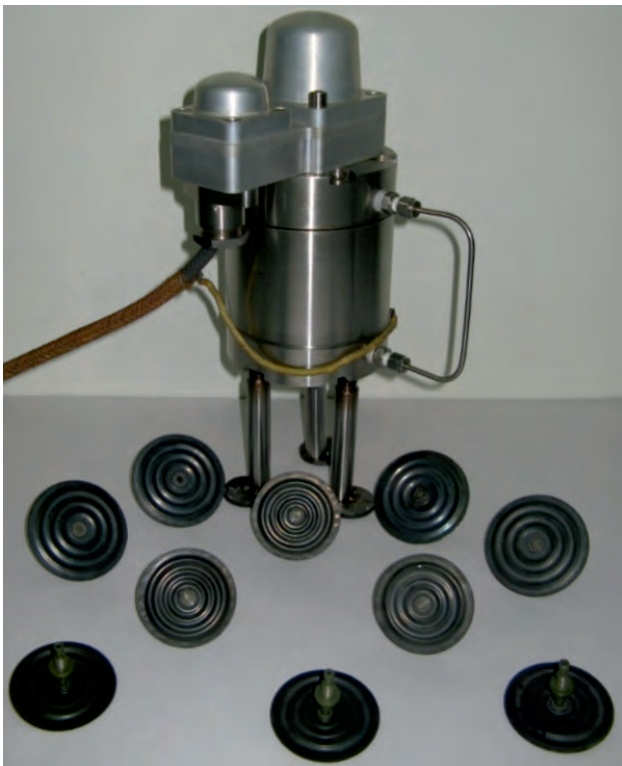


Structured packings used for vacuum distillation of heavy water.

phosphor bronze structured packing is required to increase the hydrophilic characteristics and overall upgrading efficiency of the distillation columns. A new acid/alkali dilution tank of capacity 1500 litres equipped with a motorized agitator was fabricated and commissioned. The consumption of oxygen and heavy water has been reduced by recovering and recycling.

### Nested Corrugated Capsules for LOCA-qualified DP Transmitter Developed In-house

Design, fabrication and testing of nested corrugated measuring/ isolation capsules, in tandem with a combined test set-up for functional and LOCA qualification, has been completed. These capsules would be deployed as sensing elements in differential pressure transmitters for measuring process parameters such as flow, level, pressure in process systems of nuclear reactors. Measurement accuracy in the range of 0.3% to 0.6% of span has been achieved. These capsules have passed steam chamber test at 180°C in saturated steam environment and also life cycle test.



Nested corrugated capsules and combined test setup assembly.

## Recovery of Uranium

### Purification of Uranium from Fluoride-based Slag Leached Solution

MgF<sub>2</sub> slag produced during production of metallic uranium ingot contains 1-5% uranium, which can be leached out by HNO<sub>3</sub> as uranyl nitrate solution. The slag leached solution (SLS) contains 20 to 40 gpl uranium, 300-1500 ppm fluorine along with impurities like iron, magnesium. The uranium in SLS is purified to nuclear grade by extraction method using Tri-butyl Phosphate (diluted with Dodecane) as a solvent. The fluoride ion present in SLS forms stable complexes with uranyl ion and reduces uranium recovery in solvent extraction.

A new process has been developed to directly purify SLS to nuclear grade uranium solution. The process does not require prior production of impure ADU and its subsequent dissolution before purification of uranium to the level of nuclear grade.

Based on experimental studies, a pilot scale plant has been designed, fabricated and is being installed for purification of uranium from SLS. A mixer settler with Top Shrouded Turbine with Radial Rectangular Blades (TSTRRB) type impeller has been designed for solvent extraction and stripping.



Pilot Plant for purification of slag leached solution (SLS).

### ANUSim Module to Simulate U-Pu Co-extraction

Computer programming codes were developed using Python 3.4 for extraction/ scrubbing/ stripping of nitric acid, uranium and plutonium in a cascade of stage-wise contactors. Flow rates, inlet concentrations and numbers of stages are inputs to the codes calculate inter-stage and outlet concentrations. Results were plotted in the form of graphs showing various stages, equilibrium and operating lines. The codes of extraction, scrubbing and stripping were combined to simulate a complete flowsheet comprising of extraction, scrubbing and stripping cascades. Benchmarking of results with SEPHIS was completed. The codes will now be integrated in ANUSim.

### Extraction of U(VI), Zr(IV) and Fe(III) by TBP in Unary, Binary and Ternary Condition

Solvent extraction of U(VI), Zr(IV) and Fe(III) ions in different acidity using 30% TBP in dodecane were carried out in unary, binary and ternary condition. In unary condition, distribution ratio (D) of three metal ions follow order  $U > Zr > Fe$  in all acidity, except at 8M where  $D(Zr)$  is greater than  $D(U)$ . The distribution ratio of U increases up to 3M acidity then decreases and maintains an almost fixed value up to 8M. The Zr extraction shows steady increase with acidity, whereas extraction of ferric ions decreases up to 4M, then increases, shows maximum at 5M-6M, and finally decreases up to nil at 8M. The trends of D with acidity changed in binary condition for U-Fe and U-Zr system, although

U has greater D values than Fe/Zr in all acidities. The same trend followed in ternary condition, except that Zr has higher D than U at 8M acidity.

### Zirconium and Hafnium Oxide Pilot Plant (ZHOPP)

The ZHOPP plant operated to produce nuclear pure  $ZrO_2$  using indigenous solvent TAPO. 1 kg zirconium oxide of more than 99% purity was obtained from the first campaign. In the second campaign, the raffinate containing 20g/L Zr and 2.1 g/L of Hafnium was taken up for recovery of Hf in further cascades.



Zirconium Oxide produced from ZHOPP.

### Environment Monitoring Low Flow Alarm based Fresh Air Line Manifold

The newly developed Manifold consists of four female Quick Release Connectors (QRC), which supply fresh air through rotameters having flow-

#### Maintaining Reactor Integrity

- ✧ Thermal Hydraulic experimental simulation of 'Station Black Out' scenario was carried out to ascertain the effectiveness of Passive Decay Heat Removal System in removing the residual decay heat from Primary Heat Transport System of nuclear reactor.
- ✧ A new Automated Drum Handling System has been developed for handling radioactive heavy water drums remotely. This system leads to reduced effective dose to plant operators during drum handling operations.
- ✧ Through Direct thermal denitration of uranyl nitrate, uranium oxide is arrived at in minimum number of process steps. A dedicated plant is coming up at NRB Tarapur for this purpose.

rate IR sensor and flow control for fine tuning of air supply. The IR sensor is connected to the alarm system, which comprises a 85 dB hooter along with flashing red LED which can warn the worker and the supporting team about drop of air flow below the recommended flow rate of 120 lpm. This system was extensively used during process cell modification work at PREFRE-2, Reprocessing Plant, Tarapur. The flow based alarm system has helped in identifying fall in flow rates and helped early evacuation of workers and has prevented incidents of intake through inhalation. Existing Fresh Air Line Manifolds do not have any warning mechanism regarding drop in air supply to the worker involved in the work in order to evacuate or to inform the supporting team to increase the air supply flow from manifold.



Low Flow Based Alarm System for Fresh Airline Manifolds.

### Development of on-line Iodine-129 Monitoring System

I-129 is produced in nuclear fuel as a long lived fission product and remains in the spent fuel till it is reprocessed. During dissolution of the spent fuel, 95 to 99% Iodine is released from the dissolver in vapor or gaseous form, along with particulate iodine. After treatment and filtration, off-gases are discharged into the environment through the stack. As a regulatory requirement, continuous monitoring of I-129 along with other radio-nuclides is carried out in stack discharges. As a part of up-gradation of the existing radiation monitoring system at Reprocessing Plant, an on-line I-129 monitoring system was indigenously developed using 3"x3" NaI(Tl) detector coupled to a Single Channel Analyzer. The system was successfully installed at PREFRE-2 for on-line real-time

monitoring of I-129 and its data was made available in the control room and shift HP room.



Iodine-129 monitoring system coupled to a stack monitor.

### Public Dose Assessment for Fuel Fabrication - INRP(O), Tarapur Site

Radiation dose to the public due to atmospheric (gaseous) and aquatic (liquid) discharges during normal operation of Fuel Fabrication-INRP(O) at Tarapur site coupled with Anticipated Operational Occurrences (AOOs) was estimated, as the results can be employed for arriving at the dose apportionment for the facility required for regulatory clearance of the facility. The contribution of fission products to dose is found to be negligible both for atmospheric and aquatic releases.

### Standardization of Methodology for Estimating $^{125}\text{I}$ in Biological Sample

Methodology for estimating  $^{125}\text{I}$  in urine sample has been standardized using Liquid Scintillation Spectrometry (LSS) technique. LSS was calibrated using colour and chemically quenched urine samples spiked with  $^{125}\text{I}$ . A correlation has been established between counting efficiencies and subsequent quench parameter (SQP(E)). The method has been tested by participating in intra-laboratory inter comparison exercise to estimate  $^{125}\text{I}$  in urine samples.

### Robust Health Safety Measures

- ✧ The optical properties of aerosols spread across India were evaluated by making use of a simulated COALESCE Model through inter-comparison of three GCMs with ground and satellite observations.
- ✧ Particle size distribution of potential Plutonium aerosols during reconversion operations in a reprocessing plant was evaluated.
- ✧ Depth dose distribution in irradiated products by 10 MeV electrons studied through Monte Carlo Simulation.
- ✧ Extended dose response of B-10+CR-39 for thermal neutrons studied using spectrophotometric techniques.

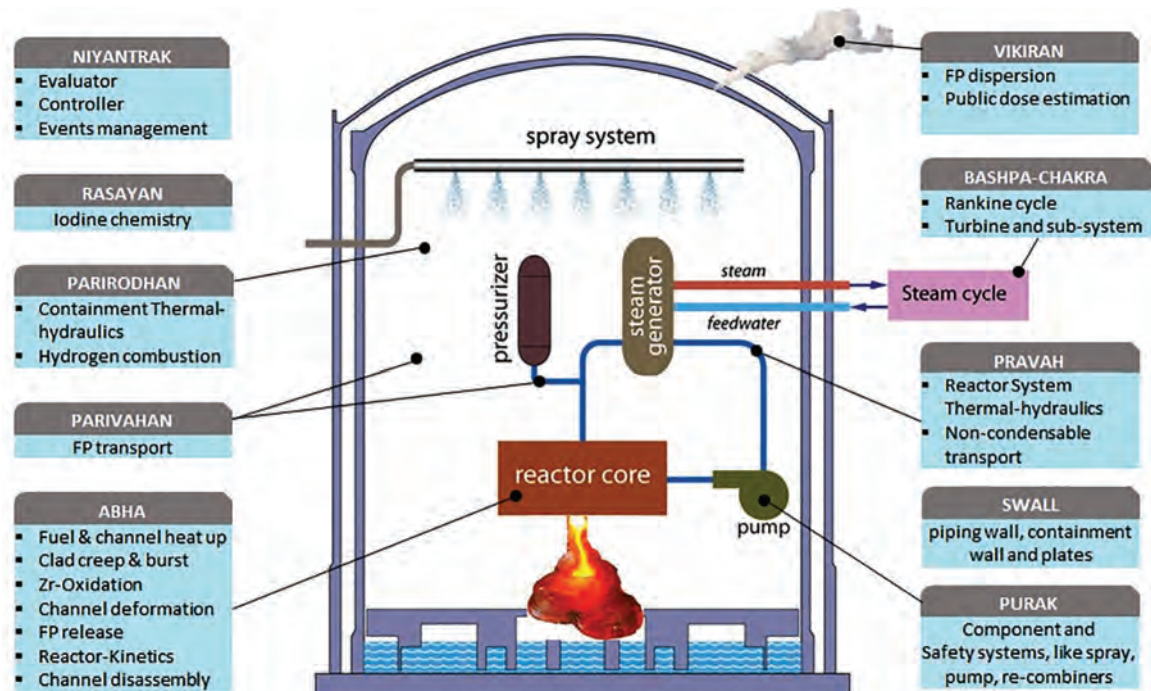
### Advanced Reactors and Associated Materials

#### PRABHAVINI 3.0 - A Safety Analysis Code

PRABHAVINI is an integral safety analysis code developed to address Design Basis Accidents (DBA) and Beyond Design Basis Accidents (BDBA) in nuclear reactors. The code can simulate various Reactor States and perform accident Source Term and Public Dose calculation. The accident source term and radiation risk analysis code PRABHAVINI v3.0 has been released to the users.

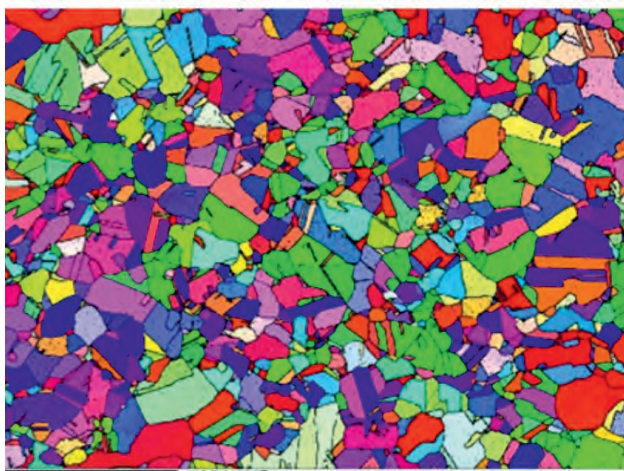
### Development of NiMoCrTi-C Alloy for MSBR Loop

Ni-12%Mo-8%Cr-2%Ti-C alloy is considered a structural material for the Indian molten salt breeder reactor. The present alloy under consideration has been developed by modifying the alloying elements in the existing commercially available base alloy accounting for strength, high temperature molten salt corrosion and radiation damage. The initial small scale trial melts (~20kg) from open air induction melted route showed undesirable (detrimental for thermo-mechanical processing of the alloy) carbide stringers and



The schematic of Engineering Modules of PRABHAVINI V3.0 Code.

excessive carbo-nitrides, which were absent in the vacuum induction melted route. Therefore, vacuum induction melt route was preferred for preparation of 2.5 ton ingots. The optimum forging temperature and strain rate were determined by conducting the thermomechanical simulation of the alloy samples at different temperatures and strain rates. The developed processing map showed that deformation at 1200°C with a strain rate of  $0.01s^{-1}$  is optimum for producing recrystallized microstructure. The as-cast ingots were successfully forged at ~1200°C. In order to optimize the recrystallization parameters for producing the strain free grains in the forged billets, lab scale heat treatments were carried out on small samples at different temperatures and time. They showed an optimum recrystallization parameter of 1080°C for 30 min. The forged billets successfully recrystallized by conducting the heat treatment at optimized recrystallization parameters. The final components for MSBR loop such as tube, plates and wire for welding are being fabricated from the forged billets.

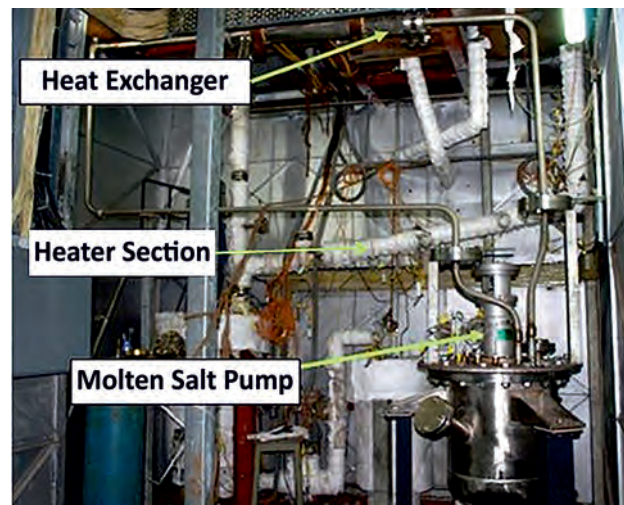


Dynamic recrystallized microstructure of Ni-12%Mo-8%Cr-2%Ti-C alloy.

### Commissioning of Forced Circulation Molten Salt Loop

Forced Circulation Molten Salt Loop (FCMSL) has been setup to study the thermal-hydraulic behavior of molten salt as a part of Molten Salt Breeder Reactor (MSBR) development programme. This loop also facilitates testing of components, instrumentation and structural materials for application in molten  $NaNO_3 - KNO_3$  salt

environment. Commissioning of the loop and thermal hydraulic experiments with heater power 4.0 kW and maximum heater outlet temperature 400°C were carried out. The pump is being operated continuously and so far, it has completed close to 600 hours.



Forced Circulation Molten salt loop.

### Accurate Determination of Niobium in Gadolinium Zirconate Doped with $Nb_2O_5$

A long standing analytical challenge of the accurate determination of niobium in gadolinium zirconate doped with  $Nb_2O_5$  (a burnable poison for CHTR) was successfully accomplished by developing a bifluoride fusion method followed by photometric determination of Nb as its pyrogallol red complex. Developed method was extended for the analysis of large number of real samples with a method precision better than 0.2%.

### Spent Fuel Reprocessing

#### Refurbishment of Plutonium Plant

Subsequent to completion of previous years of continued operations, plant shutdown activities were taken up. Decontamination of process cells was carried out to reduce the man-rem expenditure for executing the cell jobs. Integration of standby dissolver with the existing head end system was completed. Choked transfer routes were identified and were de-choked

chemically/mechanically. Repair of steam ejectors and air lift pumps was carried out. Piping of Dissolver-2 system was completed to enable connection of Dissolver-2 system with existing plant system. Installation of de-clad waste tank and associated piping was completed in dissolver cell. Replacement of one pot type evaporator was completed successfully. Installation of equipment and piping was completed for upgradation of recovered uranium product handling area to indulge automation of the process and improvisation of the area ventilation system. This will result in improved product quality of uranium oxide, reduced human intervention in the process steps along with enhanced radiological safety.

### Continuous Dissolution of Uranium in Pellet Dissolution Facility

A test loop has been set up to study the dissolution of spent fuel in continuous mode. The equipment erection and piping has been completed. The commission activities of Continuous pellet Dissolution Facility (CPDF) were taken up. These included Calibration of tanks, transfer devices, and transmitters, testing of alarms, cut off and safety interlocks. Hydro testing of equipment and piping were also completed. Performance evaluation of fuel feed system with double door arrangement and indexing operation were also carried out.



Test loop of continuous pellet dissolution facility.

### Nal (Tl) based Alpha Drum Assaying System

Shielding work for setting up of drum assaying system at RSMS, BARC was completed. Drum manipulator along with Nal(Tl) detectors have been installed. Detector collimation and positioning, efficiency test, energy calibration and system calibration are being carried out.



Alpha drum assaying system.

### Pre-treatment System for Alpha Bearing Cellulosic and Polymeric Material

A complete pre-treatment system consisting of shredding, homogenisation, conveying, pyrolysis and incineration of solid organic material and flue gas handling has been designed, fabricated and installed inside Glove Boxes at Organic Treatment Facility (OTF). The experimental setup for demonstration of pyrolysis and incineration based pre-treatment process for cellulosic and polymeric waste has been commissioned after necessary safety clearances. The pyrolyzer/ incinerator setup has been operated to get 500 gm of ash for experimental dissolution trials in plate and frame electrolyzer.

A 100A capacity electrolyser was fabricated with platinised titanium as anode and Ti as cathode with membrane/ceramic plate.



Glove Box demonstration setup for pyrolysis based polymeric and cellulosic waste treatment.



### Sample Cutting and Retrieval System for CIRUS Reactor Vessel

Active samples of CIRUS reactor vessel are required as part of ageing assessment program for material characterization, mechanical property analysis and also for radio-characterization of RV as a vital input for future decommissioning of the pile block. Four meter long Radial neutron beam holes of 4" & 12" inner diameter are the most suitable access to remotely approach the reactor vessel for taking the active samples. A remotely operated sample cutting & retrieval system for the same has been developed. Six CIRUS reactor vessel samples have been safely



Remote System being aligned with neutron beam hole.

and successfully cut and removed using the Remote system. The reactor vessel samples were transferred to a shielded cask and sent for radio-characterization for aging assessment. Man-rem expenditure was found to be well within the approved limit.

### Radioactive Waste Management

#### Management of High Level Liquid Waste

Operation of Waste Immobilisation Plant (WIP) was continued for treatment of High Level Liquid Waste (HLLW) involving partitioning of waste for value recovery and waste minimisation. About 50,000 litres of U and Cs Lean stream was subjected to TEHDGA cycle for selective recovery of Sr-An rich product from various contaminants. Sr-An product generated was further concentrated in waste concentration system to obtain an excellent volume reduction factor. Thereby, only two vitrified waste product canisters were produced, from the above waste stream. It is worth mentioning that one consignment of three overpacks (9 units of VWP) was transported to SSSF, Tarapur for interim storage again after two years.

### Waste to Wealth

- ✧ A process flow sheet for separation of radioactive Cs, Co and Sb from Zr was developed.
- ✧ Aniline-siloxane composite material was developed for sorption of Ruthenium.
- ✧ An advanced decontamination process, which can be operated at a lower temperature as well as reduced chemical requirement and waste generation based on dissolved ozone with permanganate, was developed and demonstrated.
- ✧ A dissolved ozone-coupled permanganate (*DOz-Mn*) process was developed and tested on the simulated corrosion products -  $\text{NiCr}_x\text{Fe}_{2-x}\text{O}_4$  and  $\text{CoCr}_x\text{Fe}_{2-x}\text{O}_4$  - as part of decontamination in nuclear installations.
- ✧ A test facility was established for treating low-level nuclear effluents generated in BARC facilities using Spiral module of charged nanofiltration membrane. Simulated tests with solution containing 20 ppm U in presence of 40,000 ppm  $\text{NH}_4\text{NO}_3$  provided more than 98.5% rejection for Uranium with 4% rejection of  $\text{NH}_4\text{NO}_3$ .
- ✧ In-house synthesized Di-tertiarybutyldicyclohexano-18-crown-6 (DTBDCH18C6) was evaluated for extraction of important strontium from radioactive waste.
- ✧ Systematic sorption studies of Ruthenium from aqueous media on aniline-siloxane composites exhibited better sorption for Ru (~ 78 %). Applications include deployment as a gamma radiation source in brachytherapy for treating eye cancers.

### Treatment of Legacy Intermediate Level Liquid Waste

The legacy Declad Intermediate Level Liquid Waste from WTF, PP is being processed at PHIX facility using ion exchange system consisting of highly selective resins of Cesium and Strontium. After installation of an additional chemical preparation system for handling wastes of high salt and aluminium constituents, the entire system was revamped and commissioned. Due regulatory clearances were obtained prior to hot commissioning of the system.

About 550 m<sup>3</sup> of waste has been treated safely in this campaign, achieving a Volume Reduction Factor (VRF) of 70 and overall Decontamination Factor (DF) of 1400. This process has helped in partitioning and recovery of high Cs containing eluate which is of HLW category. This Cs-rich eluate has been mixed with HLW for further processing. Thereby, partitioning of ILW led to generation of a minimal quantity of Cesium bearing HLW. The effluents generated were subjected to specific chemical treatment and transferred to WIP delay tank for further discharge.



Ion Exchange columns at PHIX System.

### Management of Low Level Liquid Waste

45,933m<sup>3</sup> of radioactive effluents were safely managed by ETP facility in line with regulatory limits. 1285m<sup>3</sup> of LLW was treated by Chemical Treatment Flow sheet involving processes of

chemical treatment, centrifugation and cementation, generating 51 units of cementized waste product. At the Decontamination Centre, 51,244 kgs of protective wear was collected, processed and recycled for users. Decontamination of cut-end rods was continued and 180 cut-end rods were fully decontaminated. 35 aluminium shields and 84 SS plugs were also recycled.

In order to lower the radioactive discharges through aquatic route, an Ion exchange plant based on selective sorbent is undergoing hot commissioning trials. During this period, 10,063 m<sup>3</sup> of radioactive effluents have been processed in the plant. 5-7 times reduction of specific activity has been obtained in this process.



Ion Exchange (IX) Plant at ETP in BARC.

### Management of Metallurgical Waste Raffinate

Metallurgical waste, generated during value recovery of special nuclear material, from slag and crucible residue, contains high inactive salts and highly corrosive environment due to the presence of fluoride ions and acids. A process scheme was developed and deployed at the plant level for management of MWPF waste. The process equipment and mixer settler system, which had processed HLW earlier, was used for MWPF waste processing. A detailed downstream treatment methodology was also formulated to handle various interfering metal ions and achieve the ETP transfer criterion. 6.6m<sup>3</sup> of raffinates from MWPF waste was successfully managed for the first time.

It has helped in separation of actinides and achieving a DF of 5000 for actinides. Product streams generated were concentrated for desired VRF. Downstream effluents were managed at LL bay by special chemical dosing and neutralization process. Thereby a high alpha bearing stream could be managed and converted to low active waste dischargeable effluents by this process.



Effluent Conditioning and Transfer System at WIP in BARC.

### Management of Radioactive Solid Waste

Rubber and plastic waste contribute around 75% of the total volume of combustible radioactive solid wastes in addition to cellulosic wastes. To achieve better volume reduction factor (VRF), plasma-based system is being operated in integrated mode with existing old conventional diesel-fired incinerator, for processing of mixed combustible and cellulosic wastes respectively. The integrated mode of operation resulted in processing of above 6300kg (~40 m<sup>3</sup>) mixed combustible wastes with effective VRF of more than 30. Around 2500kg mixed waste was processed through plasma in pyrolysis/ gasification mode, generating high calorific value gases which were further utilized to process 3800kg cellulosic wastes in conventional incineration, eventually minimizing diesel consumption in conventional incineration by more than 50%. During the process, dioxin and furans concentration in exhaust gases were measured through iso-kinetic sampling system and in-house developed methodology in collaboration with NEERI for meeting USEPA-23 guidelines. The concentration observed was below 0.1 ngTEQ/Nm<sup>3</sup>, well within the Central Pollution Control Board permissible limit.

### Role of Clay Microstructure in Diffusion of Cs<sup>+</sup> in Compacted Na<sup>+</sup> / K<sup>+</sup>

The Response of clay saturation with different exchange ions present in surrounding ground water, towards radionuclides migration was investigated in a correlation study of evolving clay microstructure with diffusion characteristics. Smectite-rich natural clay from western part of India, the probable nuclear HLW repository clay, was saturated with Na<sup>+</sup> and K<sup>+</sup>. The clay was characterized for microstructure developing in clay with clay-platelets reorganization. Small-angle X-ray diffraction revealed three and two molecular water layers present in interlayer of compacted water-saturated Na<sup>+</sup> clay and K<sup>+</sup> clay, respectively.

### Melting, Casting and Annealing of RSW Glass

A cold crucible induction melter with electric plenum heater for melter startup was developed to demonstrate melting of radiation shielding window (RSW) glass cullets. RSW glass melting and casting were carried out to establish the process parameters. A 200mm x 200mm x 70 mm thick glass slab was cast in a mould and subsequently put into an annealing furnace for its annealing. The slab after undergoing an 8-day annealing cycle, was cut into segments in a glass cutting machine, which demonstrated improved properties as desired by annealing.



Casting trial of 200 x 200 glass slab of RSW.

### RSW Refurbishment Facility

As a demonstration activity, an old inactive RSW with reduced visibility and rusted housing was

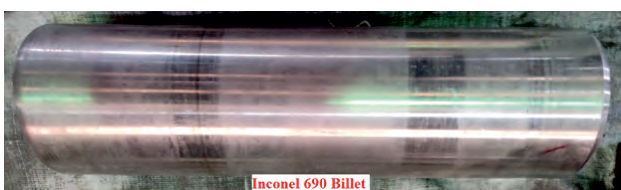
taken up for dismantling at the upcoming “Radiation Shielding Windows Refurbishment Facility”. The RSW was loaded on the transfer trolley with tie down arrangement and transferred to the assembly area. The flanges with rusted fasteners were dismantled, lead wool was removed by using the customised tools and individual glass slabs were taken out by using glass slab removing fixture. Three glass slabs, two flanges and MS housing were dismantled safely.



Demonstration of dismantling of an old radiation shielding window.

### Vitrification of Nuclear Waste

The UNS N06690 ingots and pipes deployed in vitrification process of waste management plants, particularly of Joule Heated Ceramic Melters, have been developed and manufactured in-house in a joint collaboration with Nuclear Recycle Board, NFC, Hyderabad and M/s. Midhani, Hyderabad.



Inconel 690 Billet manufactured from UNS N06690 ingots.

### Conditioning of Technetium-rich Sludge in Geo-polymer Matrix

LLWTP Tarapur receives stream of Tc-99 which is sequestered into stable iron oxide matrix so that the discharge limits are properly controlled. Further, for fixation for disposal, studies on advanced materials for cementing them in the form of geopolymers, was initiated. This matrix was characterized on inactive scale using different

diagnostic tools at DAE centres as a prelude to evaluation of superiority over cements. Post screening on inactive scale, radioactive waste stream rich in Tc-99 was fixed in geopolymers at kilogram scale and evaluated with respect to IAEA prescribed leaching methods. A six-month study on samples from the kilogram scale prepared batches suggests that the material is superior with respect to cements in terms of its chemical durability and leachability index. NRB, Tarapur has accepted the suitability for fixation of Tc-99 in geopolymers for deployment on engineering scale.

### X-ray Imaging Systems for Radioactive Waste Drum Inspection

An X-ray imaging system for inspection of internal details in a standard 200 litre waste drum has been installed and tested with the existing X-ray generator in a shielded enclosure in BARC. The imaging system consists of 700 mm x 700 mm Gadodix scintillator screen, a front coated mirror and a scientific grade cooled sCMOS camera. The camera has been shielded by a composite metal sheet (3mm Pb sandwiched between 4 mm MS plates) to ensure direct as well as scattered radiation from the front direction. This also reduces scattered X-ray photons ensuring improved image quality. Basic spatial resolution (limiting) was found out to be 1.1 lp/mm and at 0.8 lp/mm the objects with features having 600 micron spatial dimension can be well resolved (~ 10% contrast).



Image of a test drum generated using X-ray imaging system developed in BARC.



## 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.



Vikram TCR (Trombay-Chhattisgarh Rice), a mutation bred rice variety.

# Advanced Technologies, Radiation Technologies & Applications

## Research Reactors

### Apsara-U

Apsara-U was operated at a maximum power of 2.0 MW<sub>t</sub> and at an availability factor of 52.75 % during the year. Silicon wafers of 100 mm diameter were irradiated near the reactor core for development of silicon-based radiation detectors, as part of a feasibility study for neutron transmutation doping of silicon. For monitoring of reactor core, three pulse channel fission counter assemblies were installed in core. Detectors of fission counter assemblies were replaced with newly procured one. A neutron imaging and neutron depth profile facility is being erected at beam port#7 of the reactor. The reactor continued to serve as the

national facility for production of radioisotopes for medical, agricultural and industrial applications and neutron beam research.



Neutron Imaging Facility at Apsara-U.

## Dhruva

Dhruva was operated at an availability factor of 73.2% during the year. Around 510 samples of radioisotopes were irradiated in Tray rod facility; 98 samples for short duration in Pneumatic Carrier Facility (PCF) and 8 samples in Self-Serve facility.

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

## Upgradation of Accumulated Heavy Water

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

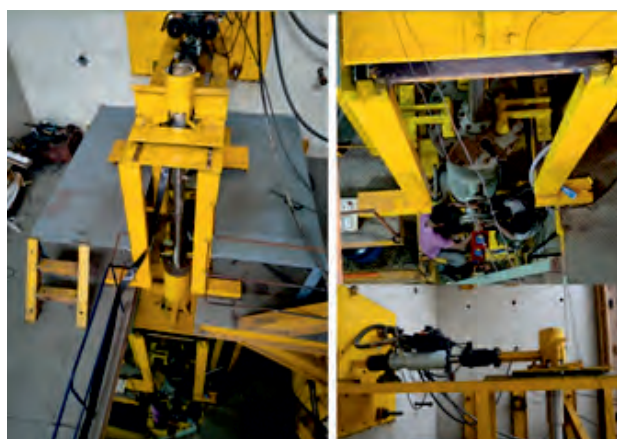
## Reactor Physics Analysis Experiments using Dhruva

Reactor Physics analysis, including optimization of axial position of the hybrid cluster inside the assembly, selection of material of Burnable Poison Rod (BPR), reactivity load, cluster power (gross as well as pin-wise), axial peaking factor, linear heat rate and their change with burn up, has been carried out for the modified experimental assembly containing hybrid cluster of twisted and cylindrical fuel pins, proposed to be irradiated in Dhruva reactor.

## Seismic Re-qualification of Dhruva Shut-off Rods

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

the seismic re-qualification was carried out successfully during May 2022. The test was carried out by exciting seismic motion at four excitation points at four different elevations of Shut off rod. The spectrum compatible time histories corresponding to the Trombay site specific envelope response spectra of X-Y directions were generated for the seismic motion excitation. The tests were carried out for 50%, 100% and 140% of DBE loading and the drop times of shut off rod were recorded. No change in drop time was recorded at 50% & 100% DBE loading and was well within the acceptable limits.



Pseudo Dynamic Test' facility

## Dhruva Shut-off Rod Headgears

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

## TPLC-32 Platform based ESCADA for Dhruva

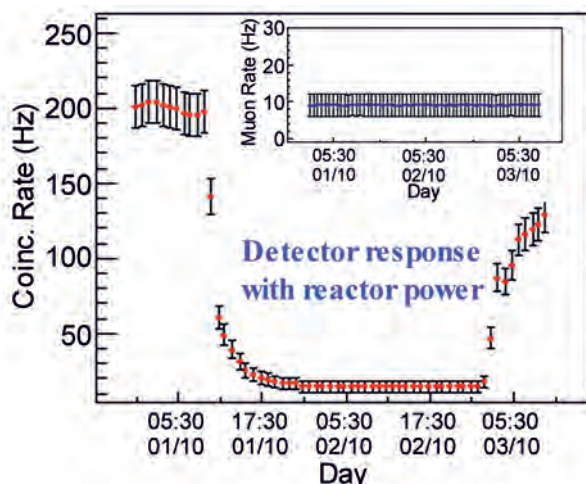
TPLC-32 platform based Electrical Supervisory Control And Data Acquisition (ESCADA) system has been developed for interlocks and monitoring of electrical subsystems of Dhruva. The system comprises TPLC-32 based dual redundant nodes in hot-standby configuration, data servers and display stations. Hardware of ESCADA has been manufactured at ECIL in line with BARC requirements.



ESCADA panels undergoing burn-in test.

### ISMARAN Detector at Dhruva for Studies in Neutrino Physics

Neutrino detection offers one of the most promising pathways to understand the fundamental interactions of nature and also to discover new physics aspects beyond standard model. Despite being the second most abundant particle, neutrinos remain elusive due to their feeble interaction. A large plastic scintillator ISMRAN (Indian Scintillator Matrix for Reactor Antineutrino) detector along with shielding was designed, fabricated and installed inside Dhruva reactor hall for measurements of antineutrinos through the Inverse Beta Decay (IBD) process. The ISMRAN detector set-up has been operated successfully in the round-the-clock mode over a period of more than a year and the response of detector elements of ISMRAN provides a tool to monitor the reactor power level in a reliable way.



Response of ISMRAN detector with varying reactor power level.

### Critical Facility

Reactor was operated 68 times during the year for surveillance, irradiation experiments, neutron activation and testing of detectors. B-10 lined uncompensated ion chambers, fission counters and B-10 lined proportional counters of Apsara-U were tested in CF. Activation of 166 samples was done as per requirements of different divisions of BARC. Feasibility of monitoring 'approach to criticality' using Lanthanum Bromide based gamma radiation detectors was taken up. Helium detectors were tested to meet the desired requirements.

### CIRUS

CIRUS reactor remained under deferred decommissioning (safe storage) state. The reactor building is being utilized for installation and commission of new facilities, including Iodine-131 processing facility, TFLS & TLC production facility. 5 samples of 50 mm diameter each were cut from reactor vessel through the beam holes for material and radio characterization as part of aggregating ageing data. Radiation field on contact of the sample was 200-300 mR/hr. Uranium slurry collection from Cut Rod Storage Bay of Rod Cutting Building (RCB) of CIRUS was continued. Close to 810 kgs of slurry has been collected in the quarter. Total cumulative collection is about 3558 kg.



CIRUS Cut-RV sample in sample gripper.



Facility for processing of I-131 at CIRUS.



### Upkeep and Upgrade

- ✧ Program applications for AAS and RRS have been developed using TPLC-32 Application Development Environment (ADE). The software was executed on Prototype TPLC-based High Flux Research Reactor developmental system.
- ✧ Design modifications were carried out in KAMINI software system. After independent verification and validation followed by the regulatory approval the updated software had been installed at the site.

## Accelerator, Laser and Plasma

### Regulated High Voltage Power Supply at LEHIPA

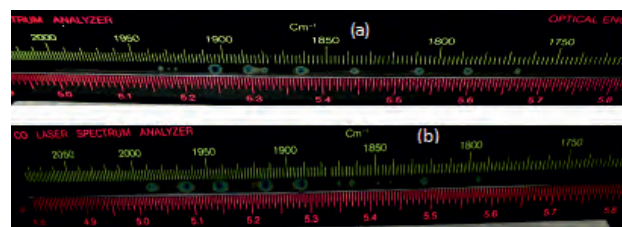
The RHVPS (100kV, 25A) system to ensure regulated high voltage power supply, was commissioned at the Low Energy High Intensity Proton Accelerator. After successful completion of wire-burn test, one of the RHVPS was integrated with its Klystron and operated in LEHIPA to achieve up to 6.8MeV proton beam acceleration in pulsed mode.



RHVPS sub-system commissioned at LEHIPA.

### Development of CO Laser

LN<sub>2</sub> cooled CO laser system was operated at different discharge temperatures starting from -100°C to -195°C and the resulting different CO laser emission spectra were recorded using CO spectrum analyzer at -100°C and at -195°C.



CO Laser emission spectra at -100°C and -195°C.

### Electron Beam Welding

A 80kV, 12kW Electron Beam Welding machine has been utilized for fabrication of 1.1 mm thick Niobium cans. These Nb cans have been qualified with MSLD leak testing, dye penetration test and pressure test. No significant leakage or swelling was observed and integrity of the weld joint was maintained. The machine was also been deployed for welding steel to steel joints of EN-25 grade for IIT, Kharagpur.



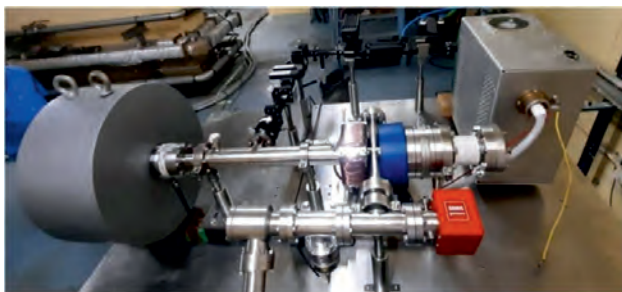
Niobium cans welded using Electron Beam Welding machine.

### Magnetic Pulse Welding

Magnetic Pulse Welding (MPW) is a solid state impact welding technique wherein a conducting flyer is subjected to magnetic pressure generated with an electromagnetic tool coil. MPW is utilized for achieving a reliable joint of Titanium (Ti) tube to Stainless Steel (SS) tube of the dissolver unit in a Fuel Reprocessing plant. Such an operation is extremely challenging with conventional joining techniques like arc welding, diffusion welding, friction welding, laser welding etc. The Ti tube to SS tube joining is established using a multi-turn coil and shaper.

### X band Linac Development

A 9300MHz, 6MeV, 0.48kW X-band LINAC cavity based x-ray source for medical applications has been developed at EBC, Kharghar, a unit of BARC. X-band Linac(s) are extremely compact and light-weight compared to their C-band and S-band counterparts. These Linac(s) have applications in

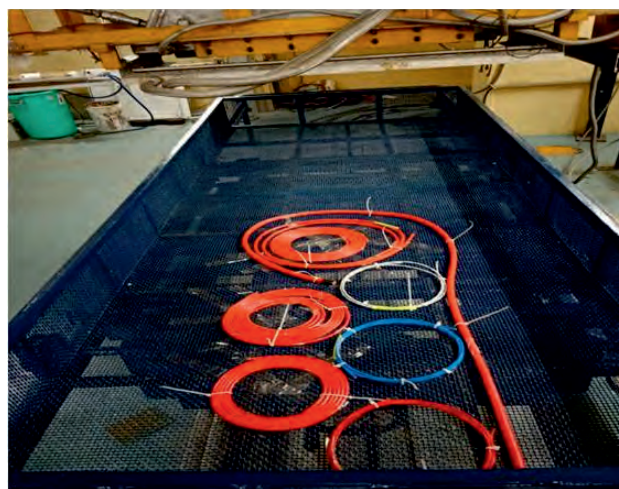


The 9MeV X-band Linac commissioned at EBC, Kharghar.

inter-operative radiation therapy, stereotactic radiosurgery and non destructive testing of materials and industrial components.

### Beam Trial Operation and Irradiation using RF LINAC

A 10MeV, 5kW horizontal RF LINAC was successfully operated at 3kW beam power. Radiation survey was carried out for this facility at 2kW and 3kW average beam power. This Linac has been utilized for irradiation of various industrial products catering to more than 35 industries and for more than 300 h for their irradiation demand. Irradiated products include electric cables, polymer sheets and epoxy prepeg-laminate sheets, cotton cloth for grafting, vegetable products and spices.



Electron Beam irradiation of cables.

### Specialized Technologies

- ✧ Two different security ink taggant detection systems based on dual wavelength Near Infrared (NIR) detection and PMT based fast detection systems were developed to meet the requirements of Bank Note Press (BNP) at Dewas. These are known as 'Divya Dristi' and 'Param Tez Dristi'.
- ✧ More than 10 distinct pico second Nd-YAG laser induced microstructures have been generated in Ti6Al4V bio-alloy, and these are being tested for their improved bio-efficiency.
- ✧ Induced radioactivity in Al, Fe & Cu materials in proton accelerator facility in the energy ranging from 100 MeV to 1 GeV was estimated.
- ✧ Monte Carlo Simulation study of neutron generation in the beam dump for 1 GeV protons carried out to provide radiological safety inputs to the upcoming accelerator facilities of DAE.

## Sensors, Detectors and Specialized Instruments

### Detectors and DAQ of Indian Cargo Scanner

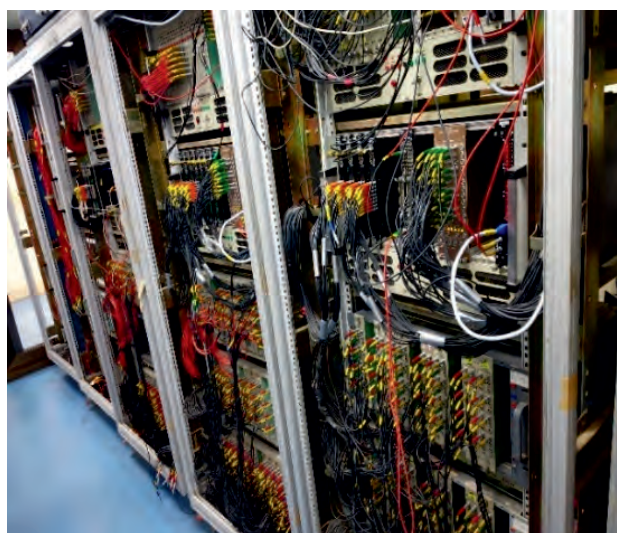
Silicon photodiode coupled CWO detectors were developed in-house for measurement of transmitted X-rays during the operation of Indian Cargo Scanner. The newly developed electronics comprise a 32-channel front end signal processing detector array board with programmable gain, integration time, and a central acquisition board. A test software was developed with essential features such as continuous acquisition with auto scrolling, run-time programmability for gain, scanning mode, display resolutions, scan count, option to save files, high and low energy setting, normalization and gamma correction. The software is equipped to function in single/ dual energy mode with commercial/ indigenous detectors.

The prototype DAQ system of the Cargo Scanner, comprising seven detector modules and 210-pixel detectors, was tested with single energy (6 MeV) and dual energy (6 MeV/4 MeV) X-rays in BARC. The detectors and electronics of the Cargo Scanner have met the ANSI qualification criteria. The system also demonstrated material discrimination capability in terms of well separated material discrimination curves for Perspex, Aluminium, Stainless Steel and Lead (Pb).

### Upgraded TACTIC Data Acquisition System at Mt. Abu

The TACTIC gamma ray telescope, equipped with an imaging camera of 349-pixels of Photo Multiplier Tube, has been in operation at Mt. Abu, India since 2001. The data acquisition system of the TACTIC originally built on a CAMAC and NIM based instrumentation system was upgraded as a distributed data acquisition system. The system consists of eight CAMAC nodes, three high voltage

nodes, trigger generator node networked over ethernet with data acquisition node. The architecture of upgraded system is a three-tier architecture having HV controllers and CAMAC controllers in the first tier as acquisition servers, TACTIC engine at the middle tier and TACTIC clients in the third tier for control, monitoring and data archival. The mechanisms incorporated in TACTIC Engine also help in ensuring safety of the PMTs against extreme exposure.



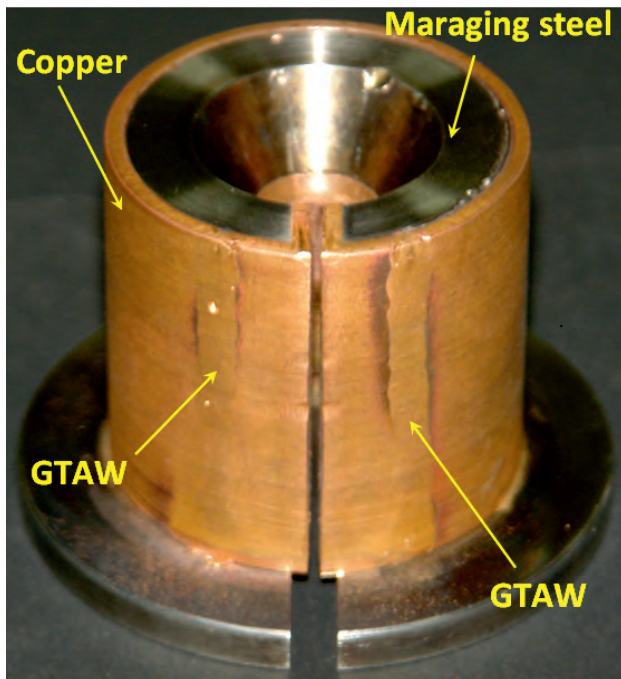
Upgraded DAQ at TACTIC, Mount Abu.

### Indigenous SiPM based Hand-held Gamma Monitor

A compact gamma monitor using indigenous SiPM (3 mm x 3 mm with 50  $\mu\text{m}$  pixel size) coupled to a CsI(TL) scintillator detector has been developed for the detection of gamma radiation. The gamma monitor has been calibrated with standard source facility in BARC and in ECIL.

### Novel Design of Hybrid Field Shaper of EMPW machine

A hybrid design of field shaper used in the Electro-Magnetic Pulse Welding (EMPW) machine was evolved based on the experiments and advanced Multi-Physics based numerical simulations. The modified design has lessened the failure and production cost of the components.



Deformed shape of hybrid field shaper EMPW.

### 5-Axis Sub Reflector Positioning Mechanism for 32m DSN Antenna of ISRO

BARC has manufactured an upgraded version of SRPM for ISTRAC, ISRO (part of Chandrayaan project) in collaboration with ECIL. SRPM is a 5-axis mechanism for dynamic positioning of Sub-Reflector. This will be integrated with 32m Deep Space Network Antenna at ISTRAC, Bangalore and will be used for tracking and sending/receiving signals from satellite. This is an important activity relating to space research and exploration programme of Government of India. After manufacturing of all the components, mock-up assembly is completed and tested before installing it at user's site.



Mock-up assembly and testing of SRPM.

### Development of Dissimilar Metal Joint

Technologies for rolled joining and diffusion bonded joining between SS and Al have been developed. Helium leak rate of  $\sim 10^{-8}$  mbar-l/s was achieved for both types of joints. These technologies will be useful in Isotope Production Reactor (IPR), being developed in BARC.



Diffusion bonded joint (SS 304 to Aluminium 6061).

### Design and Development of Cesium-137 Source Cask

Specially designed source cask has been fabricated for transportation and loading/ unloading of Cesium-137 source pencils in Agro Irradiation Facility located at Gamma garden, BARC. The cask has been designed for 21 kCi of Cs-137 source strength i.e. 30 pencil units. Lead (Pb) has been used as shielding material and cask weighs around 4300 kg. The cask has been designed to meet regulatory compliance, shielding requirements, impact load during 1.5m drop and ability to withstand normal/abnormal conditions of transport within BARC premises. After fabrication, radiometry of cask was carried out to ensure lead



Cesium-137 source cask.

integrity. Detailed radiation dose mapping of cask was also carried out after loading of Cs-137 source pencils to validate shielding design and to ensure that the dose rates are within transportable limits.

### Shielded Camera for Radiation Area

A shielded camera system that can be used in radiation field for general monitoring purpose has been developed. One such unit has been installed in BARC Food Irradiation Facility. The camera system has improved optics and control system and is easy to maintain also.



Shielded camera and its control system.

### Image Processing Software to Estimate Drop Size Distribution in Liquid-liquid Dispersed Phase

Drop size estimation algorithm based on automated multi-scale image processing has been developed and validated using a large set of images obtained from liquid-liquid dispersed phase in solvent extraction process. The algorithm employs image transformations, unsupervised learning, SQI, template correlation, among others to achieve drop detection. The algorithm is validated against manual detection and sizing and the performance report is generated. The algorithm has achieved size accuracy of 98.845% (Sauter mean diameter), recall of 91.78%, false positive of 5.83%, and precision of 94.16%.

### SCARA based Automated Microarray Sequencer

Compact Selective Compliance Assembly Robot Arm (SCARA) Micro Arrayer System with SCARA

Robot has been developed for bio science research applications. Tests on the system were carried out with samples loaded in 384-well plate. Analysis was conducted to validate print sequence, Positioning accuracy, print consistency and mapping.



Compact table-top SCARA Micro Arrayer System.

### Hardware Module for Integrated Scan Generator and Image Acquisition System for SEM

The scan generator and image grabber system of Scanning Electron Microscope (SEM) has been built using high-speed 14-bit DAC and 14-bit ADCs integrated with Zynq FPGA. Finite state machine was implemented to generate scan-X and scan-Y signals. ADCs have been synchronized with the scan pattern to generate SEM micrographs. Provision was made available in the system for acquisition of two detector signals, simultaneously.



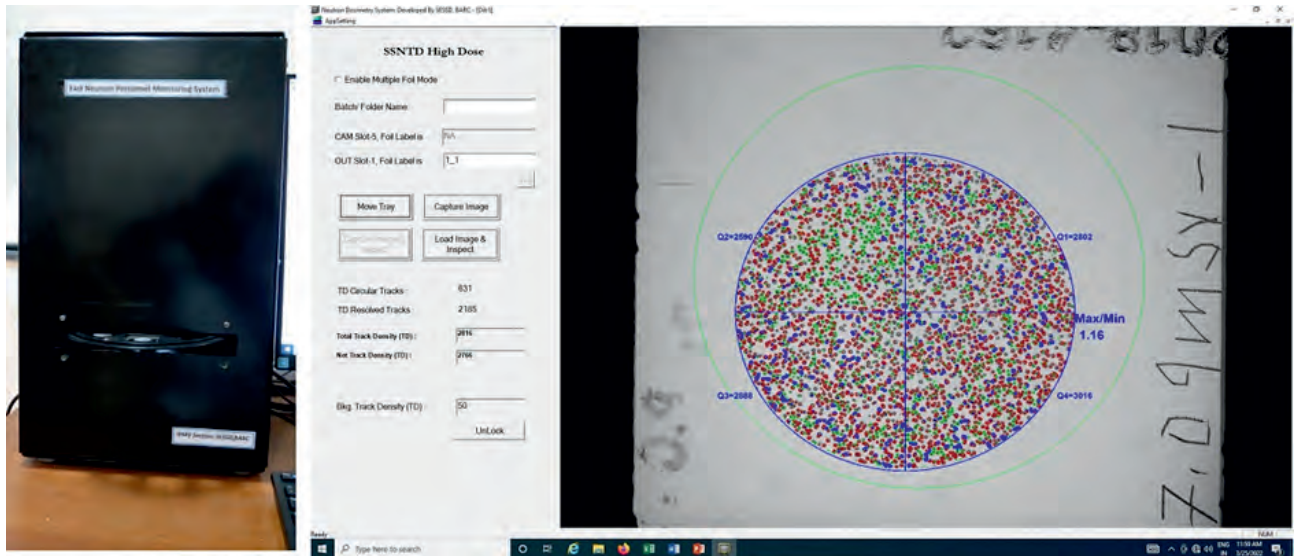
Image Grabber System of SEM.

### Fast Neutron Dosimetry System

A compact version of Fast Neutron Dosimetry System with specialized features has been developed. The key components of the system are:

a 12MP imaging set-up to image input CR-39 foil at a pixel resolution of 8 microns; a new automated circular tray for placement of CR-39 foils (instead of earlier IN/OUT tray) that minimizes

system form factor; an IA software to auto detect and count neutron tracks on CR-39 foil. The system has been tested in lab conditions using 15 irradiated CR-39 foils (of known neutron doses).



The table-top fast neutron dosimetry system; and neutron tracks obtained by the IA software.

### Specialized Technologies

- ✧ A Fissile Zone Identification System equipped with Cadmium Zinc Telluride detector was developed and commissioned in PFBR.
- ✧ Plastic thin film detectors of very low thickness (~10 μm) polymerized with styrene were developed for real-time detection of Tritium.
- ✧ A computer based 4-channel ultrasonic imaging system has been developed. The advanced system is equipped to measure Ultrasonic Pulse Velocity (UPV) besides performing automated B-Scan imaging of the Concrete/ RCC structures.
- ✧ A NDT workbench comprising 4-Channel Ultrasonic Imaging System H/W mounted in a 19"x32U DIN rack, was commissioned for ultrasonic imaging of mechanical components.
- ✧ An algorithm based on time of arrival difference (TOAD), mainly computed from Short Time Fourier Transform of acoustic emission sensor signals, was developed to locate and estimate loose part impact within sophisticated systems.

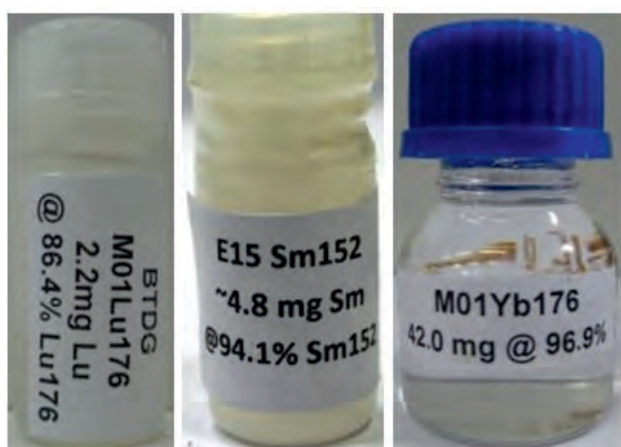
## Radiopharmaceuticals

### Isotope Enrichment for Brachytherapy and Diagnostics

Lutetium-177 produced by neutron activation of Lutetium target enriched in Lu-176 is utilized for both brachytherapy and medical diagnostics. Lutetium target could be consistently enriched from its natural abundance of around 2.6% to more than 80% using indigenously developed Laser Isotope Separation (LIS) technology. The Lu-177 produced has been supplied to various hospitals across the country and has been successfully administered to patients. Using LIS technique, it is possible to produce around 2 mg/week of more than 80% enriched Lu-176 target which will amount to a production of around 40 Ci of radiopharmaceuticals per week. Similarly Samarium-153 obtained from neutron activation of Samarium enriched in Sm-152 has been supplied and administered to patients at Tata Memorial Centre, Mumbai for bone pain palliation.

### Large-scale Production and Supply of Radiochemical Formulations

118 TBq (3200 Ci) quantity of medically useful radioisotopes were produced and chemically converted to radiochemical formulations suitable for use in human healthcare. These include  $^{131}\text{I}$  [59.9 TBq (1618 Ci)],  $^{177}\text{Lu}$  [38.7 TBq (1046 Ci)],  $^{99}\text{Mo}$  [14.4 TBq (390 Ci)],  $^{153}\text{Sm}$  [4.44 TBq (120 Ci)],  $^{125}\text{I}$  [296 GBq (8 Ci)] and  $^{64}\text{Cu}$  [185 GBq (5 Ci)]. Irradiation planning,



Enriched Lu, Yb and Sm samples.

target preparation, radiochemical processing and purification, dispensing and deployment of radiochemical products were carried out to cater to the needs of several nuclear medicine centers across the country. Total 700 consignments of radiochemical products were supplied to end users for medical use.

### Ready-to-use $^{90}\text{Y}$ -HA for Treatment of Patients Suffering from Rheumatoid Arthritis

43 doses of injectable formulation of  $^{90}\text{Y}$ -HA were prepared and supplied to 8 different hospitals that included Seth GS Medical College & KEM Hospital (Mumbai), JIPMER (Puducherry), AIIMS (Bhubaneswar), Max Super Specialty Hospital (New Delhi) and Kovai Medical Center and Hospital (Coimbatore) for treatment of patients suffering from rheumatoid arthritis of knee joints. Yttrium-90 was produced by thermal neutron irradiation of  $\text{Y}_2\text{O}_3$  target in Dhruva. The SPECT/CT (Single Photon Emission Computed Tomography/ Computed Tomography) image of the knee joint of a 36 year-old male patient suffering from rheumatoid arthritis recorded 1 hour post-administration of 222 MBq (6 mCi)  $^{90}\text{Y}$ -HA.

### Supply of $^{125}\text{I}$ Brachytherapy Seeds for Cancer Treatment

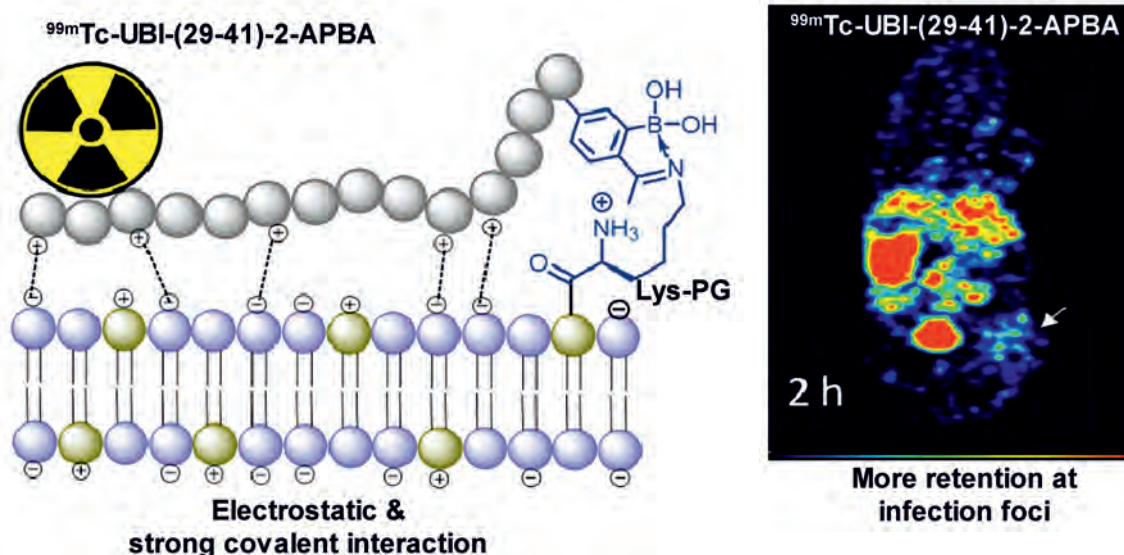
Fabrication and supply of indigenous  $^{125}\text{I}$  brachytherapy seeds was continued during the year. Radioactive seeds containing  $^{125}\text{I}$  were prepared using palladium coated silver wires and subsequently sealing the seeds in tiny titanium tubes employing Nd:YAG laser. Significant number of seeds were supplied to oncologists for deployment in the treatment of eye and prostate cancer.

### Development of Infection Imaging Agents

Development of promising bacterial imaging agents is desired for fast, accurate and early detection of infections, such as osteomyelitis and

infective endocarditis, which are not easily detected by conventional methods. Ubiquicidin and its derivatives are the most studied antimicrobial peptides that bind to anionic membranes of a broad range of bacterial pathogens. UBI (29-41) fragment labeled with radioisotopes  $^{99m}\text{Tc}$  and  $^{68}\text{Ga}$  could distinguish sterile inflammation from infection by SPECT and PET imaging, respectively. With an aim to further enhance UBI (29-41) peptide interaction with the

bacterial membrane, 2-acetylphenylboronic acid (2-APBA), a covalent probe was installed at the C terminus of the peptide. Enhanced uptake  $^{99m}\text{Tc}$ -UBI (29-41)-2-APBA was observed in *S. aureus* bacterial cells as compared to  $^{99m}\text{Tc}$ -UBI (29-41). SPECT imaging in mice model of infection exhibited high target to non-target ratio after 2 h in case of  $^{99m}\text{Tc}$ -UBI (29-41)-2-APBA confirming its potential as a promising infection imaging agent.



Interaction of  $^{99m}\text{Tc}$ -UBI (29-41)-2-APBA with bacterial membrane and pre-clinical evaluation in animal model of infection in right thigh.

### Ensuring Greater Access to Affordable Healthcare

- ⊗ Clinical deployment of ready-to-use  $^{64}\text{CuCl}_2$  solution as PET probe was achieved.
- ⊗ Supply of  $^{90}\text{Y}$ -glass microsphere (BhabhaSphere) doses for radionuclide therapy of liver cancer.
- ⊗  $^{141}\text{Ce}$ -based devices were supplied for supplementing nuclear medicine imaging.
- ⊗ Perifosine was evaluated as a Host directed therapeutic (HDTs) candidate against Tuberculosis and it showed promising results.



## Water Purification, Groundwater Management and Solid Waste Management

### Deployment of BARC-developed Water Technologies in Remote Locations

1000 point-of-use Arsenic/Iron removal water purification devices were installed in Bihar's Samastipur district. Three water purification units of 2000 LPH capacity were installed in Odisha's Khordha for removal of fluoride and salinity. A 2000 LPH capacity fluoride and nitrate removal plant was commissioned in Anand, Gujarat. Two water purification units of 12,500 litres per hour capacity deployed at Border Security Force Outposts located in Gujarat's Kutch.

Himalayan Environmental Studies and Conservation Organization (HESCO). A total of six sets of pre-monsoon and post-monsoon samples were collected for stable isotopes ( $\delta^{18}\text{O}$ ,  $\delta\text{D}$ ) and environmental tritium analysis during the study period. Rainwater samples were also collected from selected locations in the study area. From the stable isotope values of oxygen and hydrogen ( $\delta^{18}\text{O}$ ,  $\delta\text{D}$ ) of precipitation samples, the altitude effects were established for different sites. The relation between stable isotopes and altitude was used to estimate the recharge altitudes for different springs. Environmental tritium of springs was measured to determine the residence time of springs water. The recharge altitudes estimated for 18 different springs of Uttarkashi district varied from 1200-2100 meters above mean sea level



Officials of BARC and BSF present at the newly commissioned 12,500 litres per hour drinking water plant at the BSF Border Outpost in Kutch.

### Application of Environmental Isotopes in Hydrological Studies

Isotope hydrological investigations were successfully carried out to rejuvenate the drying springs in various locations in Uttarkashi and Pauri Garhwal districts of Uttarakhand during 2018-2022. These investigations were carried out in collaboration with a Dehradun based local NGO

(AMSL) whereas recharge altitudes of 8 different springs of Pauri Garhwal district were found to be in the range of 1458-1517 metre AMSL. The residence time of this spring water was found to be 1-6 years. Based on the isotope results, various recharge structures like Gibbon check dams, gully pluggings, trenches, percolation ponds, dykes (surface and subsurface) and contour bunding were constructed depending upon the

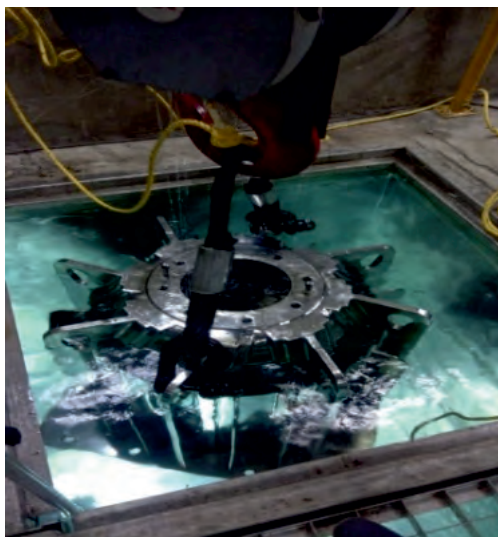
geomorphology of the identified zones. Discharge rate of the springs increased from 0.2 to 4.8 times after the construction of recharge structures which benefitted about 10,000 people residing near these springs.

### Waste Management using Plasma Technology

Around 411 kg of waste comprising of insulating nitrile rubber and cooling tower plastic was mitigated in a 24 hours plasma gasifier run. In another campaign, three different types of sludge received from Common Effluent Treatment Plant of GIDC, Gujarat was plasma treated and reduced to valuable minerals like Aluminium, Silicon, Sulphur, Titanium, Calcium, Magnesium and Phosphorous etc. Under air-plasma based e-waste incubation program, e-waste management company M/s. Eco-Reco, Palghar supplied their e-waste samples. The Air Plasma set-up was made, the supplied e-waste was treated and the mould formation was demonstrated. Another 250kg of municipal solid waste has been mitigated in the Air plasma gasifier.

### Hygienization of Sewage Sludge

The second dry sewage sludge hygienization plant, established under an MoU between BARC and Indore Municipal Corporation (IMC), started operations in May 2022 after first loading of 150 kCi of Co-60 source.



Cobalt-60 source cask being lowered into the water pool.

### hgSBR Technology based New Model Sewage Treatment Plant

A method was developed for cultivating bacteria-laden granules from waste water-borne microbes (an Indian patent application filed in April 2019 and granted in Nov 2021). The process was evaluated at a pilot scale for treating real municipal waste water. The technology from this invention was referred to as a hybrid granular sequencing batch reactor (hgSBR) and was made available (December 2019) to private companies for deployment in WWTPs. Due to commercial potential, 16 private companies, including M/s. Larson & Toubro Construction Pvt. Ltd., have signed a technology transfer agreement for technology deployment. Based on collective inputs from the users, the construction of full scale hgSBR plants was taken up. A 0.15 MLD hgSBR plant was constructed and commissioned in October 2020, to treat sewage from 320 households. The construction work of a 1.5 MLD hgSBR plant was completed for treating sewage from 3200 households in December 2022. The plant systems were tested and commissioned with regular water before operating with sewage. Apart from augmenting sewage treatment capacity, these full scale plants are used for demonstrating technological invention at a reasonable scale, gaining operational expertise and promoting technology deployment.



The 1.5 MLD hgSBR based Sewage Treatment Plant (STP) in DAE Township, Kalpakkam.

### Safe and Clean Water

- ⊗ 103 million litres of high quality water was supplied to Madras Atomic Power Station and 2.33 million litres of hybrid water was supplied to IGCAR, Kalpakkam by Nuclear Desalination Demonstration Plant operated by BARC.
- ⊗ A 1 ton per day prototype Freeze Desalination unit with direct refrigeration cycle was commissioned for carrying out experiments with UF treated normal and diluted seawater (salinity 10,000 to 33,000 ppm).
- ⊗ Prototype Electrolyser developed for removal of total dissolved solvents from ground water.
- ⊗ Disinfection of drinking water was done successfully by employing Copper-Silver Ionization method.
- ⊗ Large scale trials of radiation grafted cellulose fabric-based technology for treating cotton textile dye wastewater were conducted at an industrial site in Jodhpur where ~200 kilo litres of dye wastewater was processed to decolorized water.

## Agriculture and Food Technologies

### Radiation Induced Mutagenesis along with Recombination Breeding

Radiation induced mutagenesis along with recombination breeding has been used to develop four mustard varieties, Trombay Akola Mustard 108-1 (TAM-108-1) for cultivation in Maharashtra; Birsa Bhabha Mustard-1 (BBM-1) for Jharkhand; Trombay Him Palam Mustard-1 (THPM-1) for Himachal Pradesh; Trombay Bidhan Mustard-143 (TBM-143) for West Bengal; one groundnut variety, Trombay Akola Groundnut-73 (TAG-73) for Maharashtra. Two rice varieties, Trombay Chhattisgarh Sonagathi Mutant (TCSM) and Trombay Chhattisgarh Vishnubhog Mutant (TCVM),

have been released and Gazette notification for commercial cultivation by the Ministry of Agriculture & Farmers Welfare, Government of India, has been done in the case of production of Trombay breeder seeds, 254 quintals of groundnut, 65 quintals of pulses and 80 quintals of rice varieties were produced and distributed to different seed producing agencies for foundation and certified seed production and for final deployment to the farmers in different states. To demonstrate the performance of rice mutant varieties (TCDM-1, Vikram TCR, CG Jawaphool Trombay, TCSM and TCVM), field days were organized in collaboration with IGKV, Raipur. In addition, new Trombay pulses and oilseed crop varieties have been produced and distributed to the farmers.



Field view and seeds of Trombay Akola Mustard-143 (TAM 108-1).



Field view of Trombay Chhattisgarh Vishnubhog Mutant (TCVM).

## Biotechnological Approaches for Crop Improvement

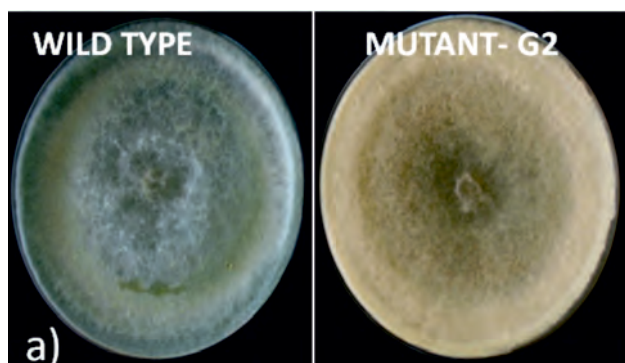
Regarding the biotechnological approach for crop improvement, groundnut rust resistance gene (VG 9514-R gene) was identified through map-based cloning, and gene-based SNP markers were developed for selection of rust resistant genotypes. Gene expression analysis and validation of candidate gene(s) from transcriptome in elongated leaf mutant of chickpea, revealed genes involved in plant cell division and development to be differentially regulated in the mutant. Gene expression analysis (*Sr26* gene) related to stem rust resistance in wheat genotypes was carried out. Understanding the functions of a NAC transcription factor revealed that NAC transcription factor MpSNAC67 is a master regulator of stress mediated senescence in banana plants. The molecular signatures involved in biotic and abiotic stress were characterized in halophyte *Sesuvium portulacastrum*, *Chlorella sorokiniana*, wheat, chickpea and banana. A novel polyketide synthase gene cluster has been identified in a commercial composting strain of *Trichoderma koningiopsis*. RNAi mediated gene silencing revealed this cluster to be responsible for brefeldin A biosynthesis. Six novel hybrid peptides with anticipated antimicrobial and cell penetrating capabilities were synthesized for further

evaluation. An efficient, rapid and reproducible micropropagation protocol for ginger has been developed, which provides disease-free good quality planting material throughout the year and can also be used in germplasm conservation of elite varieties.

## Bio-pesticide Formulation

The mutant strain of beneficial microorganism *Trichoderma virens* based formulation (TrichoBARC) has been registered with Central Insecticide Board & Registration Committee (CIB&RC), Govt. of India it is the first mutant micro-organism based bio-pesticide registered for field applications. Recently, TrichoBARC formulation has been recommended in a package of practices by ICAR for seed treatment in chickpea. Pir and Txp40 proteins from symbiotic bacteria *Photorhabdus* and *Xenorhabdus* sp. were purified and assessed for insecticidal activity against agriculturally important insect pests and mosquito larvae. The biopesticide formulation based on *Bacillus thuringiensis* subsp. *kenyae* ISPC-1 (Btk) was mass produced and evaluated under multi-location field trials. This biopesticide has been submitted to ICAR-All India Coordinated Research Project (AICRP) on chickpea to conduct multi-location field trials. An organic formulation of an *Actinomyces* isolate was found to significantly reduce damping-off disease in

vegetable seedlings in pots as well as field conditions. BARC has developed a superabsorbent hydrogel using natural polymer graft-co-polymerised with synthetic precursor using gamma rays. BARC hydrogel can absorb and retain water up to several hundred times its own weight and releases water upon root demand. BARC, in collaboration with a Pune based Sugar Institute, developed a versatile bio-regulator "ANU-CHAITANYA" containing gamma-irradiated chitosan, which boosts plant growth and activates plant defense mechanisms to tolerate abiotic/biotic stresses. A compact design (25 kg capacity) biogas plant has been commissioned at Dhruva Guest House, New Delhi.



Trichoderma virens mutant formulation ('TrichoBARC') registered with the Central Insecticide Board & Registration Committee (CIB&RC).

## Sea-route Shipment of Kesar Mango Processed using a Protocol Developed in BARC

India is one of the largest global producers of mangoes. Efforts are on to boost shipments to the US through sea-route. Commercial shipment of 16 tons of Kesar mangoes to the US in a controlled atmosphere container, has been successfully accomplished by



Mango boxes in CA Container



Status of mangoes at destination (USA)



Mangoes in USA Market

BARC developed protocol for sea-route shipment of 'Kesar' mangoes to the US.

BARC under a joint collaboration with several government bodies as well as private organizations.

## Shelf-stable Luscious and Nutritious Chiku Fruit Bites

Ripened chiku fruit (*Acharuszapota* L.) was converted to a shelf stable 'Chiku Fruit Bites' and hygienized using radiation technology. The product is shelf-stable at ambient temperature up to 6 months while retaining quality attributes including physical, biochemical, nutritional, health protective (antioxidant and antimutagenic) and organoleptic properties. The BARC developed technology would help farmers and processors of chiku fruit in its preservation and value addition.

## Development of Ready-to-eat Fish Spread

A nutritious RTE Fish Spread was developed using Bombay duck. The product is shelf stable for 60 days at chilled condition after radiation treatment (5 kGy) with acceptable microbiological and sensory qualities as compared to non-irradiated product (shelf life of 8 days). This fish-based spread can be a healthy alternative to fat and oil-based breakfast spreads.

## Refurbishment of Food Package Irradiator

Refurbishment work of Food Package Irradiator (FPI) was fully completed. Installed first in 1967, the FPI was designed by AECL Canada and has been catering to R&D requirements and support for radiation research for over five decades. The refurbished irradiator consists of smart features, including product and source handling systems and control console. The new source frame was installed with sixteen Cobalt-60 pencils (W-91 type, 89 kCi).

## Healthcare Technologies

### Validation of Quick Scan Whole Body Monitor using FLUKA Detector Modeling

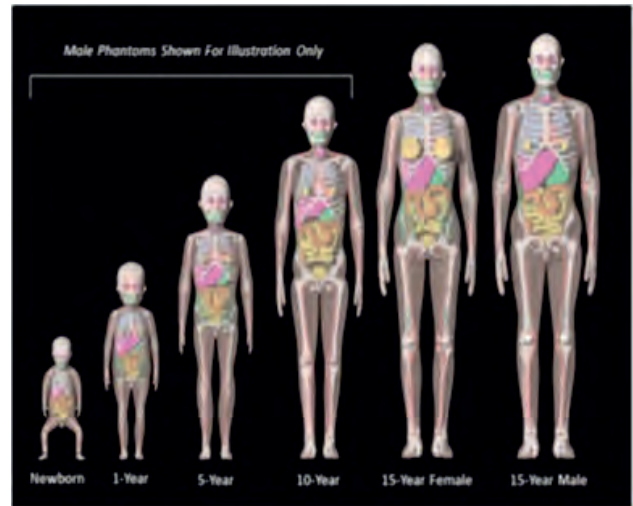
FLUKA numerical model for Quick Scan Whole Body Monitor (QSWBM) was validated using experimental source response measurements. QSWBM response was evaluated using two disc sources,  $^{137}\text{Cs}$  (661.7 keV) and  $^{60}\text{Co}$  (1173 keV and 1332 keV) of activities 38 kBq and 66 kBq respectively. For FLUKA simulations, the BEAM card was used to simulate 661.7 keV, 1173 keV and 1332 keV energies. Counting efficiency (CE) from experiment and simulations was estimated from the sum of net counts recorded in two detectors. The simulated spectra using FLUKA detector models were found to have good agreement with the corresponding experiment spectra.

### Calibration of Shadow Shield Whole Body Monitor using Adult and Paediatric Reference Computational Phantoms

Calibration factors for SSWBM are required for population monitoring during any radiation emergency. For this purpose, ICRP computational male phantom (00 Year (new born), 01 Year, 05 Year, 10 Year and 15 Year) were used to simulate WB organs for energies between 200-2000 keV. The response of the detector (counts per photon, cpp) indicates that average response at 300 keV for new-born male is 21 % higher than adult male due to phantom size. Beyond 300 keV, all phantoms show similar behaviour, with 10-year-old male having 13% higher response than new-born.

### DOSAGE – A Treatment Planning System for Bhabhatron-II

The treatment planning software – DOSAGE – designed for Bhabhatron-II automates important



Paediatric reference computational phantoms.

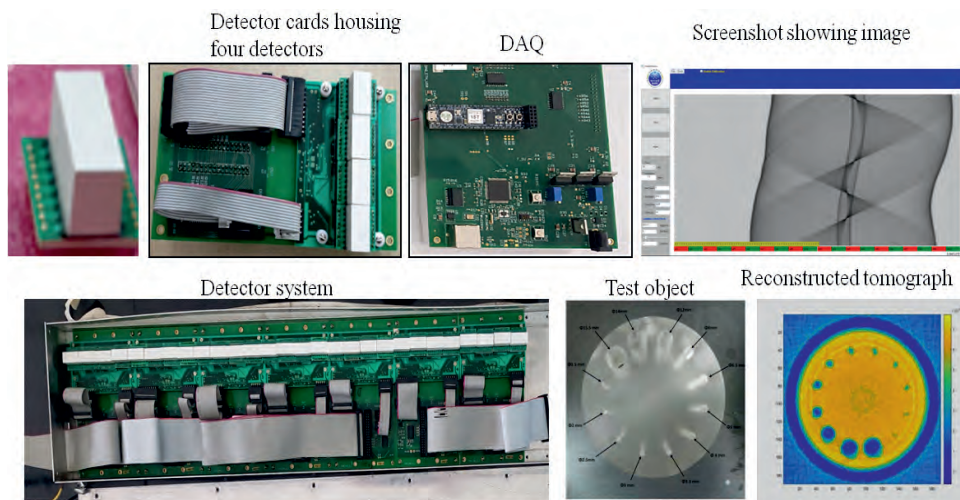
steps and determines optimal treatment parameters for cancer management. Dosimetric performance of the software was evaluated as per IAEA-TECDOC-1583 (Commissioning of Radiotherapy Treatment Planning Systems: Testing for Typical External Beam Treatment Techniques). Treatment plans were prepared by DOSAGE and seamlessly transferred to control console of Bhabhatron-II and verified for correct interpretation of all planned treatment parameters. The comparison of two dose profiles of the calculated dose from the commercial TPS and DOSAGE was found to be within acceptable limits.

### Prototype Linear Array Detector System for Industrial Tomography

The detector system for industrial tomography applications has been developed in a modular manner to meet the requirements of spatial coverage, spatial resolution and energy. The system comprises fine pitch linear array X-ray detectors of 1.3 mm pitch comprising 16 pixel photodiodes coupled to CWO scintillator pixel array. The performance for tomography was investigated by acquiring X-ray scans at every one degree rotation of the object. The system would be suitable for high energy radiography and tomography up to fixed energy levels.



Four field box treatment plan made for Ca-oesophagus using DOSAGE.



Components of prototype linear array detector system for industrial tomography.

## Hydrogen Technologies

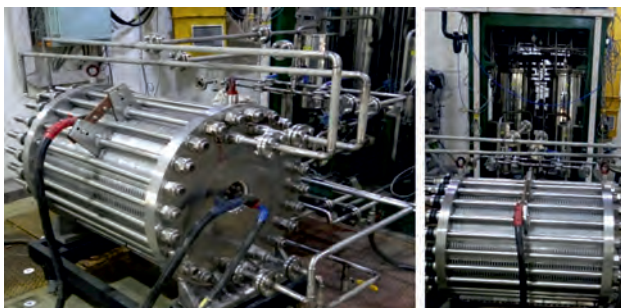
### Performance Evaluation of Scaled-up Alkaline Water Electrolyzer Stack

A bipolar filter press type single electrolyser stack consisting of 50 cells and 50 kW capacities has been designed in-house and tested. This is a first of its kind single stack module which has been scaled up from the previous scale of 25 cell stack of 25 kW

capacity. The assembled cell module was integrated with process skid of the balance electrolyzer plant and the performance evaluation of the plant was carried out successfully. Performance of the plant is as per the design intent. The plant produces >99.9% pure H<sub>2</sub> and >99.5% pure O<sub>2</sub> at cell exit itself up to 1.5 bar(a) discharge pressure. The studies in scaling up of the process provided validation for the design of 150 kW capacity cell stack.

### Revamped Radiotherapy

✳ Dosimetry validation of treatment planning software (TPS) for Bhabhatron-II to support its utilization in 3D conformal radiotherapy has been carried out.



The 50-cell stack of alkaline water electrolyzer plant.

### Development of High Integrity Tank Type Alkaline Water Electrolyzer

Tank type electrolyzers of stainless steel-make were developed for high leak integrity applications. In order to prevent electrolysis on the metallic structural components, an insulating coating had been applied. Insulating coating material, capable of withstanding high temperature, very high electrical resistance and highly corrosive alkaline media has been identified. Compact and novel joining techniques are employed to achieve very high leak integrity with flexibility for maintenance work. Electrodes were developed to achieve moderate current influx, in unipolar type of cell design. Trial runs have been conducted on the cell and operated up to a current density of 7500 ASM. Hydrogen gas was obtained at >99.98% purity whereas oxygen stream purity of ~ 99.5% has been observed. A future cell design has been completed for a higher capacity cell with more compactness for industrial applications.



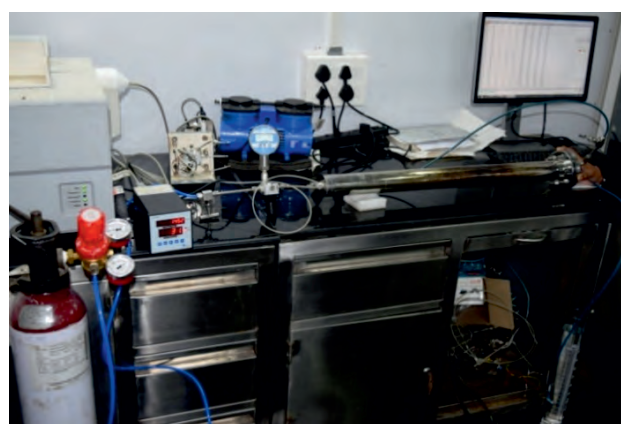
Tank-type electrolyzer assembly.

### Metal Membrane for Separation of H<sub>2</sub>

Pd (75%) - Ag (25%) coated membranes were tested in batch mode for hydrogen isotope separation, with a feed composition of 92.73% H<sub>2</sub> and 7.27% D<sub>2</sub> at room temperature at a gauge pressure of 1 bar. Flux of membrane was found to be 4.5 LMH. Results of the analysis are tabulated below. A separation factor of 1.2 is achieved in the batch.

The membrane was tested for H<sub>2</sub>-He gas mixture at a pressure of 1.2 bar in batch mode. A hydrogen flux of ~5 LMH was achieved. Results of GC analysis showed that He concentration in reject stream was found to be 3.7% while it was found to be 2.7% in feed stream, which indicates He becomes concentrated in the reject stream in a duration of 1 hour.

Testing of Pd-Cu (6-40 wt%) metal membrane in bio-fuel production unit has been carried out to assess the stability of metal membrane in bio-jet fuel production unit. The permeance of the in-house developed membrane was found to be ~ 1 GPU with a hydrogen recovery of 37 and 54% at 1.5 and 2 bar, respectively. The membrane permeance, after exposure to a vent gas environment for 24 hours, was reduced by ~75%. The membrane was regenerated in a mixture of H<sub>2</sub> (10%) - He (90%) at 0.2 bar and 250 °C in 5 hours and the flux was restored up to 85% of the original flux (of the control membrane).



Experimental set-up for testing of metal membrane in light isotope separation.

### Process Development for Copper-Chlorine Thermochemical Cycle for H<sub>2</sub> Production

Product looping experiments for all the four process steps were successfully carried out to



establish cycle integration in off-line mode. Hydrolysis reaction of 150g  $\text{CuCl}_2$  hydrogen crystals from the crystallization step was carried out in a fluidized bed reactor. The Hydrolysis product was successfully processed in tubular thermolysis reactor at 480-500°C with complete oxygen evolution. Feasibility of thermolysis-electrolysis looping was established using  $\text{CuCl}$  obtained from the thermolysis step. Crystallization operation was done using spent electrolyte solution at an average temperature of 2°C to establish product looping of electrolysis-crystallisation-hydrolysis steps. The individual steps have been optimized for efficient integration. The necessary auxiliary steps that include systems for  $\text{HCl-H}_2\text{O}$  separation and molten salt handling were designed and demonstrated. Integration of thermolysis reactor with high temperature withdrawal and quenching system for molten  $\text{CuCl}$  product was successfully demonstrated. A novel method based on adsorption was developed and demonstrated as an alternate to energy intensive pressure swing distillation method to obtain >99%  $\text{HCl}$  purity for efficient integration of hydrolysis-electrolysis steps. For selection of suitable MOC for the high temperature thermolysis reactor in molten  $\text{CuCl}$  media, corrosion experiments were carried out for 75 hours with prospective and ceramic coupons. Graphite,  $\text{SiC}$  and alumina were found to be stable in molten  $\text{CuCl}$ . Development of Process Flow Diagram (PFD) and Process and Instrumentation Diagrams (P&IDs) for bench-scale integrated cycle have been completed.

### Development of High Efficiency De-Oxo Catalyst

Catalytic recombination of hydrogen with oxygen is a promising method used for maintaining low impurity in hydrogen or oxygen streams. The same methodology is also used for maintaining  $\text{H}_2$  concentration in hydrogen handling environment

well below its lower explosive limit (LEL). Deoxocatalysts were developed in-house with different Pd loading on  $\gamma$ -alumina ( $\text{Al}_2\text{O}_3$ ) support. The catalytic activity is evaluated for catalytic recombination of  $\text{H}_2\text{-O}_2$  using 2% hydrogen in air gas mixture. The experimental runs have been carried out in the temperature range of 30 to 150°C using a re-circulating packed bed batch reactor and the overall rate constants were estimated.

## Specialized Technologies

### 14 MeV Sealed D-T Neutron Generator and its Utilization for Quantification of Uranium Ore

Sealed D-T neutrons generator-emitting 14MeV of neutrons was developed in-house for the first time in the country for detection and characterization of U ore grade through use of Sealed D-T neutron generators. An active neutron interrogation probe consisting of neutron source was tested under lab-condition on various grades of U-ore and it is proposed to be tested in actual boreholes at AMD, Jamshedpur. These neutron sources can be turned ON or OFF at the user's request. As a result of this feature, they are extremely helpful in a wide range of on-field applications, including mining exploration, on-site mineral sorting, oil well logging, coal-calorific value assessment, uranium ore grade quantification.



A sealed 14 MeV D-T neutron source along with its control unit.

### Seeding Future Energy Systems

- ✦ The prototype Hydrogen/ Oxygen generation plant for electrolytic water splitting had been completely revamped, which involved integration and commissioning of a 6-cell electrolyzer module and product gas purification unit.

## Technology for Producing High Purity Silicon

Trial runs of CVD reactor was completed to produce high quality polysilicon from MG grade silicon, using completely indigenous technology, which has been demonstrated for the first time in the country. A detailed report has been prepared for “Polysilicon Manufacturing in India: Steps towards Atmanirbhar Bharat” in which cost for producing Polysilicon in India has been estimated and the effect of various parameters on final production cost has been analyzed.



CVD reactor for production of high purity Silicon.

## Launch of NUCON PLC

BARC, ECIL and IGCAR have jointly developed a safe and secure PLC NUCON series 1000 and 2000. To demonstrate the capabilities of NUCON PLC in meeting stringent requirements of large size distributed control systems, a test facility with master hot standby configuration for handling nearly 10,000 I/O has been setup at ECIL. The safety class IC version of this platform has been successfully evaluated by an independent committee confirming its suitability for use in upcoming projects of NRB. The PLC has important applications in the programs of DAE units, Department of space, steel, oil, gas and power sector.

## Development of Machine Learning System

Installation and commissioning of Machine Learning system - PRAGYA - was completed. The

system consists of a constellation of 12 high-end AI servers, where each server is equipped with two 48 cores AMD EPYC CPUs, four Nvidia A100 GPUs and 1 TeraByte RAM. The software stack of the system is equipped with CUDA SDK, RAPIDS toolkit, Anaconda Python and ML libraries. The performance benchmark of the system is 683 TFLOPs (HPL FP64). The system would offer dedicated hardware and software resources for Machine Learning applications to BARC users.



Machine Learning system - PRAGYA.

## Preparation of Certified Reference Materials (CRM)

The exercise involving inter-laboratory comparison of tea powder for preparation of suitable CRM was completed. Under this, the concentration of potential impurities (in trace amounts) present in commercially available tea such as K, Mg, Ca, P, Pb, Mn, Al, Fe, etc., were estimated and compared across 10 different state-of-art laboratories within the country. The analytical data obtained through this exercise has been used for the certification of 15 property values with measurement uncertainty obtained by robust statistics for future use as certified reference material.

Digestion of granite rock sample was standardized and the completely dissolved sample was analyzed by ICP-OES route. Detectable signals were obtained for Ce, Dy, Er, Gd, La, Nd, Sm and Yb.

Method validation for Si, Ca, Fe, Ti, Zn and Ga in alumina reference material was tested on the Alumina Reference Material ALU-12.

## Combined Electrolysis and Catalytic Exchange (CECE) System

Endurance testing for catalyst performance of Pt:CA:PTFE/PFA catalyst, developed for catalytic exchange columns of CECE demonstration process, was carried out, integrating with PEM water electrolyzer. The overall volumetric mass transfer coefficient is high enough to make the CECE process feasible for decontamination purpose, where 100 to 1000 decontamination factor (DF) is required. Fuel cell system is an effective and safe alternative to burner condenser to increase the overall efficiency of Combined Electrolysis and Catalytic Exchange (CECE) process. PEM based fuel cell is successfully operated and tested at different current density to evaluate the polarization characteristics and operational behaviour of the fuel cell. Fuel cell is mainly operated in ohmic region at low current density and the overall resistance of fuel cell stack is observed to be nearly  $0.5\Omega$ .

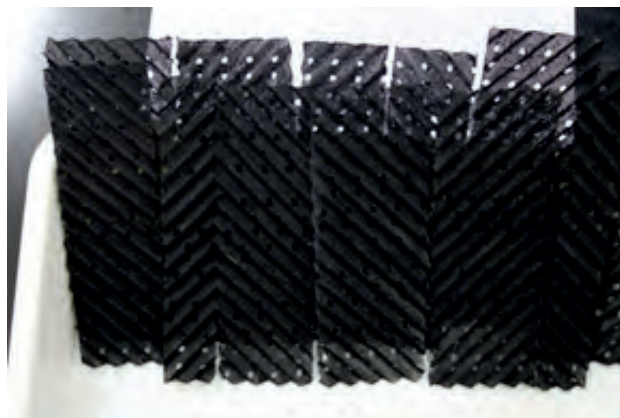


PEM Fuel Cell System.

## Synthesis of LPCE Catalyst

BARC has developed high activity structured hydrophobic catalyst structured packing modules for hydrogen-water isotope exchange process in a joint collaboration with RRCAT, Indore. In this activity, high activity Platinum on Carbon Aerogel

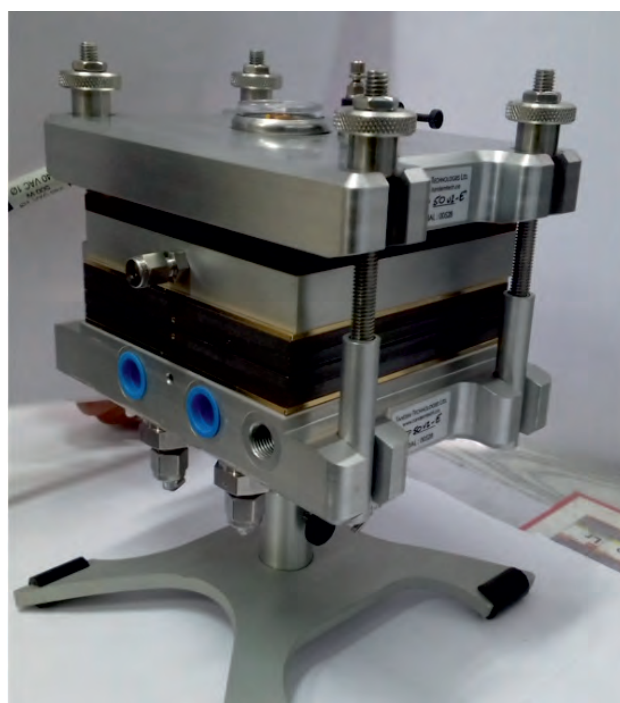
(CA) hydrophobic catalyst (Pt-Carbon Aerogel-PTFE/PFA) was synthesized and coated on stainless steel wire mesh strips for further assembly into structured packing modules. This development will lead to reduction in size and cost of catalytic exchange sections, required for large scale heavy water production plants by  $H_2O-H_2$  exchange process.



Wire mesh strips (after catalyst coating).

## Electrochemical Separation of Hydrogen-Helium Gas Mixture

Electrochemical separation is a novel technique for bulk hydrogen and helium gas separation. 2D CFD model of electro-chemical reactor for Hydrogen-Helium separation was developed by coupling mass, momentum and charge conservation



Electrochemical Cell.

equations. Sensitivity analysis was done at different current densities and the polarization characteristics were evaluated. Further, the behaviour of the electrochemical separator was investigated by varying different operating parameters viz. temperature, cathode pressure and feed flow rate. In-house experimental data was generated using indigenously prepared membrane electrode assembly (MEA). Efficiency and recovery of electrochemical cell was also estimated for electrochemical separation.

### Development of Helium Gas Recovery System

Helium is used in various industrial processes, but it is very expensive (~₹ 8000/kg) and its availability is limited. Helium gas recovery system has been developed to demonstrate the recovery, purification and re-use of the helium gas vented out from various process systems.



Helium gas recovery system.

### Installation and Commissioning of Cryogenic Purifier Modules

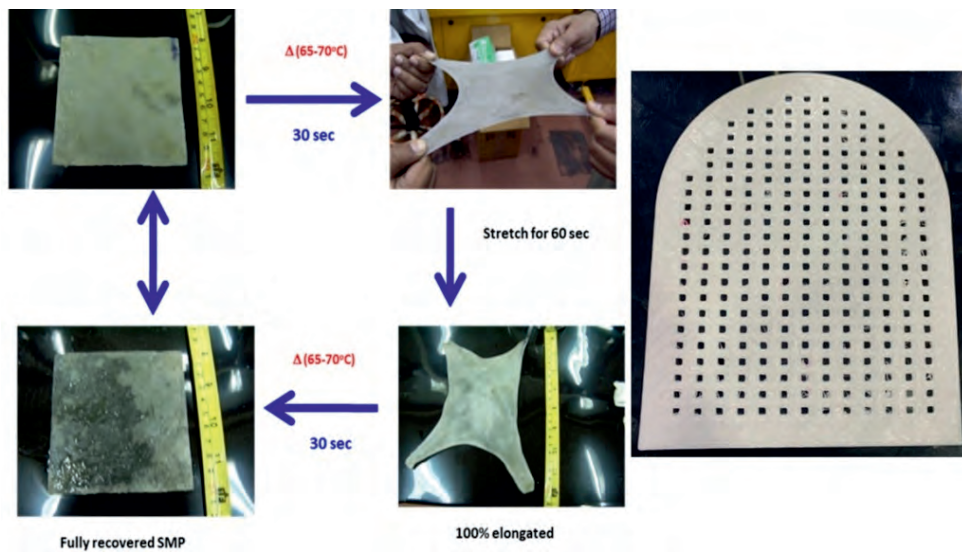
Two sets of cryogenic purifier modules have been installed and commissioned for the purification of helium and hydrogen streams. The cryogenic vessel has been designed in-house with a coil-in-coil type heat exchanger for cold recovery and to reduce liquid nitrogen consumption along with the specific adsorber coil bed. The purifiers are filled and drained with liquid nitrogen multiple times for simulating thermal cycles and checking the integrity due to thermal shocks and the purifiers were found to be intact.



Coil-in-Coil type Recuperator of Cryogenic Purifier Modules.

### Development of Shape-recovery Alloy-based Radiotherapy Facemask

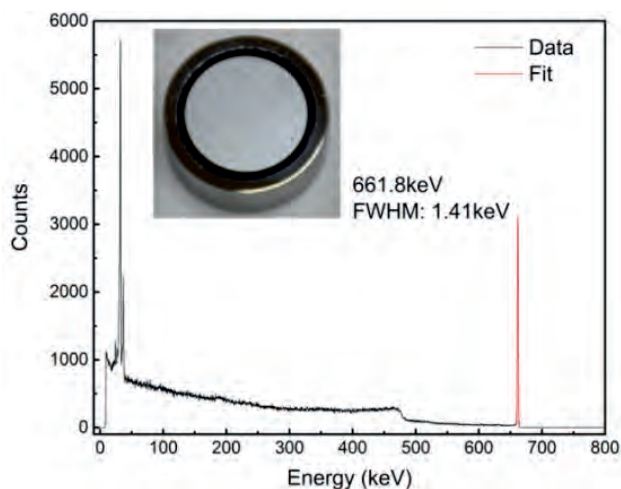
To immobilize a body part for radiotherapy and orthopedic applications, shape recovery polymers (SMP) are increasingly used in the modern clinical practice. Currently employed fixation devices are imported and quite expensive. Low-cost high-performance radiation processed biodegradable polymer based SMP alloy with recovery temperature of 60°C has been developed. Solvent-free mixing protocol was developed by scanning several formulations and absorbed dose standardized to achieve SMP alloy of optimum crosslinking density and melt elasticity. PALS and rheological investigation were carried out for fine tuning the dose requirement. The developed radiation processed blend shows reversible shape recovery, with >90% shape fixity and recovery. The blends can be converted to any desired shape or size. Inclusion of multiple phases in the thermoplastics with uniform crosslinking resulted in a high quality but comfortable degree of immobilization. These developments further underscore the utility of high energy radiation for healthcare applications.



Shape recovery cycle of the radiation processed SMP and a 3D printed specimen of SMP.

### HPGe Detector of Active Volume 3 cc and FWHM of 1.41 KeV at 662keV

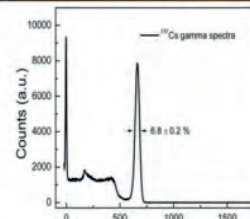
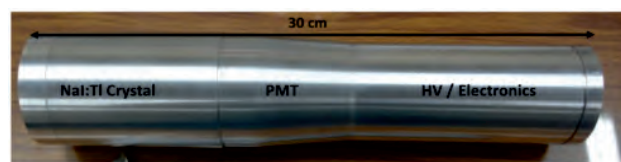
After successful demonstration of in-house developed HPGe detector from procured HPGe single crystal, the detector was further optimized. The fabricated diode with leakage current less than 10 pA at a bias of 1000V had been mounted on the cold finger of an indigenously designed and fabricated liquid nitrogen cooled dipstick. The diode was connected to preamplifier and other electronic components developed, and tested for gamma radiation. The resolution of the acquired spectra is found to be 0.2% at 662keV with line width of the <sup>137</sup>Cs peak around 1.41 keV. Further, the FWHM of the indigenous detector was compared with an 8 cc volume commercial detectors. A diode with 10 cc active volume is under fabrication.



The fabricated n-type HPGe detector.

### Fabrication of NaI Detector Assembly as an Import Substitute

NaI single crystal growth has been carried out to meet the requirements of the department. A pre amplifier board suitable for NaI detector has been designed and commercially fabricated. The PMT along with the crystal was connected to the pre-amplifier board and a DC-DC converter to give HV supply to the PMT. The full assembly is encased in an aluminium housing with a port to arrive at 12V input. The energy resolution of the detector at 662 keV is better than 7%. Ten such detector assemblies have been made available for departmental use.

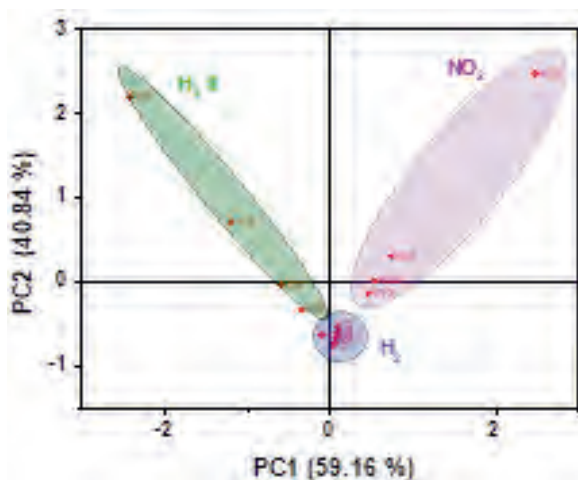


The fully integrated NaI:TI scintillator crystal based detector assembly and the pulse height spectra measured for <sup>137</sup>Cs.

### ZnO nanowires and SnO<sub>2</sub>-rGo based e-nose

Pattern recognition algorithms based on principal component analysis (PCA) were successfully applied on an e-nose based on ZnO nanowires and SnO<sub>2</sub>/rGO (reduced graphene oxide) nanohybrids. The featured

matrix was studied by applying the PCA, which is performed by using the correlation matrix form. The 2D PCA classifier accounts the variance of about 59.16% and 40.54 % for PC1 and PC2, respectively. Thus, PCA has been found to be an efficient algorithm to discriminate H<sub>2</sub>S, H<sub>2</sub> and NO<sub>2</sub> analytes.



Two-dimensional PCA plot showing discrimination of H<sub>2</sub>, H<sub>2</sub>S and NO<sub>2</sub>.

## COVID-19 Technologies

### Development of Liposomal Vaccine Candidate against COVID-19

Liposomal vaccine against COVID-19 which was developed earlier, which induced very high titre neutralization antibodies, was evaluated for its *in vivo* efficacy in viral challenge experiments in hamster model at IISc Bangalore and the data suggested a significant protection from SARS-CoV-2 in vaccinated hamsters as compared to control. Viral load in vaccinated mice was reduced by >4 log units (99.99%) compared to unvaccinated control. The vaccine is now ready to go to clinical trials. RBD gene of SARS-CoV-2 was cloned in BCG such that it expresses the protein, which can be used as a vaccine against COVID-19.

### Key Drug Targets for Developing Therapeutics against COVID-19

SARS-CoV-2 papain-like protease (PL<sub>pro</sub>) is an important drug target for developing therapeutics against COVID-19. After high-throughput biochemical screening, Comp65 was identified as a novel inhibitor of PL<sub>pro</sub>. The compound showed

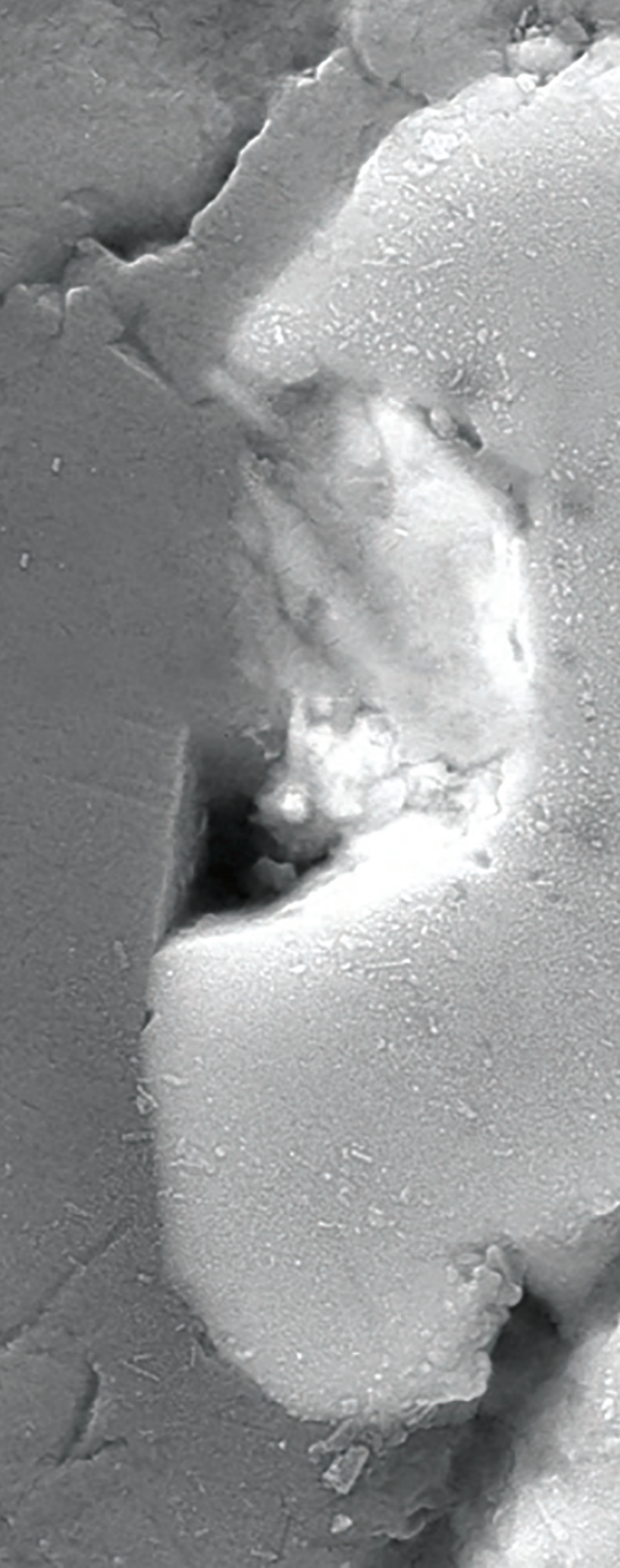
large reduction in viral load (EC<sub>50</sub> = 50 μM) when tested in VeroE6 cells infected with a local SARS-CoV-2 variant (at M.O.I = 0.1). Its therapeutic efficacy through other routes of administration needs to be explored. Further, a novel inhibitor against SARS-CoV-2 Nucleocapsid protein has also been identified using high-throughput fluorescence-based methods and was further confirmed by EMSA, SPR and NMR-based methods. The identified inhibitor was found to inhibit the binding of the protein to its target RNA substrate.

### Effect of Chlorophyllin (CHL) on SARS-CoV-2 Infection and Inflammation

SARS-CoV-2 challenge study in golden Syrian hamsters showed that CHL offered protection against SARS-CoV-2 infection with decreased viral load, lung pneumonitis and decreased lung pathologies. CHL significantly inhibited mRNA expression of IL-6 and TNFα in splenocytes of infected animals. The prophylactic group performed better in mitigating SARS-CoV-2 over therapeutic regimen. Phase II clinical trial of CHL has been completed and an application has been submitted to Drug Controller General of India (DCGI) for emergency use authorization in COVID-19 patients. CHL also inhibited viral infection induced interleukin-6 in the serum of COVID-19 patients.

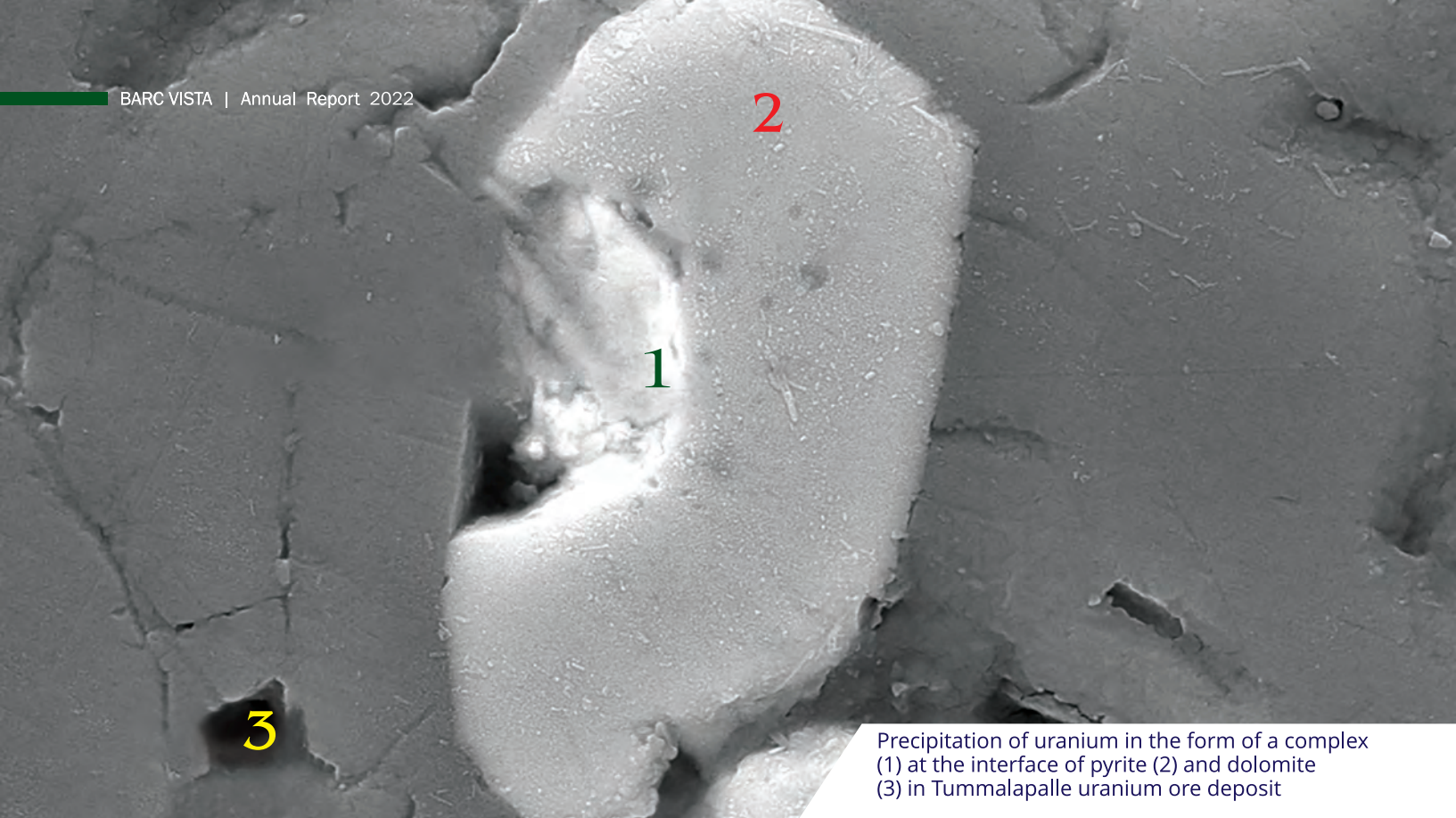
### Atomic Molecular Dynamics Study on the Mechanistic Aspects of Interaction of Lethal Delta Variant of SARS-CoV-2 Virus with Human Enzyme ACE2

Among the various reported mutant variants of SARS-CoV-2, such as, B.1.1.7 (alpha), B.1.351 (beta), B.1.617.2 (delta), P.1 (gamma), the Delta variant is known for its high infectivity and severity. However, molecular level understanding of the origin of such high infectivity and lethality has remained elusive. Current atomistic molecular dynamics simulation studies have shed light on the interaction of SARS-CoV-2 receptor binding motif and ACE2 enzyme of the human body and the interfacial contact area between the two has been identified as a key parameter that correlates with the infectivity and severity of the different mutant viruses.



# 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.



Precipitation of uranium in the form of a complex (1) at the interface of pyrite (2) and dolomite (3) in Tummalapalle uranium ore deposit

# Basic and Directed Research

## Astrophysical Sciences

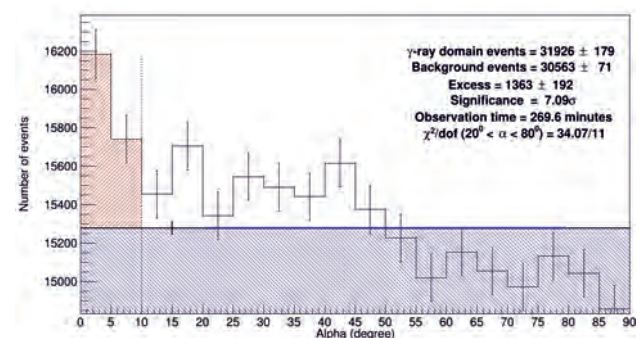
### MACE Observations

The MACE telescope started regular science observations after its commissioning in September 2021. The telescope was deployed for more than 150 hours to monitor high energy gamma-ray emission from a number of Galactic and extragalactic sources during the last one year. Apart from the consistent detection of the standard candle, Crab Nebula, statistically significant gamma-ray photons have been detected from the active galactic nuclei Mrk 501 in a live time of approximately 7 hours with high confidence level. This detection indicates a probable short-term flaring activity in the source.

### Phenomenological Studies In Astroparticle Physics

Long-term multi-wavelength studies of two gamma-ray sources 3C 279 and 1ES 1959+650

monitored with the TACTIC telescope have been performed to investigate the behavior of non-thermal broadband emission. The broadband spectral energy distribution (SED) from 3C 279 is modeled under the conventional frame work of single zone synchrotron and external Compton processes while the SED modeling of 1ES 1959+650 suggests that a two zone emission model is required to better explain the source behavior.



The detection of high energy gamma-ray signal from the active galactic nuclei Mrk 501 using MACE observations made in August 2022.



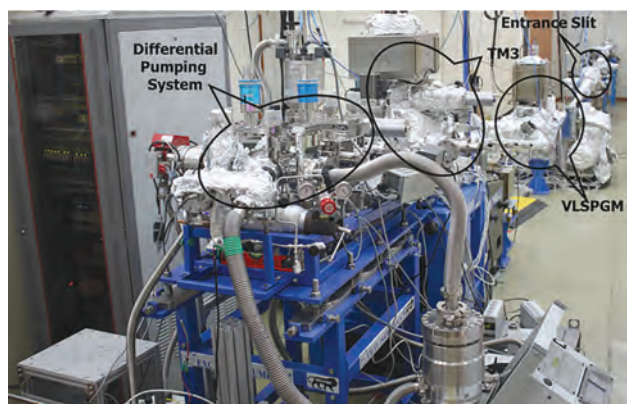
## Gulmarg Neutron Monitor

The Gulmarg Neutron monitor has been deployed for detection of secondary cosmic ray neutrons and neutron bursts correlated with natural atmospheric lightning discharge activities. Data collected for more than 500 hours was analyzed and no significant solar activity modulation was observed. It indicates the low phase of the solar activity. Several upgrade activities have also been undertaken to improve the sensitivity of the experiment and lowering its time resolution. Feasibility studies for deploying new type of neutron detectors such as solid state and He<sub>3</sub> detectors have also been carried out. It is observed that He<sub>3</sub> detectors are suitably placed as a better alternative to the existing BF<sub>3</sub> detectors.

## Synchrotron Beam line

### High Flux Atomic, Molecular and Optical Science Beam Line

A new high intensity and high resolution undulator based beam line called Atomic, Molecular and Optical Science (AMOS) beam line has been developed at Indus-2 Synchrotron source, Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. The beam line can deliver high flux photons (flux  $\geq 10^{12}$  photons/sec) in the photon energy range of 6 - 800 eV at a high resolving power ( $\sim 10000$ ). Studies on highly excited and super-excited states of atoms and molecules can be conducted in this beam line for understanding photochemical processes in the upper atmosphere, astrophysical objects, plasmas, environmental sciences and in

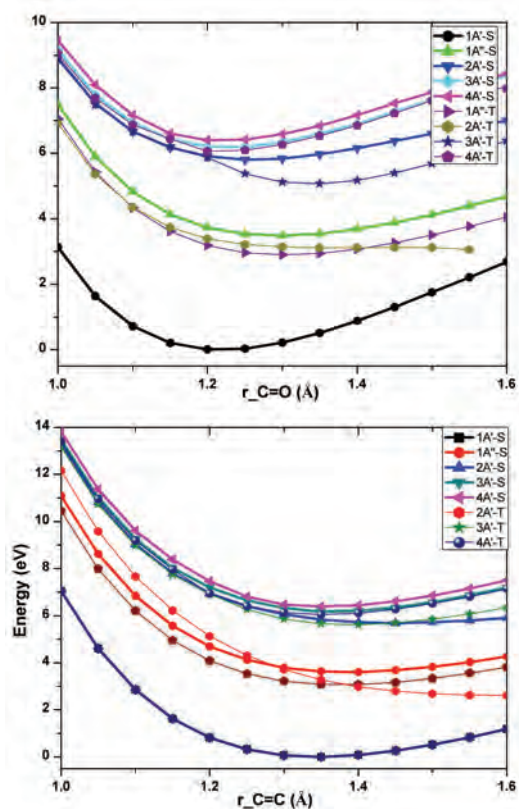


The AMOS beamline at Indus-2.

high temperature industrial processes. After successful installation and testing, first photoabsorption spectrum of xenon atomic lines has been recorded using synchrotron radiation. Observed spectrum consists of atomic Rydberg transitions converging to first ionization potential of xenon. A line width of 2 meV is recorded at 8.4 eV.

### VUV and IR Spectroscopy Studies using Photophysics Beamline at Indus-1

Spectroscopic studies of the ground and electronically excited states of polyatomic molecules are carried out by FTIR technique UV-VUV photoabsorption using Photophysics beamline at Indus-1. Some of the important studies include molecules of astrophysical interest such as Benzonitrile, pharmaceutically important molecules such as dimethyl acetamide and crotonaldehyde. The UV-VUV absorption experiments required to understand the photochemistry as well as Vibrational spectra of these molecules were carried out by infrared spectroscopy.

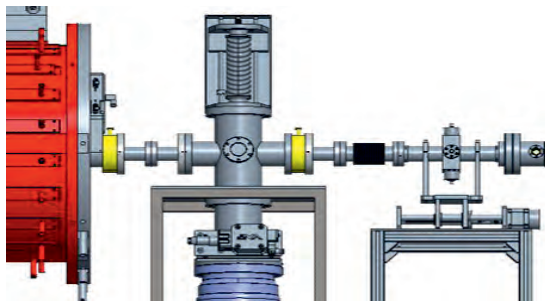


Potential energy curves of ground and first few electronic excited states of crotonaldehyde along  $r(\text{C}=\text{O})$  and  $r(\text{C}=\text{C})$ .

## Ion Accelerator

### Commissioning of LEHIPA Beam

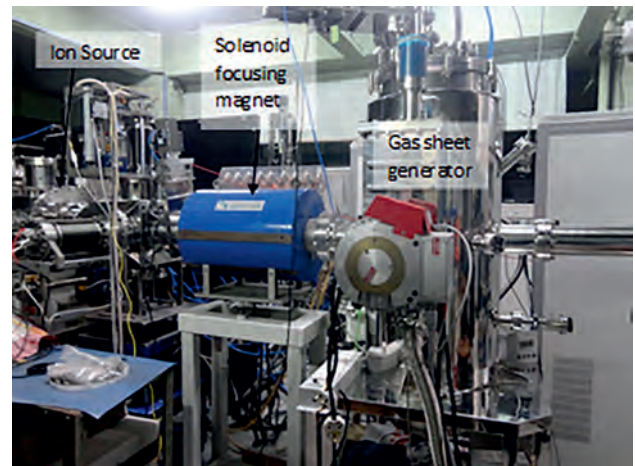
The Low Energy High Intensity Proton Accelerator (LEHIPA) has achieved a significant milestone by clocking 11 MeV beam energy. The first two DTL tanks were installed in the LEHIPA Linac tunnel, and the beam was efficiently accelerated from 3 MeV to 11 MeV. The beam energy was accurately measured by employing the Time of Flight (ToF) technique using two Fast Current Transformers (FCTs). The time difference of 160 ps between the two FCT signals corresponds to 11 MeV. The DTL transmission was also optimized to achieve a high transmission rate of around 94%.



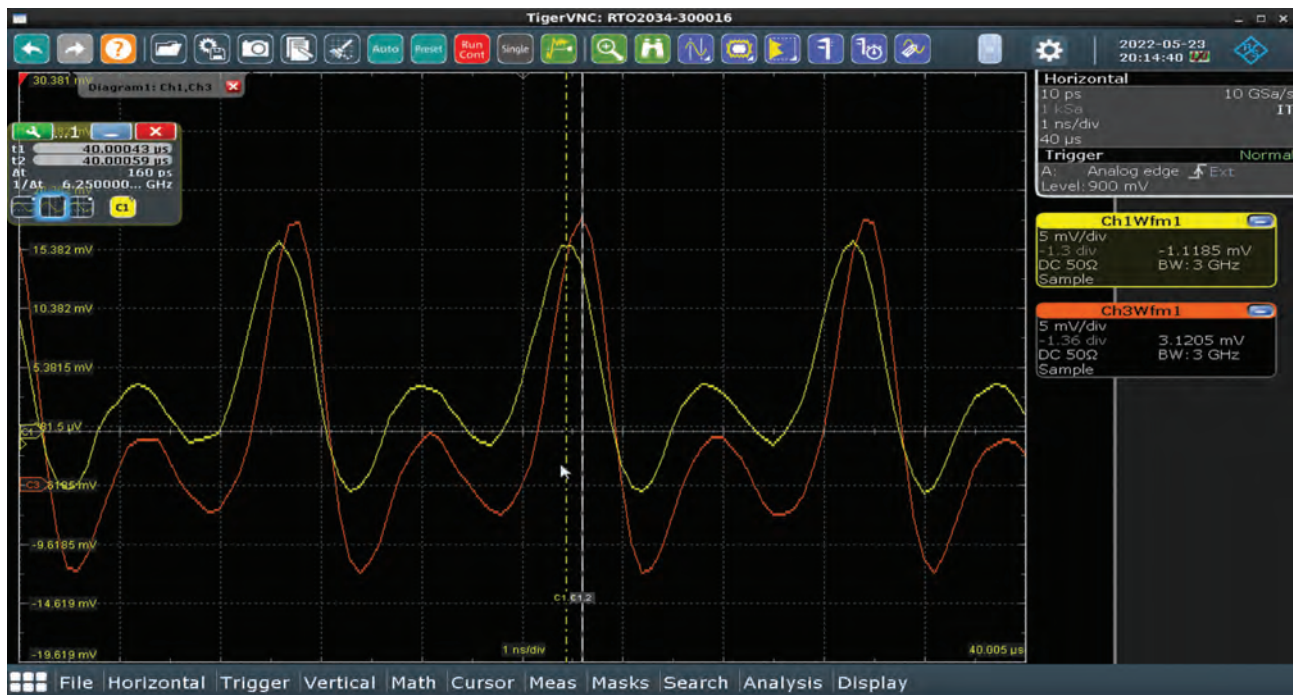
Schematic of LEHIPA beam line after the DTL.

## Non-invasive Beam Profile Monitor (BPM)

A non-invasive 2-D beam profile monitor based on beam-induced fluorescence of a gas sheet was designed and developed through in-house efforts. This technology has the potential to improve current practices by overcoming thermal and radiation damage associated with traditional invasive techniques. Furthermore, non-invasive approach significantly reduces beam loss and allows for online operation of the beam profile monitor.



The test bench of 2-D beam profile monitor.



The two FCT signals recorded within time difference of 160 ps.

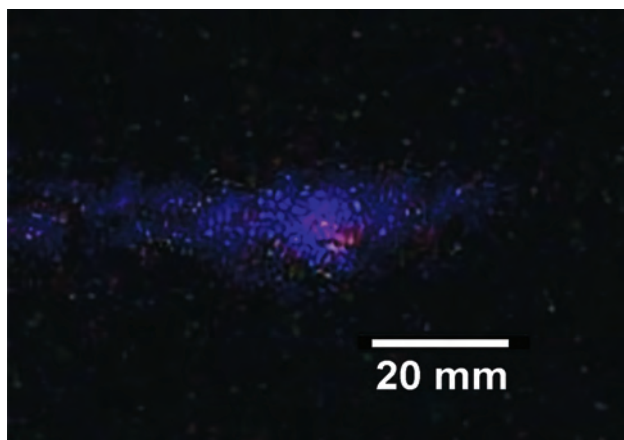
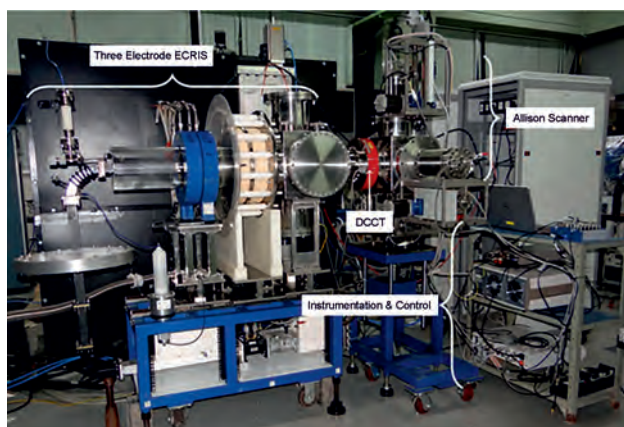


Image generated using gas sheet based beam profile monitor.

### ECR Ion Source Activity

The 5-electrode ECR Ion Source (ECRIS) showed improved emittance at 50 keV and longer pulses of >10 ms compared to the 3-electron system. This exercise, which involves characterisation of source, was taken up as part of the efforts to improve the quality of pulsed beam.



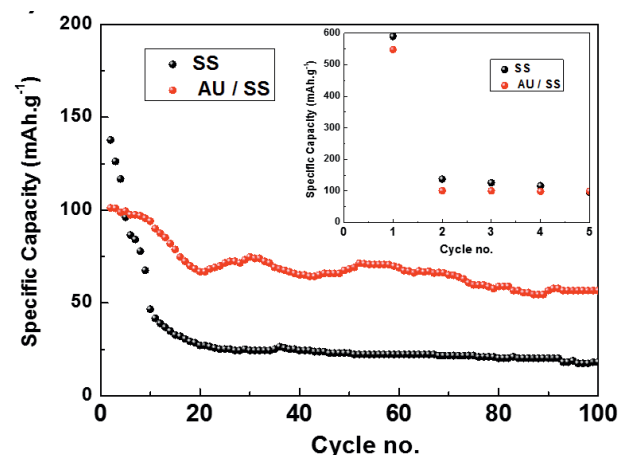
Experimental set up of beam emittance characterization of ECRIS.

## Batteries

### Bi-layer Thin Film Structure for Improved Stability of Ni-rich Cathode in Li-Ion Battery

$\text{LiNi}_x\text{Mn}_y\text{Co}_z\text{O}_2$  (LNMC) has emerged as a promising cathode material for Li ion batteries (LIBs),

particularly for large scale energy storage in automotive applications. A bi-layer electrode for Li ion batteries has been deposited mimicking spherical core shell structure with LNMC-333, which provides better stability, as an outer layer and with LNMC-811 which provides higher capacity as an inner layer. This is a novel, highly reproducible and easily scalable thin film route to prepare a composite electrode having both the properties of LNMC-333 and LNMC-811 battery material. The thin films of LNMC-333 and LNMC-811 electrodes have been deposited by RF magnetron sputtering at two different Ar pressures of  $7 \times 10^{-2}$  and  $2 \times 10^{-3}$  mbar on SS substrates. The core-shell structure with LNMC-811 as an inner layer and LNMC-333 as an outer layer gives the benefit of higher capacity of LNMC-811 with improved structural stability of by LNMC-333.



Specific capacities of LNMC thin film cathode on SS and Au-SS substrate as a function of cycle number cycled between 2.5 V and 4.3 V for LNMC-333 electrode.

## Mass Spectrometers and Spectroscopy

### Mass Spectrometer Leak Detector for Corrosive Environment Applications

A modified version of helium mass spectrometer leak detector (MSLD) has been developed for

### Establishing the concept of Use-and- Recycle for ensuring sustainable energy

- ⊗ A methodology was developed for separation of Li from spent Li ion battery.
- ⊗ New electrode materials were developed for Na ion battery with high capacity.

corrosive environment applications. The detector is equipped to operate in vacuum mode with minimum detection limit of  $5E-12$  mbar.l/s, and a dynamic range of leak detection from  $1E-4$  to  $5E-12$  mbar.l/s.



MSLD for corrosive environment applications.

### Laser Spectroscopy of Yttrium Monoxide (YO) Molecule

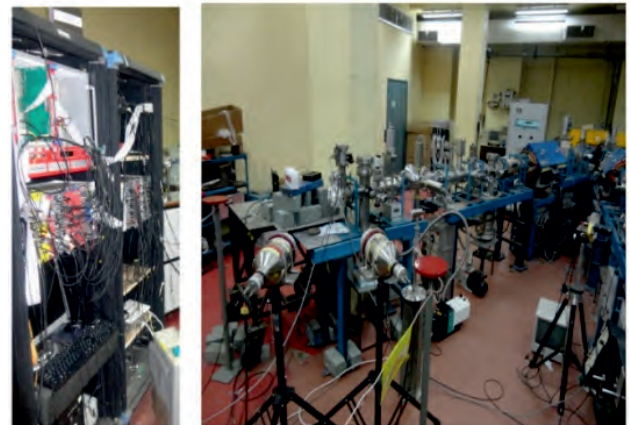
The supersonic molecular beam setup was used to investigate the electronic structure of YO molecule using laser-induced fluorescence spectroscopy. Theoretically predicted  $C^2P_i$  state, unobserved hitherto was detected experimentally. Investigation of newly observed excited electronic states in this work exhibit severe perturbation, revealing the complexity in the electronic structure of YO molecule.

## Nuclear Physics

### Fast Neutron Induced Fission of Actinides

Measurement of the prompt fission gamma-ray spectra (PFGS) and prompt fission neutron spectra (PFNS) in the fast neutron induced fission of actinides is important in the development of GEN IV fast reactors and Accelerator Driven Systems. While PFGS is required for accurately estimating the gamma heating in reactor cores, PFNS plays an important role in predicting criticality of nuclear systems accurately. Measuring of prompt fission

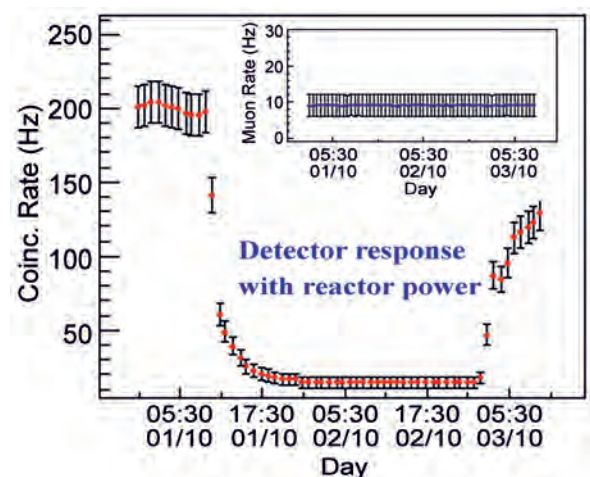
gamma-rays and neutrons emitted in the fast neutron induced fission of  $^{232}\text{Th}$  have been carried out at incident neutron energies of 1.5 MeV, 2.1 MeV and 2.8 MeV using quasi-monoenergetic neutron beams produced at the FOTIA facility BARC. The extracted prompt fission gamma-ray spectra for  $^{232}\text{Th}(n,f)$  when compared with the existing data of  $^{252}\text{Cf}(s,f)$ ,  $^{239}\text{Pu}(n,f)$  and  $^{238}\text{U}(n,f)$ , showed noticeably lower intensity of photons at energies less than 0.7 MeV, which cannot be explained by the existing models.



Prompt fission neutron and gamma spectra measurement setup.

### Measurements using ISMRAN Detector at Dhruva for Neutrino Physics

Neutrino detection offers one of the most promising pathways to understand the fundamental interactions of nature and also to discover new physics aspects beyond the standard model. Despite being the second most abundant particle, neutrinos remain elusive due to their

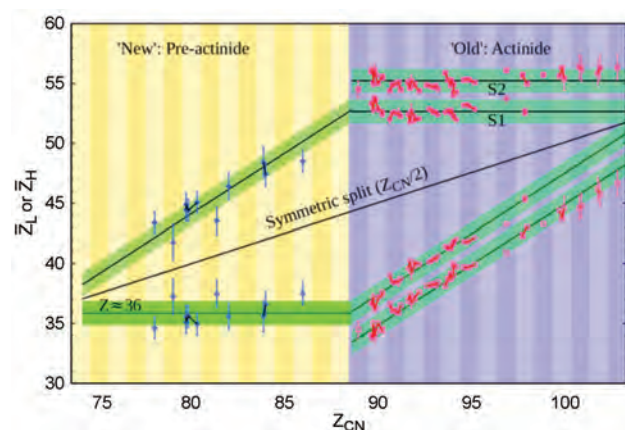


Response of ISMRAN detector with varying levels of reactor power.

feeble interaction. A large plastic scintillator ISMRAN (Indian Scintillator Matrix for Reactor Antineutrino) detector along with shielding was designed, fabricated and installed inside Dhruva reactor hall for measurements of antineutrinos through the inverse beta decay (IBD) process. ISMRAN detector setup has been operated successfully in the round-the-clock mode over a period of more than a year and the response of detector elements of ISMRAN provides a tool to monitor the reactor power level in a reliable way.

### New Insights into Nuclear Fission

In an experimental study carried out using the BARC-TIFR Pelletron LINAC facility, Mumbai, it was demonstrated that nuclear dynamics plays a significant role in fission in the pre-actinide region. A consistent analysis of the available data revealed a regular pattern, establishing the stabilizing role of the light fragment nuclear charge in the pre-actinide region in contrast to actinide region. Combining the light fragment-driven stabilizing effect with previously established leading effects in the actinide region, a striking connection has been found, illustrating the general dominance of proton shells in low-energy fission. This could steer the path for a unified theory of fission.

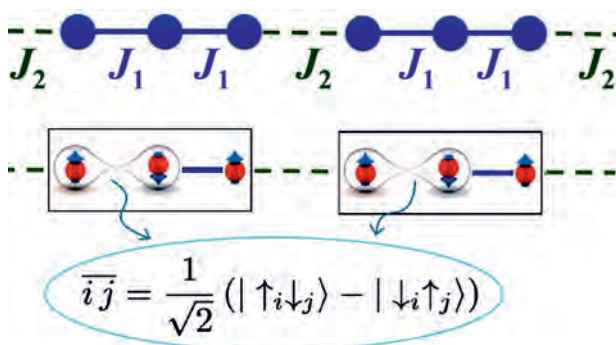


Evolution of the mean atomic number of the light (heavy) fragment ( $Z_{L(H)}$ ) in asymmetric fission as a function of atomic number of the fissioning nuclei ( $Z_{CN}$ ) from above rare-earth to very-heavy and super-heavy elements.

## Solid State Physics

### Realization of Near Room Temperature Spin Quantum Entanglement

Quantum entanglement phenomenon occurs when a group of quasi-particles interact and share spatial proximity in a way such that the quantum states of each particle of the group cannot be described independently of the states of the others. The novel quasi-particle excitations of strong spin-entangled ground state of a quantum spin-1/2 trimer-chain antiferromagnet were demonstrated for the first time. Such a model spin-1/2 trimer-chain antiferromagnet has been achieved in the compound  $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$  where the group of three spin-1/2 of  $\text{Cu}^{2+}$  ions are strongly coupled to form a spin-trimer, and such trimers are magnetically weakly coupled to make a spin-chain. Most importantly, such entangled spin-states are found to be very stable against temperature and persist up to near room temperature ( $\sim 250$  K), which has a special importance for practical device applications in the upcoming quantum technology.

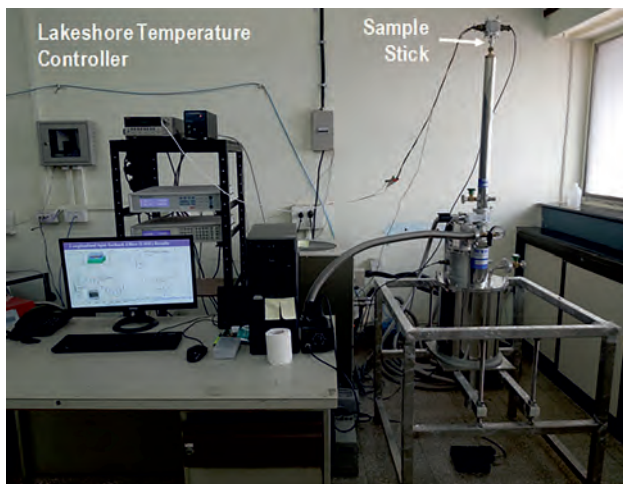


A schematic snapshot of the quantum entangled spin-state.

### Facility for Longitudinal Spin Seebeck Effect Measurements

Spin Seebeck Effect (SSE) is a spin analogue of the conventional Seebeck Effect. An indigenous facility has been set up for the measurement of

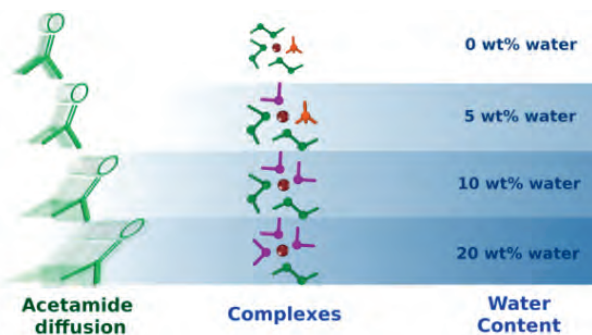
longitudinal Spin Seebeck Effect in magnetic materials over 10-450 K. Using this facility an enhanced longitudinal spin Seebeck voltage, comparable to that reported for thin film samples, has been achieved in Au deposited on polycrystalline ferrimagnetic  $Y_3Fe_5O_{12}$  (YIG) sample.



Spin Seebeck effect measurement setup.

### Controlling Microscopic Molecular Motions in Deep Eutectic Solvents using Water

Deep eutectic solvents (DESs) have become a very promising media for various industrial and manufacturing processes. In particular, DESs based on acetamide and lithium salts have shown potential to be applied as electrolytes in lithium ion batteries, which serve as an essential component in modern technologies like electric vehicles and solar power storage. Employing neutron scattering and Molecular Dynamics simulation techniques, microscopic effects of water on the transport properties of DESs were explored. Investigations revealed a strong connection between the



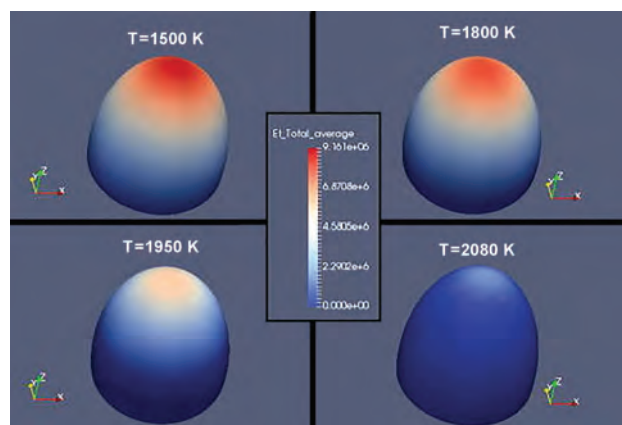
QENS spectra of pure DES and DES + 20%  $D_2O$  at Q-value of  $1.4 \text{ \AA}^{-1}$  along with the model fitting based on localized translation diffusion mechanism.

microscopic motions and hydrogen bond interactions occurring in DESs. By using water as an agent to control the hydrogen bond interactions in DESs, we demonstrated that we can produce systems with higher conductivity and mobility.

### Study of Transition from Source Limited to Space Charge Limited Emission of Electrons for Curved Thermionic Emitters

For diodes having curved thermionic emitters, transition from source limited to space charge limited (SCL) emission of electrons was investigated using in-house Particle-In-Cell (PIC) code PASUPAT. The transition to SCL regime was found to occur at higher temperature for high aspect ratio emitters. In a separate study, it was also shown that, near the emitter tips, where field varies rapidly, semi-analytical field can be used to transport electrons emitted from LAFE. This will be helpful in the development of LAFE based emission module in PIC codes which otherwise require huge computational resources to model a few hundred emitters.

The PIC code PASUPAT has been upgraded with advanced Monte-Carlo based collision module to handle interaction of electrons with neutral atoms. PIC technique takes care of interaction among the charged particles. The Swarm Parameter (drift velocity) for electron transport under applied electric field in Argon gas was calculated. The simulated results have shown good agreement with the published data.

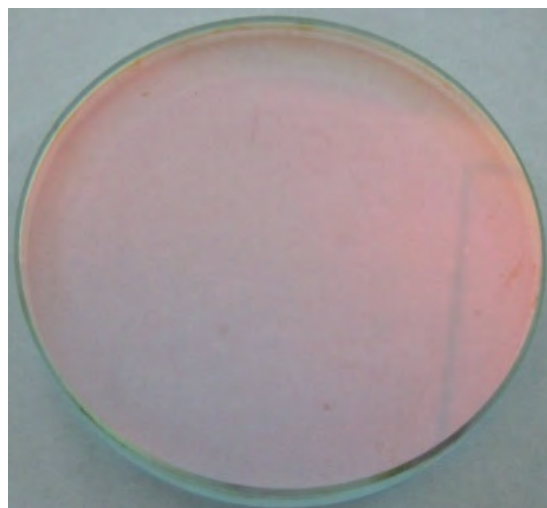


The net electric field (space charge and applied field) at the surface of hemi-ellipsoidal emitter for different temperatures.

## Technical Physics

### High Reflection Multilayer Mirrors for Micro Raman Experimental Set-up

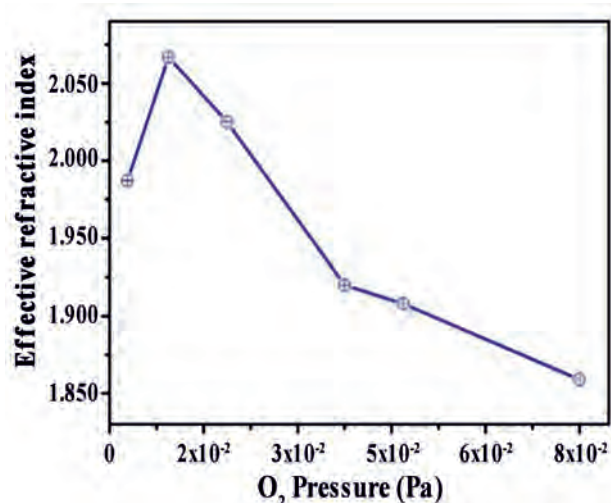
A customized high reflection optical multilayer based mirror having reflection of 99.99% at a wavelength of 532 nm and 45 degree angle of incidence has been developed successfully. The mirror design consists of 35 layers of  $\text{TiO}_2/\text{SiO}_2$  sequential quarter wave thin film layers for achieving the high reflection and is developed using the e-beam deposition system. This mirror is useful for micro Raman experimental setup used for material studies under high pressure.



High reflection optical multilayer based mirror.

### Morphological Study of Reactive Electron Beam Deposited Tantalum Penta Oxide Thin Films

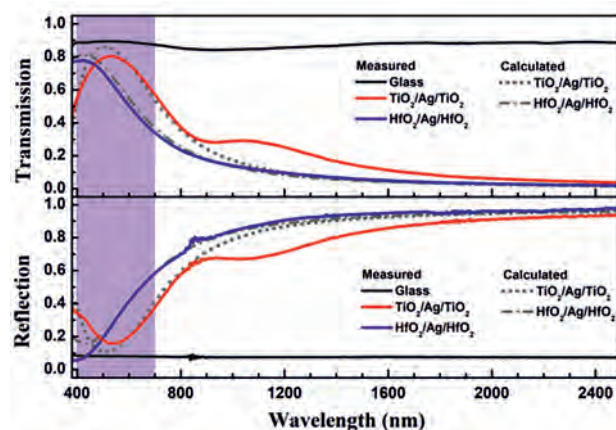
Tantalum penta oxide is one of the new materials being used for developing optical thin film layer based devices. A study of properties of Tantalum penta oxide thin films was carried out by coating them by reactive electron beam deposition technique. The effect of  $\text{O}_2$  flow rate during the thin film deposition on refractive index ( $n$ ), extinction constant ( $k$ ), and film porosity has been studied through spectroscopic ellipsometry. Film density is measured with grazing incidence X-ray reflection measurements whereas surface morphology of the films has been characterized by Atomic Force Microscopy (AFM).



Variation of refractive index of Tantalum penta oxide with  $\text{O}_2$  pressure.

### Transparent Heat Mirrors for Energy Efficient Windows Application

Transparent heat mirrors (THM) capable of transmitting visible light by reflecting the infrared light have been designed for energy efficient smart windows application. The  $\text{TiO}_2/\text{Ag}/\text{TiO}_2$  coated mirrors showed an average transmission of around 77.60 % in the visible region of 400-700 nm and an average solar reflection of 67.55 % in the near-infrared region of 700-2500 nm, while the  $\text{HfO}_2/\text{Ag}/\text{HfO}_2$  coating shows average transmission of 58.66 % in the visible region and average solar reflectivity of 81.91 % in the near-infrared region.



Measured and calculated transmission and reflection spectra of  $\text{TiO}_2$  (35 nm)/Ag (20 nm)/ $\text{TiO}_2$  (35 nm) and  $\text{HfO}_2$  (35 nm)/Ag (20 nm)/ $\text{HfO}_2$  (35 nm) transparent heat reflector coatings.

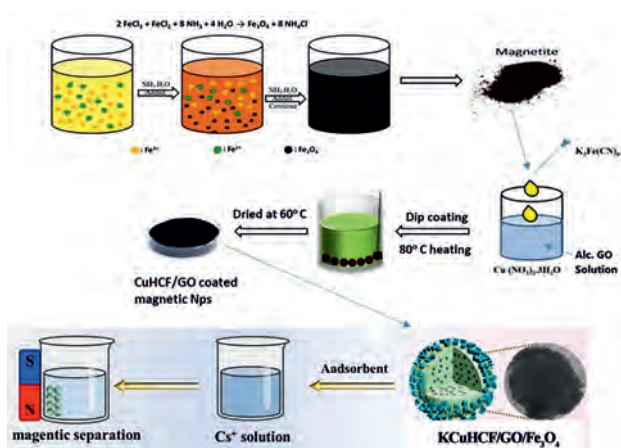
## Chemical Sciences

### Development of LaPO<sub>4</sub> based Machinable Ceramics

With a view to developing machinable ceramics for high temperature applications, composites of LaPO<sub>4</sub> and Al<sub>2</sub>O<sub>3</sub> were explored. A solution processing followed by high temperature calcination process was adopted to prepare hexagonal and monoclinic LaPO<sub>4</sub>. The method could be used to prepare about 500gm sample in a batch which can also be scaled up. Sintering behaviour of composites of La<sub>2</sub>O<sub>3</sub> and LaPO<sub>4</sub> as well as mixtures having different proportions were studied. Denser ceramic entity could be obtained in all the samples except Al<sub>2</sub>O<sub>3</sub> by sintering at 1400°C.

### Synthesis of Cobalt Hexacyanoferrate Sand Composite for Removal of Cesium Ion from Low-level Radioactive Waste Water

Natural sand was modified with cobalt hexacyanoferrate (CoHCF) using a simple and effective approach to produce a composite material for selection adsorption of cesium ion. The batch studies showed selective adsorption of Cs over a wide pH range from 1 to 10 with adsorption capacity of 5 mg/g. Detailed studies suggest both film diffusion and intraparticle diffusion as the rate controlling step in the adsorption process. A magnetic nanocomposite of Fe<sub>3</sub>O<sub>4</sub>/Graphene oxide (GO)/potassium copper hexacyanoferrate (KCuHCF) had been synthesized



Schematic of synthesis of Fe<sub>3</sub>O<sub>4</sub>/GO/KCuHCF Nanocomposite.

via wet chemical and co-precipitation method for selective adsorption of cesium ion. Our synthesized nanocomposite enhances the stability and recovery of KCuHCF even after radioactive Cs ion absorption.

### Catalytic Hydrolysis of Ammonia Borane with Cucurbituril-functionalized Transition Metal Nanocomposites

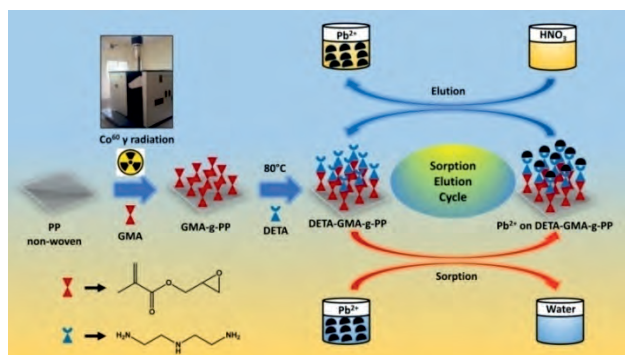
The screening of cucurbituril-functionalized Co:Ni nanocomposites (Co:Ni:CB) as catalysts has been carried out for the hydrolysis of ammonia borane (AB). The substantial decrease in the activation energy (103.8 kJ/mol to 32.04 kJ/mol) for the hydrolysis of AB has been achieved with Co:Ni:CB nanocomposite. Ammonia release during hydrolysis is significantly prevented in the presence of Co:Ni:CB nanocomposite. The reusability of the catalysis was examined by the repeated hydrolysis of ammonia borane (AB) for six cycles in intervals of 24 hours each. The catalytic activity of Co:Ni:CB nanocomposite remains constant, whereas the activity of nanocomposite without cucurbituril, Co:Ni, decreases by 60% after three cycles.

### Development of Glycidyl Methacrylate Grafted Polypropylene Non-woven Fabric for Selective Sorption of Metal Ions

Poly-propylene (PP) non-woven fabric was grafted with glycidyl methacrylate (GMA) under <sup>60</sup>Co gamma irradiation using simultaneous irradiation grafting method. Amine functionalized grafted non-woven fabrics were synthesized by reacting the GMA grafted PP fabric with different amines, ethylene diamine (EDA), diethylenetriamine (DETA), triethylenetetramine (TETA) and ethanol amine (EA), 2-picolyl amine (PA). To check sorption capacities of grafted fabrics towards specific ions, sorption experiments were performed using Pb<sup>2+</sup>, Cd<sup>2+</sup>, Cu<sup>2+</sup>, Co<sup>2+</sup> and Au<sup>2+</sup>. DETA functionalized grafted fabrics showed good sorption capacity for Pb<sup>2+</sup> (208 mgg<sup>-1</sup>). PA functionalized fabrics could show



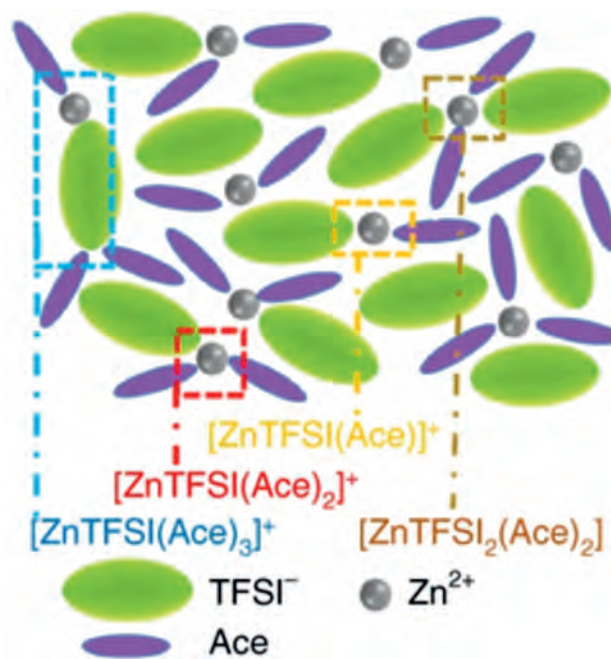
sorption of  $\text{Au}^{+2}$  up to  $\sim 600 \text{ mgg}^{-1}$  following Freundlich adsorption isotherm. In both cases, sorption kinetics were found to be very fast, which is evident from the fact that more than 97% of targeted ions could be recycled in less than 10 min when operated in 5 cycles.



DETA functionalized GMA grafted PP non-woven fabric for recovery of  $\text{Pb(II)}$ .

### Ultrafast Electrolyte Solvation Dynamics related to Zn Ion-batteries using 2D IR Spectroscopy

Electrolyte solvation and interfacial model in battery materials is emerging over the concept of formation of Solid-Electrolyte Interface (SEI) on the electrode surface in determining the electrolyte composition for better electrode performance in metal ion batteries in recent times. Here, the aim was to understand the solvation dynamics of an eutectic electrolyte composed of  $\text{Zn(TFSI)2}$ -Acetamide electrolyte by varying their composition through 2DIR spectroscopy using  $\text{SCN}^-$  as a local vibrational probe. The linear and 2DIR spectroscopy reveals that the ultrafast solvation dynamics are strongly influenced by the composition of the constituents in the electrolyte system which can be directly correlated to the transport properties of the electrolytes. The vibrational dynamics show bi-exponential behavior corresponding to two different molecular structures like free electrolytes or loose ion-pairs and intimate ion pairs. Reported MD simulation results suggest that the contribution of these entities varies with the composition of the constituents which was reflected in the observed dynamics. These dynamics indirectly hint at the transport properties of the metal ions in the battery materials.



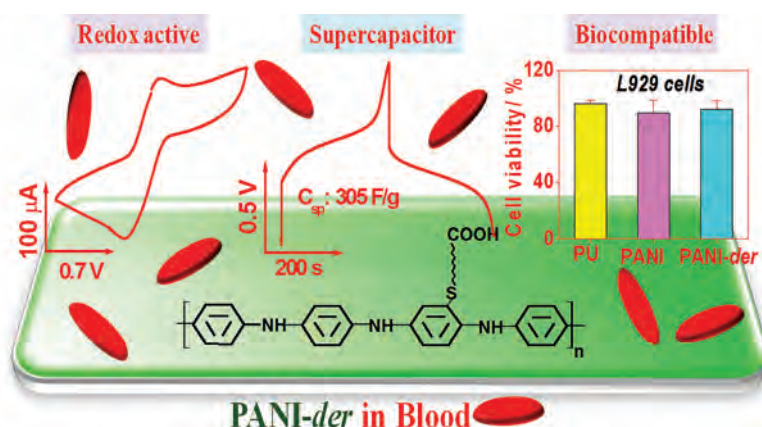
Molecular arrangement in Zinc eutectic mixtures as proposed by MD simulation.

### Determination of Platinum in Serum of Oncology Patients for Haematological Toxicities and Carboplatin

Carboplatin is used for chemotherapy in the treatment of cancer and its exposure depends upon its renal clearance. The dose calculation thus varies depending on the glomerular filtration rate (GFR). As measured GFR (mGFR) may not always be available an estimated GFR (eGFR) is commonly used for carboplatin dose calculation. A method has been developed using GFAAS for determination of Pt in serum of oncology patient and carboplatin.

### Organically Modified Polyaniline for Physiological Fluids Operable Supercapacitor Electrodes

Recent developments in implantable electronic medical devices have prompted an increasing demand for energy storage devices which are operable in physiological fluids. Fabrication of such devices requires materials that are electroactive in physiological fluids and biocompatible. A polyaniline derivative, carboxylic acid-tethered polyaniline (PANI-der), was synthesized by click



Schematic depicting redox-activity, energy storage capability and biocompatibility of PANI-der in blood.

chemistry route. PANI-der which is inherently redox active at neutral pH, was evaluated as an electrode material for physiological fluids operable supercapacitor. PANI-der displayed high specific capacitance and energy density in physiological fluids (phosphate buffer solution, blood, serum, urine and sweat) and culture media (DMEM and LB broth). For instance, in blood, PANI-der displayed a specific capacitance of 305 F/g which is 254 times higher than that of conventional PANI. Further, PANI-der exhibited good cyto-compatibility during voltage cycling in A549 cell lines even after 1000 galvanostatic charge-discharge cycles. Owing to inherent redox activity in physiological fluids and biocompatibility, PANI-der has potential for integration with *in vivo* medical devices.

### Room-temperature Synthesis of Bimetallic Co-Ni based Zeolitic Imidazolate for H<sub>2</sub> Storage

ZIF-67 (Co as metal centre) and Ni-doped ZIF-67 (Co-Ni ZIF-67) were synthesized by simple precipitation method at room temperature. Heterogeneous crystalline porous structure of bimetallic ZIF-67 was confirmed from XRD, SEM and textural characterization based on N<sub>2</sub> adsorption-desorption isotherm. The isotherm for ZIF-67 is type-I indicating micro-porous nature of the sample. Co-Ni ZIF-67 shows mixed type-I and type-IV isotherms indicating the presence of both micro and meso-pores. The multipoint BET surface areas of ZIF-67 and Co-Ni ZIF-67 samples are 756 and 893 m<sup>2</sup>/g, respectively. H<sub>2</sub> storage capacities of ZIF-67 and Co-Ni ZIF-67 are ~ 2 wt.% and 3 wt.% (at 77K & 25 bar) respectively.

## Healthcare Materials and Drug Discovery

### Development of Glass based ceramics for Hyperthermia Application

Ferromagnetic crystallites in glasses [(64-x)SiO<sub>2</sub>-17 Y<sub>2</sub>O<sub>3</sub>-19 Al<sub>2</sub>O<sub>3</sub>-x Fe<sub>2</sub>O<sub>3</sub> (x=8-16) mol%] were developed through optimization of bulk composition – structure – properties (thermal, magnetic) for hyperthermia application.

### Zinc Gallate based Persistent Luminescent Formulations for Targeted Boron Neutron Capture Therapy

Recent research and developments have been taken up in the field of oncology are based on non-invasive formulations and their multi-modal, -functional or theragnostic utility. In view of this, we have developed biocompatible, tumor targeting nano-formulation consisting of zinc gallate [(ZnGa<sub>2</sub>O<sub>4</sub>:0.5%Cr (SZGO:Cr)]-based persistent luminescence nanoparticles which was loaded with <sup>10</sup>B(OH)<sub>3</sub>. This was further conjugated with tumor targeting pH-insertion peptide (pHLIP) i.e., SZGO:Cr-<sup>10</sup>B-NF. The pHLIP has an affinity for local acidity of cancerous cells originating due to lactic acid formed due to altered glycolysis pathway in case of cancer cells. The formulation exhibited ability for detection of cancerous tissues and effective treatment by BNCT as well as facilitated *in vivo* bioimaging due to the persistent emission up on excitation with visible light. During the therapy, melanoma or fibrosarcoma tumor developed on

right thighs of C57BL/6 or BALB/c mice respectively, resulted in reduction of tumor volumes by ~80-85%. Additionally, histopathological studies have exhibited the biocompatibility of formulation.

### Label-free Optical Bio-sensing of Non-cancerous and Cancerous Tissues from Mice

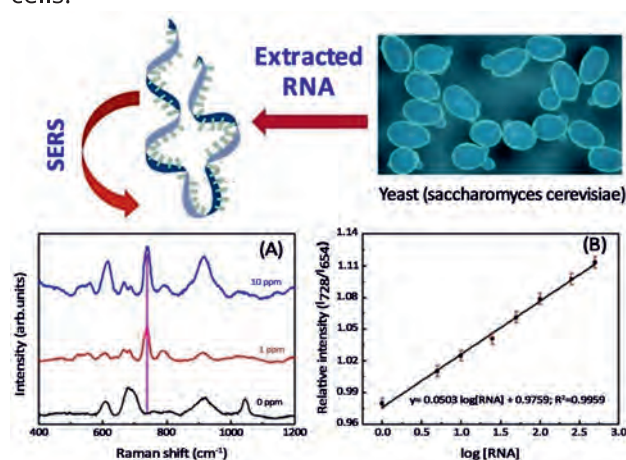
Spectroscopic distinction of non-cancerous and syngeneic cancerous tissues has been demonstrated by label-free fluorescence and circular dichroism (CD) spectral features of a probe dye, thiazole orange (TO). The fluorescence emission of TO displayed significantly higher emission enhancement with the DNAs from cancerous tissues. On the other hand, the circular dichroism (CD) measurements of TO-DNAs showcased distinct spectral features in their induced CD (ICD) bands originating from DNAs from cancerous tissues as against that from non-cancerous tissues. This study offers a facile, effective, label-free optical method for the diagnosis of cancer tissues.

### SERS based Detection of RNA

SERS measurements were carried out for the detection of RNA from Yeast (*Saccharomyces cerevisiae*). In order to improve the S/N ratio, novel Ag substrate was prepared for the SERS measurements. The SERS spectrum recorded with 532 nm excitation showed a strong characteristic peak at  $728\text{ cm}^{-1}$  corresponding to the ring breathing mode of adenine. The  $728\text{ cm}^{-1}$  vibration showed a gradual increase in intensity as a function of RNA concentration. The limit of detection of yeast RNA was found to be  $< 1\text{ ppm}$ . The methodology developed for the detection of yeast RNA will be explored further for fingerprinting of RNA extracted from different cell lines.

SERS studies have been initiated to distinguish lung carcinoma cell from normal lung cell. Silver nanostructures were used as SERS substrate. Unlike normal lung cells, distinct vibration bands that appear at  $\sim 562\text{ cm}^{-1}$  and  $906\text{ cm}^{-1}$  in the

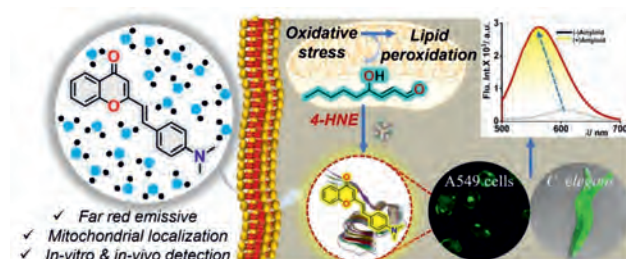
carcinoma cells are possibly due to the conformational changes in the nucleic acids and proteins in these cells which results in different binding characteristics on the surface of silver nanostructures. Results suggest that the SERS technique may be used as a diagnostic tool to differentiate lung carcinoma cells from normal lung cells.



(A) Concentration dependent SERS spectra of RNA extracted from Yeast, (B) Raman sensitivity curve in the concentration range of 1-1000 ppm of RNA

### Styrylchromone-based Fluorophore for Amyloid Detection

A far-red emissive styrylchromone-based fluorophore (SC1) has been synthesized for fluorescence-based detection of amyloid fibrils. SC1 records exceptional modulation in its photo-physical properties in the presence of amyloid fibrils, which has been attributed to the extreme sensitivity of its photo-physical properties towards the immediate micro-environment of the probe in the fibrillar matrix. The probe is also able to monitor the kinetic progression of the fibrillation process, with an efficiency comparable to that of the most popular amyloid probe, Thioflavin-T. SC1 exhibited excellent biocompatibility and exclusive



Schematic representation of protein aggregate detection induced by 4-HNE and its detection by a styrylchromone derivative in A549 cells and *C. elegans*

accumulation at mitochondria which allowed us to successfully demonstrate the applicability of this probe to detect mitochondrial aggregated protein induced by an oxidative stress indicator molecule 4-hydroxy-2-nonenal (4-HNE) in A549 cell lines.

### Fe<sub>3</sub>O<sub>4</sub> Nanomagnets for pH Responsive Delivery of Gemcitabine and *in vivo* Tracking by Radiolabeling

Gemcitabine, a well-known nucleoside analogue, has shown tremendous potential against solid tumors. However, its clinical use is limited due to its poor biological half-life and low target to non-target ratio. In this regard, polyphosphate grafted Fe<sub>3</sub>O<sub>4</sub> nanomagnets (PPNMs) were developed for efficient delivery of gemcitabine hydrochloride (GEM). The GEM loaded PPNMs (GEM-PPNMs) exhibited pH triggered release of the loaded drug, substantial cellular uptake, and higher toxicity towards human lung cancer (A549) and breast cancer (MCF-7) cell lines over pure drugs. Further, the biodistribution of these nanocarriers was assessed by their tracking in a mouse model through radiolabeling with <sup>64</sup>Cu and <sup>177</sup>Lu. Though the radiolabeled system exhibited higher uptake in the liver and spleen upon intravenous injection, a substantial uptake of the same was also found in the tumor.

### Mesoporous NaGdF<sub>4</sub>:Ho-Yb@m-SiO<sub>2</sub> Upconversion Nanophosphors as a Potent Theranostic Probe Material

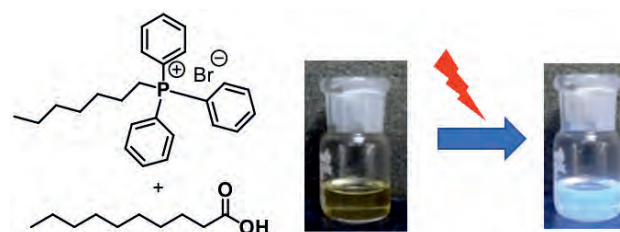
Nearly monodispersed NaGdF<sub>4</sub>:Ho-Yb upconversion nanoparticles (UCNPs) are synthesized by thermolysis of respective rare earth oleates. UCNPs are made biocompatible by mesoporous silica (m-SiO<sub>2</sub>) coating. These particles exhibit the red and green bands in visible range upon excitation at 980 nm laser. A systematic study is carried out to demonstrate the use of these UCNPs as drug (DOX) carrier. Toxicity study and bio-imaging using DOX-loaded UCNPs have been demonstrated. UCNPs are also radiolabeled with <sup>177</sup>Lu using m-SiO<sub>2</sub> coating to demonstrate its potential application as a carrier of the therapeutic radionuclide *in vivo* for radionuclide therapy.

### In-house Production of Single Domain Antibody Against Tuberculosis through Phage Display Library

The phage display library was constructed from PBMNC of camel immunized with MTB proteins. Nanobody clones were isolated using the recombinant immunodominant antigen of MTB, ESAT-6 in bio-panning. The clones were sent for sequencing to confirm they belong to nanobodies sent for sequencing. The anti-Tb nanobodies will be useful in diagnosis as well treatment of TB.

### Dopant Free Blue Light Emitting Novel Hydrophobic Deep Eutectic Solvent as Liquid Scintillators

Health hazard, supply challenges, and high cost have raised the global need of rare earth free luminescent materials, for white light emitting diodes. A novel hydrophobic deep eutectic solvent employing cheap and green chemicals, in which the phenomenon of  $\pi$ -electron cloud distortion of the phenyl rings via hydrogen bonding leads to an efficient all liquid luminogen, with narrow (full-width at half-maximum of ~24 nm), stable, bright, multiwavelength excitable blue emission (Commission Internationale de l'Éclairage (CIE) coordinates of 0.206, 0.208) centered at around 425 nm, and with a photoluminescence quantum yield (PLQY) of 23%. The potential of the DES as a liquid scintillator was further demonstrated with radioactive sources emitting alpha and gamma radiations.

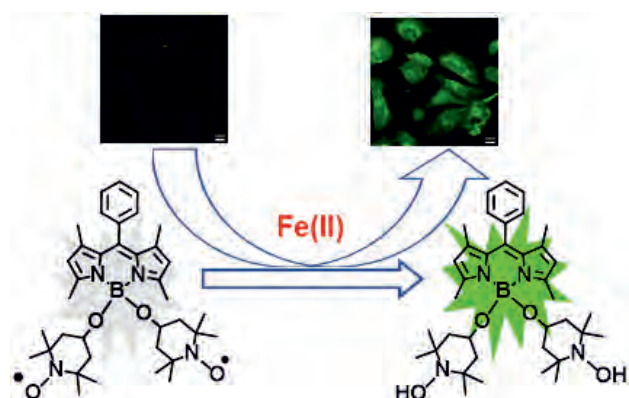


Novel DES as DOPANT free liquid scintillator.

### A Selective Turn on Fluorescence Sensor for Intracellular Labile Iron Pool

Intracellular labile iron pool (LIP) has been associated with cellular toxicity, and regarded as

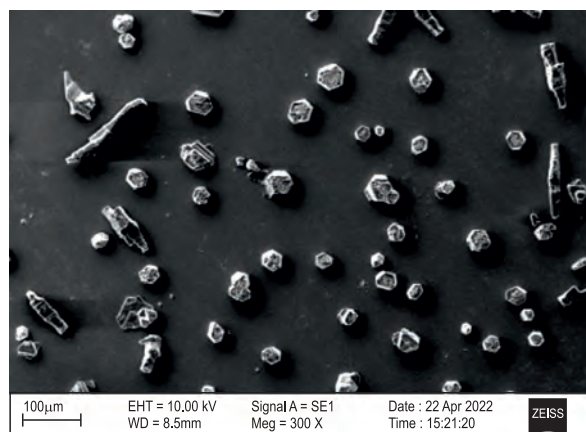
one of the factors affecting many diseases. However, fluorescence probes for detection of LIP are limited. The aim of this project was to design and develop a turn-on fluorescence sensor for LIP. BARC developed a diradical, triplet ground state stabilized pro-fluorescent nitroxide, as a turn on sensor for similar purpose. The probe showed high sensitivity with Fe (II)-selective turn-on response via reduction of the biradical. This is a first example of a BODIPY based fluorescence turn-on sensor selective towards Fe (II).



BODIPY-TEMPO diradical for selective fluorescence turn-on sensing of intracellular Fe(II).

### Synthesis of Highly Fluorescent BCNO Nanoparticles for Uranium Sensing

Boron carbo-oxynitride (BCNO) nano-particle was prepared by facile single step synthesis and found to have high luminescence (Quantum Yield = 93%) and 70 nm dimension ascertained by fluorescence, microscopy and small angle XRD (SAXS). BCNO was further characterized by NMR, IR and wide angle XRD and experiment results were corroborated by theoretical data. Further theoretical studies elucidated interaction of BCNO with hexavalent



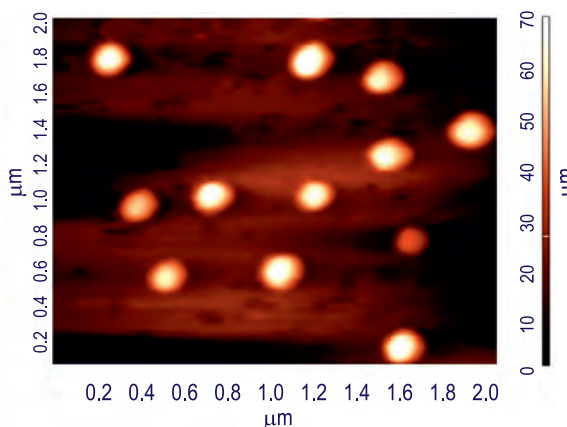
SEM and TEM images of BCNO.

uranium and thus electrocatalytic sensing of uranium in environmental and biological samples was found to be enhanced by BCNO. Uranium signal from the supernatant solution for bio-remediation was increased by BCNO coating on glassy electrode proving BCNO application as an effective uranium sensor in complex biological matrices.

### Bio-fouling Studies

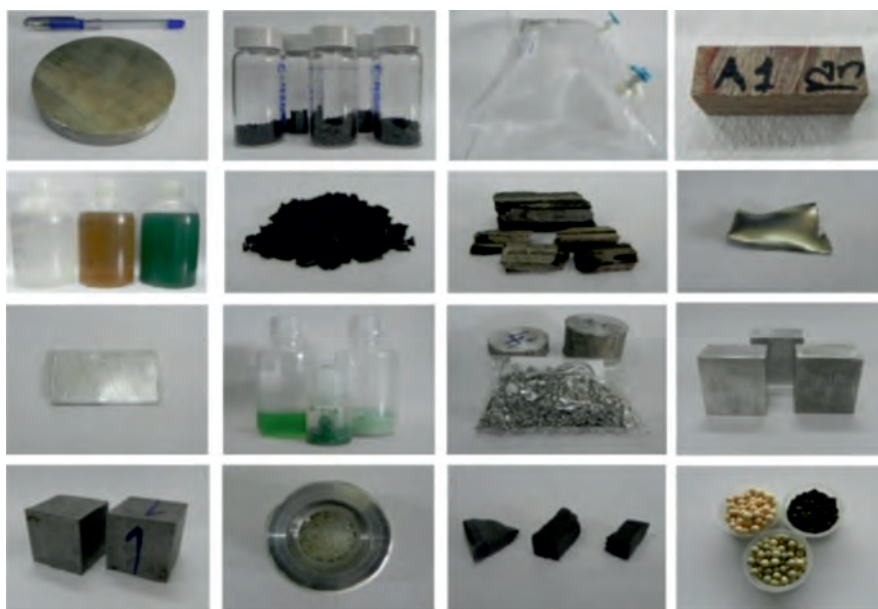
#### Bacteriophages for Biofilm Control

As an alternative to chemical methods, biological control using bacteriophages was investigated to improve environmental sustainability. Apart from selectively inhibiting biofilms, this approach may interfere with larval settlement and the overall biofouling process. As part of this process, bacterial and bacteriophage diversity was determined in the water samples collected from different parts of the seawater cooling system of Madras Atomic Power Station. Selected bacterial strains were identified as having efficient biofilm-forming potential and chlorine tolerance. Bacteriophages specific to chlorine-tolerant and biofilm-forming bacteria were isolated and identified. Interestingly, isolated bacteriophages were found to be highly tolerant to various stressors like salt (up to 20%), temperature (50°C for 4 h), and chlorine (up to 4 ppm for 30 min), making them a choice treatment for controlling biofilms even in harsh environments. Growth and biofilm formation by *Klebsiella pneumoniae* was retarded in the presence of specific bacteriophages.



### High-end Analytical Services

- ✧ Reference materials for trace elements (Mn, Cr, Cu, Ni, Pb, Zn, Co, Fe) in marine sediment were prepared in-house.
- ✧ Reference Material of 4 Conductivity Solution (100  $\mu\text{S}/\text{cm}$ , 150  $\mu\text{S}/\text{cm}$ , 1000  $\mu\text{S}/\text{cm}$  and 1400  $\mu\text{S}/\text{cm}$ ) was prepared in-house.
- ✧ DO Monitor developed for Nuclear and Societal Applications.
- ✧ Large varieties of materials were analyzed for chemical composition, trace constituent concentrations, surface and thermal properties etc. (>3500 samples with ~10000 determinations).



- ✧ The state-of-art NABL ISO-17025:2017 accredited laboratory facilities of BARC Analytical Chemistry Division provided several high-end analytical services to address pan-India requirements, including analysis to detect presence of toxic metals in water, quality aspects of low alloy steel for important BARC projects as well as constituent units of DAE, time-to-time requirements of PSUs, law enforcement agencies and also academics.

## Materials Science

### Magnesium Potassium Phosphate (MKP) cement - Radiation Stability Testing

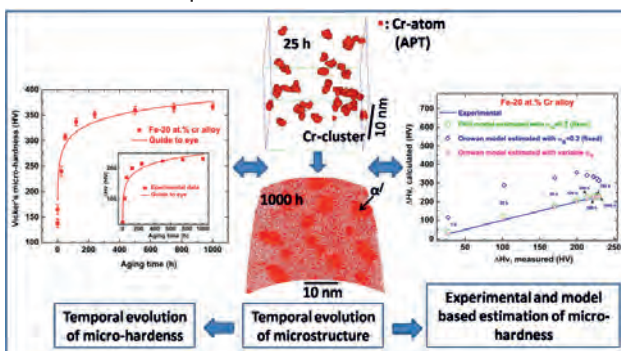
Magnesium potassium-based phosphate cement  $\text{MgKPO}_4 \cdot 6\text{H}_2\text{O}$  (MKP) is a promising matrix for immobilizing nuclear wastes. MKP samples were irradiated in 10 MeV electron beam with doses 10-20 MGy using indigenous RF linear accelerator (LINAC) housed at Electron Beam Centre (EBC), Kharghar, as part of studies to understand the effect of radiation.

Fourier transform infrared spectroscopic measurements, for both hydrated and dehydrated (at  $1000^\circ\text{C}$ ) samples revealed bands in the  $760\text{--}1159\text{ cm}^{-1}$  region attributable to the symmetric and anti-symmetric stretching frequencies of  $\text{PO}_4^{3-}$ . The bands located in  $500\text{--}600\text{ cm}^{-1}$  region were ascribed to the anti-symmetric and symmetric O-P-O bending modes. The number of distinct peaks was higher for the as-prepared hydrated MKP due to additional bending and vibration modes of the hydroxyl group from the water. After irradiation, the number of infra-red active modes were reduced for as-prepared MKP specimen while no appreciable change was recorded for annealed

specimen. For each specimen, the surface area decreased after irradiation, which may be due to agglomeration/ change in porous structure. The specimens do not indicate any thermal destabilization after irradiation.

### APT based Quantification of Cr-rich Phase Separation and its Relationship with Mechanical Properties in Fe-20 at.% Cr Alloy

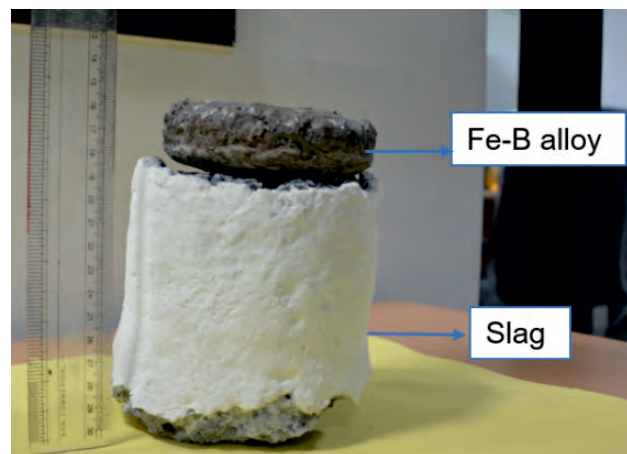
Embrittlement of high-Cr ferritic/martensitic (F/M) steels or oxide dispersion strengthened (ODS) ferritic steels due to irradiation and/or thermal aging is a critical problem that can endanger fail-safe operation. In order to study this, thermal aging induced change in micro-hardness is directly correlated with underlying microstructural evolution at nano-scale for high-Cr binary ferritic Fe-20 at.% Cr alloy. The reason for hardening of the alloy is attributed to the decomposition of ferrite phase into the ultrafine Cr-rich  $\alpha'$  phase in the Fe-rich matrix. A combinatorial methodology utilizing atom probe tomography (APT), transmission electron microscopy (TEM) and small angle neutron scattering (SANS) is followed for reliable quantification of  $\alpha'$  precipitates (diameter > 2 nm) with reduced uncertainty for samples aged for 50 h onwards. It is demonstrated that selection of suitable hardening model (Friedel-Kroupa-Hirsch model) with fixed source strength of 0.2, Orowan model (variable source strength value between (0.04-0.14)) along with reliable quantification of microstructural evolution ( $\alpha'$  precipitates here), can successfully estimate the experimentally observed mechanical response.



Theoretical model based estimation of temporal evolution of micro-hardness for thermally aged Fe-20 at.% Cr alloy utilizing reliable quantification of phase separation parameters (nucleation-growth).

### Preparation of Rare Earth Metals for Nd-Fe-B Magnet

Metallic raw materials required for the preparation of Nd-Fe-B magnet such as neodymium (Nd), didymium (Nd-Pr) and terbium (Tb) were successfully produced from indigenously produced rare earth oxides by employing calciothermic reduction. Required purity was achieved in these metals and the magnets prepared from these by DMRL were found to be at par with imported Nd-Fe-B magnets of same composition.



Fe-12%B alloy (containing lower than 1% impurities) produced from indigenously prepared rare earth oxides.

### Preparation of Rare Earth Metals, their Alloys and Compounds

End-of-life compact florescent lamps (CFLs) are hazardous electronic waste due to presence of toxic heavy metal mercury. A lot of such CFLs are accumulated by Indian recyclers. These CFLs also contain yttrium and europium, which are valuable rare earth elements. A technology has been developed which employs aqueous processing for recovery of not only the rare earth elements, but also hazardous mercury using in-house developed selective polymeric resins.

### Recovery of Cobalt, Nickel and Molybdenum from Alloy Steel Scrap

Due to the absence of viable primary deposits, India is dependent on imports to fulfil domestic and strategic requirements of nickel, cobalt and molybdenum. Large quantities of maraging steel

scrap are generated at M/s. Mishra Dhatu Nigam Limited (MIDHANI) during production, machining, processing and end of life products. Maraging steel contains good amount of these metals. A hydrometallurgical process has been developed to recover these from the scrap in >99% purity with >90% recovery. The process has been demonstrated for plant scale implementation.



Cobalt recovered from alloy steel scrap.

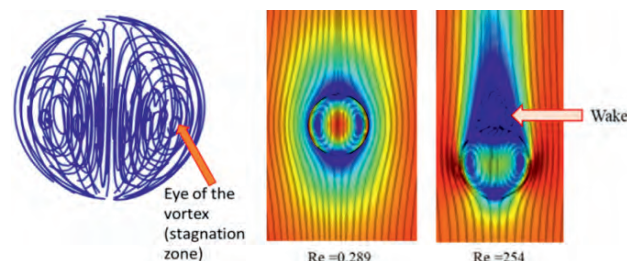
## Computation and Modelling

### 3D CFD Modelling of Packed Bed Membrane Reactor for HI Decomposition

A 3D based CFD model was developed to model decomposition of hydrogen iodide into hydrogen and iodine in a packed bed membrane reactor. The model is based on coupling of fluid flow, chemical reaction, species transport and heat transfer. The model was validated with experimental data available for a single tube geometry (average relative error ~ 12 %). The validated model was used to predict % decomposition of HI in the scaled-up geometry (12 tube packed bed membrane reactor). Percentage decomposition of HI is found to increase with reduction in mass flow rate of HI. The model was used to evaluate possible geometric modification to enhance conversion in scaled-up geometry. In addition, effect of the gap (few millimetres) between the catalyst bed and the reactor outer wall on catalyst bed temperature was also studied using a 3D CFD model.

### Development of CFD-based Drag Model for Simulating Turbulent Two-phase Flow of Concentrated Liquid-liquid Dispersions

To reduce the empiricism in equipment-level CFD models for simulating turbulent flow of concentrated liquid-liquid dispersions, a drag model is developed using a CFD model based on unit cell approach. In this approach, the flow inside a droplet kept in the unit cell is solved along with turbulent flow of the continuous phase flowing through the cell after implementing appropriate boundary conditions at the liquid-liquid interface. The effect of dispersed phase holdup is simulated by changing the volume of the drop while keeping the unit cell volume the same. Results from the simulations carried out using unit cell approach were used to obtain a drag model. The drag model obtained thus will be implemented for equipment-level simulations of liquid-liquid two-phase flow in Pulsed Disc and Doughnut Column (PDDC) and Annular PDDC.



Effect of dispersed phase holdup and degree of turbulence on drag coefficient at a fixed Reynolds number.

### ANUSim Module to Simulate Solvent Extraction Process in a Columnar Contactor

A new module of ANUSim (a python-based simulator dedicated for nuclear chemical processes) to simulate solvent extraction in a columnar contactor was developed. The module named as ANUSim-DCS (ANUSim - Differential Contactor Simulator) is based on axial dispersion model and can be used to simulate extraction of up to 3 non-interacting species. The module takes inputs on hydrodynamic parameters (continuous and dispersed phase axial dispersion coefficients, dispersed phase holdup and Sauter mean drop



diameter), equilibrium data, mass transfer coefficient, geometric parameters and operating parameters and predicts end concentrations and concentration profiles of the solutes in the aqueous and organic phases. A GUI is developed to make the module user-friendly. The module is validated with axial concentration profiles of uranium obtained during extraction and stripping experiments conducted in a 3-inch diameter PDDC.

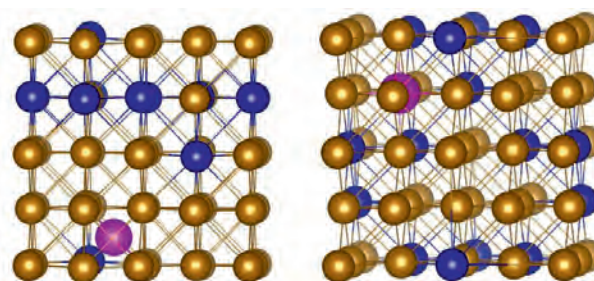
### Modelling and Simulation of HCl-H<sub>2</sub>O Separation using Pressure Swing Distillation

HCl-H<sub>2</sub>O separation is required for integration of hydrolysis and electrolysis steps of Cu-Cl cycle of hydrogen production. HCl-H<sub>2</sub>O separation using PSD is considered to be the most energy intensive process in Cu-Cl cycle of hydrogen production. Thermodynamic modeling based on gamma-phi approach using NRTL(Non Random Two Liquid) and EOS: Predictive SRK was carried out to further enhance the VLE (Vapour Liquid Equilibrium) prediction and achieve < 0.1% deviation with respect to the experimental data. Simulation of PSD flow sheet in open source software (COFE) and heat integration along with sensitivity studies were carried out to identify the scheme to minimize the total annual cost. Conceptualization and simulation of PSD flow sheet was modified to enhance acid concentration in the bottom product of Low Pressure Column (LPC) before feeding it to High Pressure Column (HPC). The modified flow sheet leads to enhanced driving force for mass transfer in HPC resulting in more efficient separation in HPC and reduction in separation cost.

### Permeation of H Isotopes through Fe-Cr Binary Alloy

DFT calculations were carried out on binary bcc and fcc Fe-Cr system with different composition. The lattice parameter of bcc FeCr was found to be intermediate of pure bcc Fe and Cr. The absorption energy for H atom was found to be endothermic. The tetrahedral (T<sub>d</sub>) void was found to be more stable compared to octahedral (O<sub>h</sub>) void in bcc FeCr and O<sub>h</sub> void was found to be more stable in fcc FeCr.

For bcc FeCr, the Fe-H distance in T<sub>d</sub> void was 1.66 Å and Cr-H was 1.73 Å. For pure Fe, the Fe-H bond distance was 1.657 Å and Cr, the Cr-H bond distance was 1.680 Å which indicates that the interaction of H-atom with Fe is stronger than Cr. Further, the adsorption of H at hollow site was found to be more stable compared to bridge and top sites. The energetic analysis indicates adsorption at top site is endothermic similar to adsorption on Fe(100) surface.



Structures of H in T<sub>d</sub> and O<sub>h</sub> voids of fcc-Fe-Cr. Brown: Fe; blue : Cr; pink :H (bigger sphere for representation purpose only).

### Solubility of H Isotopes in hcp-Ti

The calculated values of permeability for H<sub>2</sub>, D<sub>2</sub> and T<sub>2</sub> were found to be 6.30x10<sup>-19</sup>, 1.50x10<sup>-19</sup> and 0.74 x10<sup>-19</sup> mol.m<sup>-1</sup>.s<sup>-1</sup>. Pa<sup>-0.5</sup> at 298K in hcp-Ti by DFT. The calculated values of solubility (Θ) for H<sub>2</sub>, D<sub>2</sub> and T<sub>2</sub> in hcp-Ti at 298K were found to be 5.77x10<sup>5</sup>, 1.35x10<sup>5</sup> and 0.66x10<sup>5</sup> mol.m<sup>3</sup>.Pa<sup>-0.5</sup>. The solubility of H was seen to be greater than D and T. The computed values of solubility of H, D and T were seen to be decrease with temperature.

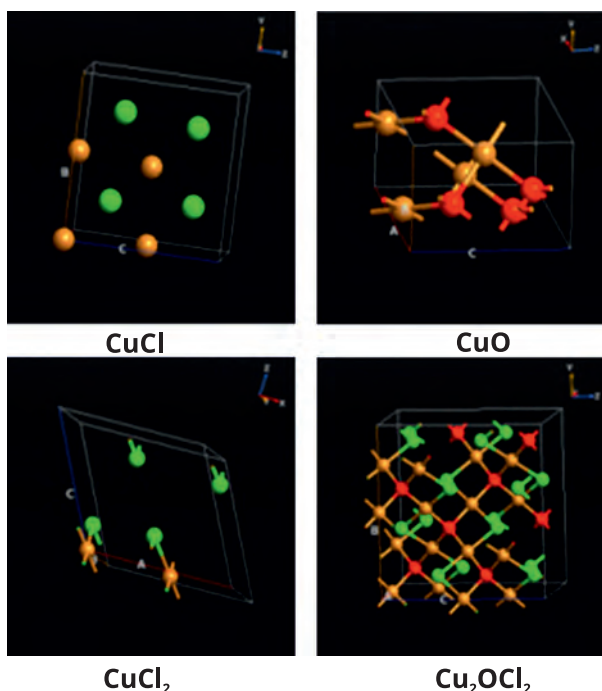
### Dissociation and Surface Diffusion of H Isotopes through Cu

Dissociation pathway for H<sub>2</sub> molecule on Cu(100) surface was established through bridge and hollow paths. The dissociation to bridge positions has lower barrier energy for dissociation and re-association of H<sub>2</sub> compared to hollow positions. Further, surface to subsurface diffusion of H isotopes was established on Cu(100) surface.

### Structural, Thermodynamics, EXAFS and XANES Spectra of Different Species in Cu-Cl Cycle using DFT

The structures of CuCl, CuCl<sub>2</sub>, CuO, Cu<sub>2</sub>OCl<sub>2</sub> 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. The specific heat for CuCl, CuCl<sub>2</sub>, CuO, Cu<sub>2</sub>OCl<sub>2</sub> at wide range of temperatures were calculated. Near edge X-ray Absorption spectrum was calculated for absorbing Cu atom at L2 and K-edges in CuCl, CuCl<sub>2</sub>, CuO and Cu<sub>2</sub>OCl<sub>2</sub> using DFT. The calculated electronic charge density was used for the evaluation of the XANES spectrum using xspectra software as implemented in the Quantum espresso software.



Optimized bulk structures (left) and calculated Specific heat of as a function of temperature (right).

### Effect of BaO Doping in NBS Glass Matrix

BaO doped sodium borosilicate glasses were simulated by molecular dynamics simulations. Significant change in short range/intermediate range order of glass was captured by radial distribution function, coordination and angle distribution, structure factor and probability of linking different structural motifs. Increasing non-bridging oxygen (NBO) suggests the role of barium as a network modifier which facilitates easy incorporation of waste oxides in the glass. The increased NBOs make the glass network weak and thus reduce glass transition temperature. The chemical resistivity of glass is augmented by BaO addition.

### First Principle AIMD Validation of MD Potentials for Glass Simulation

The applicability of B-K-S potential model was tested for Zn doped NBS glasses of varied compositions by comparing the results with ab initio molecular dynamics (AIMD) simulations. Results shows good match for density, contribution of non-bridging oxygen NBOs, Zn-O peak position and distribution of ZnO<sub>n</sub> polyhedrals in the glass matrix, estimated from AIMD and MD simulations. The comparative results for AIMD and MD generated radial distribution function (RDF), coordination number (CN) distribution, angle distribution function and MSD profiles were quite satisfactory.

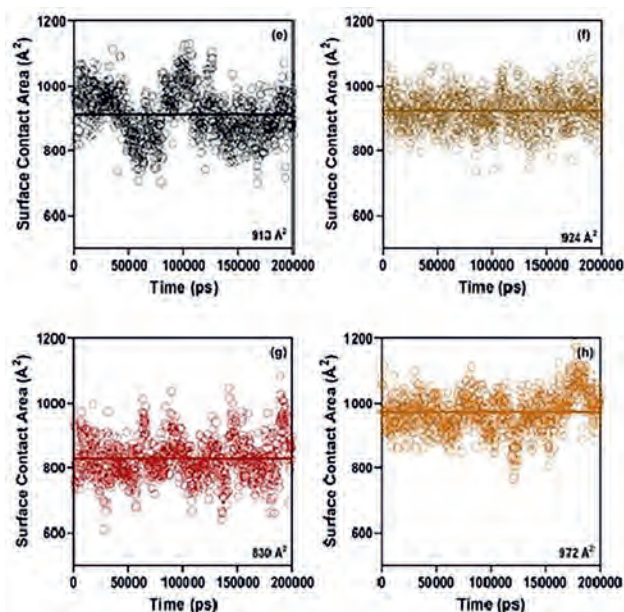
### Effect of ZnO Doping in NBS Glass Matrix

Combined experiments and molecular dynamics (MD) simulations were performed over wide range of compositions. A significant change in glass structure was monitored from short range order parameters: pair correlation function, coordination number, as well as intermediate range order parameters: bond/angle distribution profiles, structure factor. Results show good match of MD estimated trend for Young Modulus, glass transition temperature, and leaching data with the experimental observations. Low R (Na<sub>2</sub>O/B<sub>2</sub>O<sub>3</sub>) and high K (SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub>) of ZnO doped sodium borosilicate (Zn-NBS) glass surface compared to bare NBS represents the more stable structure of glass surface for Zn-NBS than NBS. During contact with water, Na<sup>+</sup> ions were less likely to leach out from glass to aqueous solution for Zn doped glasses. The enhanced chemical resistivity of Zn-NBS was also established from the increasing activation energy for diffusion of Na ion. The glass water interaction was also modelled by keeping the amorphous structure of simulated glasses adjacent to a box having 2000 number of water molecules with density 1.0 g/cm<sup>3</sup>. During the simulation, Na ions were found to diffuse from bulk glass region to the interface and some of them even migrated to the bulk aqueous phase. The results show that the leaching of Na ions can be

reduced with ZnO doping. The similar trend of reducing Na leach rate with Zn addition or increasing Zn concentration in NBS matrix were noticed from the experimental studies. The systematic study of network connectivity, ring statistics, diffusion and ion/water migration provides a significant understanding of glass dissolution mechanism.

### Atomic Molecular Dynamics Study on the Mechanistic Aspects of Interaction of Lethal Delta Variant of SARS-CoV2 Virus with Human Enzyme ACE2

Among the various reported mutant variants of SARS-CoV2, such as, B.1.1.7 (alpha), B.1.351 (beta), B.1.617.2 (delta), P.1 (gamma), the Delta variant is known for its high infectivity and severity. However, molecular level understanding of the origin of such high infectivity and lethality has remained elusive. Current atomistic molecular dynamics simulation studies have shed light on the interaction of SARS-CoV2 receptor binding motif and ACE2 enzyme of the human body and the interfacial contact area between the two has been identified as a key parameter that correlates with the infectivity and severity of the different mutant viruses.



Surface contact area of human ACE2 protein with (e) Wild, (f) Alpha (c) Kappa, and (h) Delta variants of SARS-CoV2.

## Radiochemistry

### Thermophysical & Structural Studies of Potential Ceramic Waste Form

New compositions in charge coupled (monovalent and trivalent) substituted fluorapatite with formula  $\text{Na}_1\text{Ln}_1\text{Ca}_8(\text{PO}_4)_2\text{F}_2$  where Ln = Nd, Pr, Gd, Tb, Dy, Er, Ho, Tm, Yb and Lu) were synthesized by conventional solid state route. Powder X-ray diffraction (PXRD) of these samples shows that out of these 10, only four compositions (where Ln = Pr, Gd, Tb and Ho) were phase pure. Other six compositions have small impurity lines of  $\text{LnPO}_4$  in the PXRD patterns. The structure of the four phase pure compounds were determined by Rietveld refinement of PXRD patterns which show structure similarity with  $\text{Ca}_{10}(\text{PO}_4)_2\text{F}_2$ . Further, these compounds were characterized by FTIR spectroscopy. Based on recognized ternary and quaternary compounds in  $\text{SrO-ZrO}_2\text{-P}_2\text{O}_5$  systems and product phases identified in 23 synthetic mixtures, obtained by reacting SrO,  $\text{ZrO}_2$  and  $\text{P}_2\text{O}_5$  in different molar proportions, phase diagram of  $\text{SrO-ZrO}_2\text{-P}_2\text{O}_5$  system was drawn at 1573 K and phase boundaries were established. Formation of three quaternary phosphates,  $\text{SrZr}_4(\text{PO}_4)_6$ ,  $\text{SrZr}(\text{PO}_4)_2$  and  $\text{Sr}_7\text{Zr}(\text{PO}_4)_6$  was confirmed at this temperature.

### Synthesis and Studies on Proposed Inert Matrix Fuel

To investigate uranium solubility at Zr-site,  $[\text{Nd}_{1-x}\text{U}_x]\text{Zr}_2\text{O}_7$  ( $0 \leq x \leq 1$ ) samples were synthesized by a solid-state route under reducing and oxidizing conditions and thoroughly characterized by X-ray diffraction and Raman spectroscopy. XRD studies reveal that uranium forms a solid solution throughout the composition range adopting the pyrochlore-type phase or the fluorite-type phase depending upon composition and synthesis conditions. Combinations of chemical analysis and XANES studies indicate an O/U ratio of 2.00(3) in the reduced samples and close to 2.66(3) in the oxidized samples. Raman spectroscopy and EXAFS measurements reveal the local structure and is compared to the bulk structure obtained from XRD analysis.

## Studies on Actinides in Deep Eutectic Solvents

Selective sequestration of radiotoxic actinides is extremely critical from a perspective of nuclear fuel reprocessing and environmental remediation but because of the challenges involved, safety concern and the time domain, the research related to same has been affected. In the present work we have explored hydrophobic deep eutectic solvent (DES) based on dodecyltriphenylphosphine bromide to yield a simple, fast, efficient, and environmentally benign method for micro-extraction of highly radiotoxic plutonium, followed by its subsequent quantification. This work has an additional triumph as Pu(IV) can be selectively extracted from U(VI) and Am(III). In the reusability and recycling studies, the stripping (more than 90 % in single cycle) and radiolytic stability (up to 750 kGy) of the solvent systems indicated reasonably encouraging results.

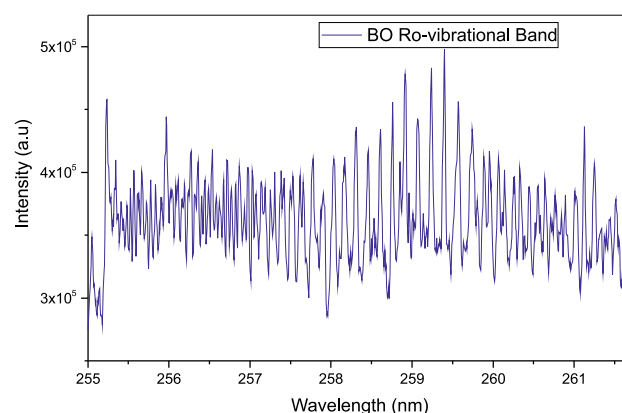
## Utilization of Nuclear Analytical Techniques for Chemical Characterization

External PIGE and Neutron Activation Analysis using high flux reactor neutrons were utilized for automobile (car) windshield glass forensics, in which trace elements like rare earth elements (REEs) and some transition elements were very helpful in grouping studies i.e., to find similarity and or to discriminate one glass from other among various car manufactures.

## Temporal Study of the BO Molecular Spectra in a Laser Induced Plasma Characterization

The reported molecular lines of boron at 255 nm are observed by recording the LIBS spectra of the sample using grating 2400 lines/mm. From the recorded spectra, vibrational-rotational spectra of both the boron isotopes were identified. The variation in intensity of the molecular peaks recorded spectra against delay time was also found out. The band origins of B-X transitions of BO were calculated using the diatomic constants from NIST database and F. Melon et al., (1985) and were

observed at 243.86, 255.31 and 267.71 nm corresponding to (0-1), (0-2) and (0-3) vibrational transitions respectively. The temporal analysis of these BO lines were done by varying the delay time from 0.2  $\mu$ s to 15  $\mu$ s. Along with BO molecular emission, temporal decay of boron atomic lines, B(I) (261.35 nm), B(II) (345.13 nm) and B(III) (247.9 nm) were also analyzed. The temporal nature of Plasma temperature and electron density calculated using Boltzmann plot method and Saha-Boltzmann equations. On careful analysis of the data, it can be understood that all the BO bands show maximum emission intensity around 4-6  $\mu$ s and decays, whereas the atomic peaks decay very fast in the order B(III) > B(II) > B(I). The (0-1) band is interfered by highly intense B(I) peaks at 249.68 and 249.77 nm. This caused a decrease in intensity of the molecular emission in earlier delay times. Similarly, (0-3) band was also interfered by atomic peaks. Similarly, the temporal nature of A-X transitions of BO was also analyzed with maximum intensity around 8  $\mu$ s delay. The possibility of obtaining triatomic BO<sub>2</sub> emission lines were also checked and (300-000), (200-000) and (100-000) transitions of BO<sub>2</sub> emission lines were identified.



BO B-X Rotational-vibrational molecular band observed in LIP.

## Structural and Thermophysical Studies on Advanced Fuel Systems

The HT-XRD analysis of (U<sub>0.80</sub>Gd<sub>0.20</sub>)O<sub>2.00</sub> obtained from reduction of (U<sub>0.80</sub>Gd<sub>0.20</sub>)O<sub>2+x</sub> compound at 1673 K in Ar/8% H<sub>2</sub> atmosphere showed that the XRD patterns of the compound remained similar up to 658 K but for a shift in peak positions, which may be due to either expansion or combined effect of expansion and oxidation.

$U_{1-y}La_yO_{2+x}$  ( $y=0.02, 0.05, 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9$ ) compounds were synthesized by gel-combustion method and reduced in Ar-8% $H_2$  atmosphere at 1700°C. All compositions formed fluorite type phase except for  $y=0.9$ , which is a mixture of fluorite and  $La_2O_3$ . The reduced samples were oxidized at 1250°C in air. The oxidized samples are a mixture of  $M_3O_8$  and fluorite  $MO_{2+x}$  for  $y < 0.3$ , while pure  $MO_{2+x}$  fluorite phase was observed for  $0.3 < y < 0.8$ . An 8 atom % solubility of La in  $U_3O_8$ , which showed non-solubility of La in  $U_3O_8$  phase. The lattice parameters of fluorite phase were determined using XRD data analysis. The samples were also characterized by Raman spectroscopy for probing the local structure. The complete phase relation in U-La-O system under reducing and oxidizing atmosphere was established.

### Basic Characterization Studies on Fuel and Related Materials

A new methodology was developed for determining oxygen to uranium ratio (O/U) in solid samples. This method is considered to be better in comparison with the Modified Davies-Gray Method for determining uranium (IV) and total uranium content in samples. The results obtained using both these methods were comparable with the error limit of 0.03 in O/U values.

### Synthesis and Uptake Studies of Metal-Organic-Framework

Aluminium based CAU-1  $NH_2$  Metal organic framework was synthesized using solvo-thermal method for Thorium adsorption studies. The product was characterized using XRD and FT-IR. Around 100 ppm of Th stock solution at different pH (2-8) levels was prepared. To this, 5 mg of CAU-1  $NH_2$  was added and subjected to shaking for 7 h and centrifugation followed by TXRF analysis. At pH ~7, maximum adsorption was observed. However, to avoid the possibility of precipitation of Th, further experiments were carried out at pH of 5. Adsorption isotherm studies at different Th (25, 50, 100, 200 and 250 mg/L) concentrations were carried out and Langmuir isotherm was followed.

Kinetic studies revealed pseudo second order adsorption and selectivity among different metal ions (Fe, Co, Ni, Cu) and U at different initial concentrations. Recyclability studies with respect to Th adsorption in Al based CAU-1  $NH_2$  showed decreasing tendency of Th adsorption with an increase in number of cycles. Nevertheless, Th could be adsorbed ~ 65% even during third cycle and hence MOF could be utilized for successive cycles.

Two Aluminum based MOFs namely CAU-10-H and CAU-10- $NH_2$  were synthesized by hydrothermal method using Al as metal center and isophthalic acid and 5-aminophthalic acid as linkers in U adsorption studies. These were further characterized using XRD, FT-IR, TGA and SEM. pH dependence of U adsorption for both the adsorbents were carried out from pH of 2-7. Maximum adsorption was observed at pH=4 and pH=7 for CAU-10-H and CAU-10- $NH_2$  respectively. A kinetic study of uranium adsorption was carried out to determine the equilibration time required for adsorption. It was observed that the equilibrium reaches within 2.5 h of time during equilibration. Both unfunctionalized and  $NH_2$  functionalized UiO-66 (Ce) MOF were employed for arsenic adsorption from aqueous solutions and were found to be promising materials for the task.

### Trace and Major Element Determination in Samples by TXRF

A micellar dispersion containing N,N,N',N'-tetraoctyldiglycolamide (TODGA) was used for pre-concentration of lanthanides present at ultra-trace level in different types of environmental water samples. A total of 10 lanthanides viz., La, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Tm, and Lu were pre-concentrated by CPE and analyzed by TXRF technique. PLSR algorithm had been used to deconvolute the complex XRF spectra of 10 lanthanides of interest in synthetic and real water samples at ultra-trace level. The developed methodology can analyze 10 lanthanides simultaneously having concentration as low as 1  $\mu\text{g/L}$  with good accuracy and precision. Analysis of lanthanides at such low concentration level in

presence of high overlapping spectral interference has been done for the first time using TXRF technique. The detection limits obtained for different lanthanides are in the range of 0.02-0.3 µg/L, which are the lowest detection limits reported for the analysis of lanthanides using TXRF/XRF.

A simple method for determining uranium in various types of water samples has been developed using TXRF. For this work, 2-amidoxy trimethoxy silane was synthesized and immobilized on TXRF quartz sample. It was observed that the ionic strength or presence of different interfering ions like Na<sup>+</sup>, Mg<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Sr<sup>2+</sup>, Rb<sup>+</sup> did not change the sorption behavior of the amidoxime based membrane. Further studies have shown that the methodology can determine U concentration in the range of 0.25-50 µg/L with a detection limit and accuracy of 0.013 ng/mL (13 parts per trillion) and 1.9%, respectively. The method was successfully applied for the U determination in natural water samples like ground water, river water and seawater.

### Development of Separation Methodologies for Fuel Samples

An HPLC method based on extraction chromatography for separation of lanthanide fission products, thorium and uranium has been developed to analyze Nd fractions isolated by thermal ionisation mass spectrometry (TIMS). Studies were carried out for dissolution of advanced fuel samples employing sequential treatment with sodium hydroxide and nitric acid treatment. The dissolution process could be completed in three days by heating under the IR lamp. The dissolved solution was spiked with Nd and Th and injected into an HPLC system having a reversed phase column modified with N,N,N,'N'-tetraoctyldiglycolamide. Under the optimized chromatographic conditions, separation of rare-earth elements, thorium and uranium fractions from the dissolved fuel sample was achieved. The results of these experiments conclude that the dissolution medium is compatible with the mobile phase used for the chromatographic separation.

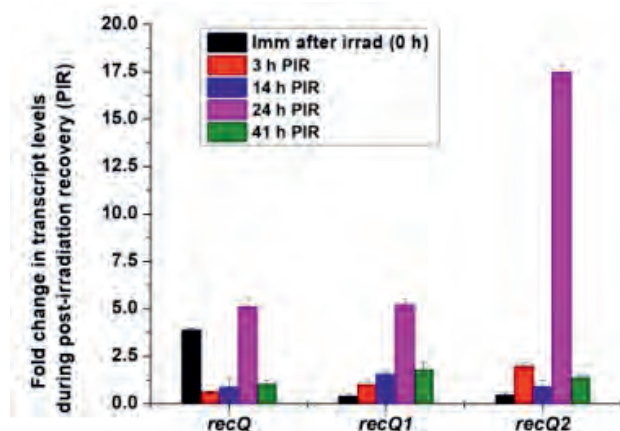
## Biology

### Green Technology for Remediation of Heavy Metals

Glass-adhered axenic *Nostocmuscorum* (Nm) biofilms, earlier shown to bio-remediate Cd, Pb and Ni, also exhibited efficient adsorption of Sr as analyzed by Energy Dispersive X-Ray Fluorescence (EDXRF) spectroscopy. This paves the way for the development of green technology for remediation of heavy metals using these biofilms, which are stable at wide pH range of 4-10, in the presence of other industrial wastes tested and can tolerate up to 6 kGy of-radiation.

### DNA Repair Mechanisms in Nostoc

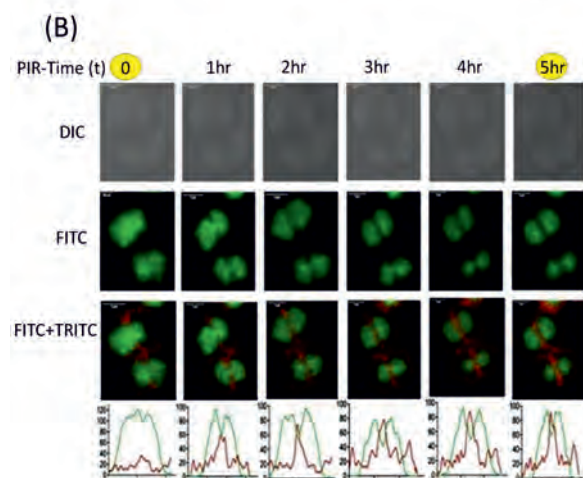
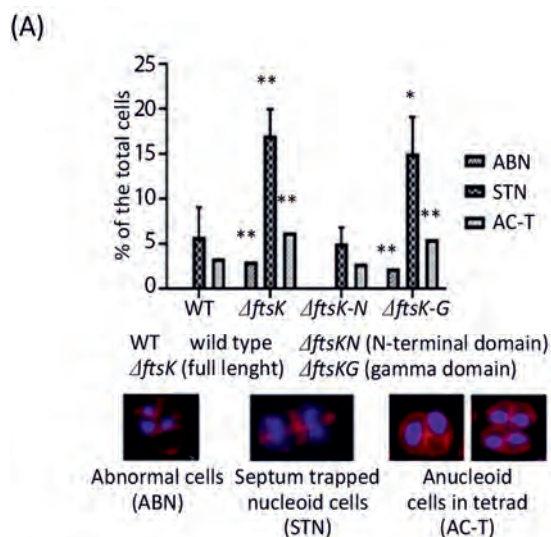
The cyanobacterium, *Nostoc* PCC7120 exhibits high radiotolerance (LD<sub>50</sub> of 6 kGy) and robust DNA repair system. RecQ helicases are known to play a defining role in radiation resistance. *Nostoc* has 3 RecQ helicases, with distinct C-terminal regions and predicted interacting protein partners. All three genes were found to differentially express upon exposure to -radiation and during post-irradiation recovery. Further, DNA repair in *Nostoc* is speculated to be through synthesis-driven DSB repair pathways. This was substantiated by the observed increase in radiotolerance of *Nostoc* cells overexpressing Nucleoside diphosphate kinase (Ndk), which is involved in the synthesis of (d)NTPs.



Modulation of transcript levels of multiple recQ helicases of *Nostoc* 7120 during post-irradiation recovery.

## Role of DprA and DR0041 in DNA Repair in *Deinococcus*

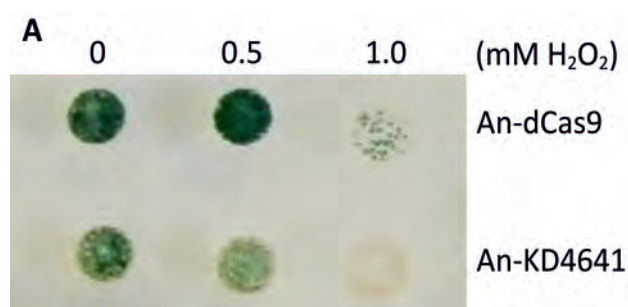
Role of two DNA repair proteins - DprA and DR0041 of *Deinococcus* - was elucidated. In the absence of DprA, *Deinococcal* cells used error prone single strand annealing (SSA) pathway instead of Extended Synthesis dependent strand Annealing (ESDSA) pathway. DR0041, which interacts with SSB protein, was shown to bind multiple DNA substrates including ssDNA, dsDNA, 3'&5' flap DNA and Holliday junction suggesting its involvement in house-keeping DNA metabolic functions following DNA damage. Role of FtsK (DNA motor protein) in genome segregation and cell division processes was shown in *Deinococcus*. Another protein DivIVA was shown to play an important role in cell polarity determination and interacted with genome segregation and cell division proteins.



Effect of deletion of *drFtsK* on nucleoid morphology (b) Cellular dynamics of *deinococcalFtsK-RFP* during post-irradiation conditions.

## Oxidative Stress Tolerance in Cyanobacteria

Knockdown mutant of *alr4641* (encoding an atypical 2 Cysteine peroxiredoxin) was obtained using CRISPR-based repression in the cyanobacterium *Anabaena*. In comparison to the control strain, the knockdown strain showed reduced growth, decreased photosynthetic efficiency, a lower content phycocyanin and more sensitivity to oxidative stress. Thus, 2-Cys-Prx appears to be the principal protein that defends *Anabaena* from oxidative stress.



The 2-Cys-Prx knockdown strain is more sensitive to oxidative stress.

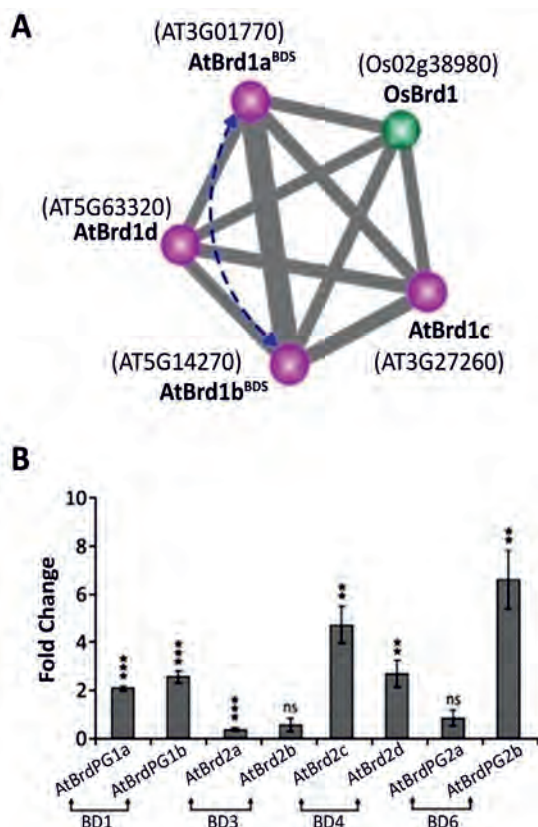
## Molecular Mechanism of Programmed Cell Death in *X. Axonopodis*

To understand the mechanism of programmed cell death in *X. Axonopodis* pvglycines (Xag), comparative transcriptome analysis of wild type Xag in PCD inducing (PIM) and non-inducing media (PNIM) was carried out. PIM showed up-regulation of 21 genes related to flagellar component. Xag showed 67% increase in swarming motility when cultured in PIM. In another experiment, an octapeptide has been purified from the culture supernatant of Xag cells when grown in PIM. High throughput screening analysis has shown that addition of synthetic octapeptide to fresh culture of Xag causes significant increase in cellular mortality (up to 49%) compared to control cells (23% mortality).

## Role of Bromodomain Containing Proteins in Plants

Plant bromodomain (Brd)-containing genes involved in epigenetic regulation with focus on expression of duplicated-pairs were analyzed in

arabidopsis and rice. Bromodomain-containing genes are crucial for cellular mechanisms, like epigenetic regulation, chromatin dynamics and splicing. Several duplicated Brd-gene pairs in arabidopsis and rice were identified that were investigated for orthologs as well as expression patterns. The Brd-homologs were placed into 13 conserved ortholog groups indicative of functional conservation. The AtBrd and riceBrd-duplicates showed differential expression patterns in various tissues and stress-specific environments. Additionally, splice-variant specific qRT-PCR analysis revealed modulation of splicing of certain Brd-homologs in different tissues and response to phytohormone treatment and salt stress. The duplicated Brd-homologs in both the plants seem to have diverged post-duplication, with impact on regulation as well and gene-protein structure.



(A) A conserved ortholog group of Brd-homologs of arabidopsis and rice. B) Quantitative RT-PCR analysis of four block-duplicated AtBrd genes in response to salt-stress.

### Synthesis of OTBN, an ADI for anti-hypertensive –sartan group of drug

o-Tolylbenzotrile (OTBN) is an advanced drug intermediate (ADI) for –sartan group of drugs, used for treatment of high blood pressure and heart

failures and is imported in huge quantities in India to manufacture drugs like Losartan, Candesartan etc in bulk amounts. The aim of the project was to develop an indigenous synthetic protocol for OTBN in order to promote local manufacturing and also to curb import dependency. An indigenous protocol was developed with higher yield than reported before, low waste generation and minimum environmental impact, avoiding use of heavy toxic metals.

### Laycha Brown Rice Reduces Radiation Induced Immune-suppression in Mice

Laycha brown rice (as food supplement) reduced radiation induced immune-suppression in mice exposed to 2 Gy or 4 Gy whole body (WBI). The mice which were given Laycha rice as food supplement and exposed to WBI showed significantly higher WBC counts, lymphocyte counts and granulocyte counts as compared to mice which were exposed to only WBI and given normal food or RKM1 black rice as food supplement.

### Hospital based Newborn Study

Over 4000 new-borns were monitored in two collaborating Government hospitals located in normal and high-level natural radiation areas (N&HLNRA) of Kerala coast for congenital malformations and other pregnancy outcomes such as still births, twins and low birth weight during the year 2022. Multiple regression analysis showed no dose response in any of the malformations.

### Biological Mechanisms in Response to Ionizing Radiation - Gene Expression Studies

Gene expression profile of HDAC2, HDAC8, SIRT1, SIRT2 and SIRT7 was studied at low (0.1 Gy) as well as high (2.0 Gy) dose at different time points (4 hr and 24 hr) in resting and proliferated PBMCs. A significantly higher expression (> 2-fold) of HDAC8, SIRT1, SIRT2, SIRT7 was observed in proliferating lymphocytes after 2.0 Gy dose at 4 hr and 24 hr time points as compared to un-proliferated cells.



HDAC2 did not show much difference in transcription pattern between proliferated and unproliferated cells. Results indicate differential activity of chromatin modifying enzymes in proliferating lymphocytes.

### Biological Mechanisms in Response to Ionizing Radiation - RNASeq Studies

RNASeq data on radio-adaptive response study in HLNRA of Kerala coast was further analysed. Interactome analysis of uniquely expressed genes in HLNRA individuals was carried out and a network of significantly interacting genes from our database was created. Regulatory network and Splicing variant analysis was done using RNAseq in HLNRA and HLNRA individuals. Validations of 15 highly differentially expressed genes were selected, primers were designed and validation of expression profile of these genes is in progress using real time qPCR.

### Advanced Radiopharmaceuticals

#### Preclinical Studies for Evaluation of $^{68}\text{Ga}$ -PentixaFor and $^{64}\text{Cu}$ ( $^{64}\text{Cu}$ -ATSM) as a Potential Diagnostic and Therapeutic Radiopharmaceutical

Studies were carried out with  $^{68}\text{Ga}$ -PentixaFor as diagnostic and ( $^{64}\text{Cu}$ -ATSM) as potential therapeutic radiopharmaceuticals for lympho-proliferative carcinoma and hypoxic lesions of cancer respectively, at RMC, BARC. These  $^{68}\text{Ga}$  and  $^{64}\text{Cu}$

radio-labelled drugs formulations have undergone preclinical studies proving their potential for diagnosis and treatment of chemo-resistant lymphoma and hypoxia lesions, in cancer respectively.

#### Preclinical Evaluation of HER2 Targeting, Clinical Grade $^{177}\text{Lu}$ -Pertuzumab & $^{177}\text{Lu}$ Trastuzumab: Therapeutic Antibody-ligand Conjugates

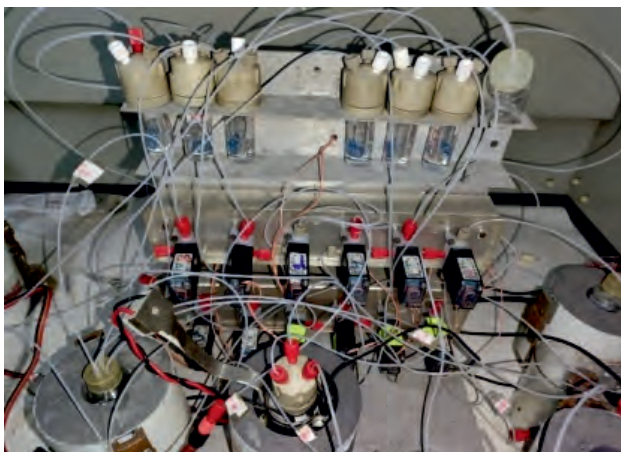
Antibody based radiotherapy agents including  $^{177}\text{Lu}$ -Trastuzumab and  $^{177}\text{Lu}$ -Pertuzumab were developed at RMC, BARC for targeting HER2 expressing and ER negative breast carcinomas. Membrane embedded protein Herceptin 2 expressed on different cancers and its feasibility as a tumor-imaging and targeting agent in specific cancer, including ovarian and breast cancer, have been put into use in this project. Preclinical evaluation of the developed Her2 targeting RPs was performed for in vitro and in vivo pharmacokinetics and dynamics indicating significant target specificity and stability.

#### In-house Production of $^{68}\text{Ga}$ in Medical Cyclotron Facility for Patient Use

Using liquid target of  $^{68}\text{Zn}(\text{NO}_3)_2$  aqueous solution placed in Niobium target holder and beam current at  $25\mu\text{A}$  with (p, n) reaction, 20mCi of  $^{68}\text{Ga}$  was produced which trapped in cation resins. It was further purified using indigenous purification module.

#### Ensuring Affordable Healthcare

- ✧  $^{177}\text{Lu}$ -Pertuzumab receives nod from the apex committee for use as a therapeutic radiopharmaceutical.
- ✧ Development of F-18 Labelled estradiol for breast cancer imaging.
- ✧ Fully automated radio synthesis of F-18 labeled Pterostilbene and its imaging.
- ✧ Synthesis and evaluation of  $^{18}\text{F}$ -FDS (Fluoro-deoxy-sorbitol) for brain tumour and bacterial infection imaging.



Automated module for  $^{68}\text{Ga}$  purification and radiolabeling.

## Cancer Studies

### Bio-markers Identification in Neuroendocrine Tumors

In a pilot study carried out in collaboration with Radiation Medicine Centre (RMC), whole blood RNA sequencing was carried out on 100 samples to evaluate potential biomarkers. About 10% of the transcriptome was differentially expressed between 02 of the healthy volunteers and neuroendocrine tumor (NET) patients. After appropriate normalization, gene counts were processed through machine learning to identify a gene signature that could correctly predict the healthy or NET groups.

### Identification of Gene Signatures to Predict Radiotherapy Response

Transcriptomic data of radio-resistant lung cancer (A549) cell line under 2-D and tumorspheres was analyzed. Additionally, transcriptomics data of radiotherapy (RT) responders and non-responders in lung adenocarcinoma (LUAD) patients was obtained from TCGA database for correlation with radio-resistant cell lines data and differential gene expression analysis. From the analysis, 120 genes were selected based on the significant correlation of cell line data with transcriptomic data of LUAD patients, which was used to predict RT response in patients using machine learning algorithms. Analysis showed that 122 genes were commonly expressed between the radio-resistant cells cultured in 2-D and tumorsphere conditions.

### Understanding the Mechanism of Radioresistance in Cancer Cells

The mechanism of radio-resistance in A549 cells, parental A549 cells (C-A549) were compared with isogenic cell line obtained after multiple irradiation (C-10FA549) with or without a challenging dose (R-A549 and R10F-A549, respectively). LC-MS analysis identified alteration ( $\text{FC} \pm 1.5$ ) of 696 proteins in single (R-A549) and 786 proteins in multiple  $\gamma$ -irradiated (C-10F)A549 cells as compared to control A549 cells. Functional annotation showed up-regulation of DNA repair/recombination, NF- $\kappa$ B signalling, MAPK cascade, response to  $\gamma$ -radiation and down-regulation of apoptosis, protein stabilization, mRNA polyadenylation in R-A549 cells. Observations suggest that cells after multiple irradiation fractions, seem to reprogram their survival by slowing growth and saving their resources via processes such as mRNA stability, protein folding and even downregulating DNA repair proteins, which may then lead to their observed invasive phenotype.

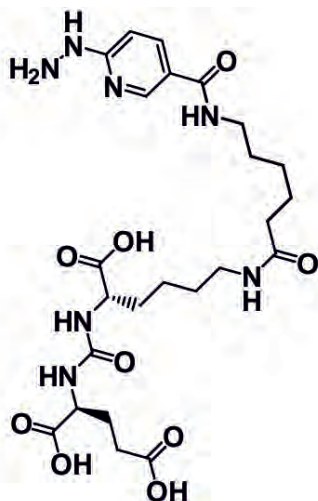
### *In situ* Visualization of Protein-nascent RNA Interactions in Single Cell

A method was developed for *in situ* visualization of Protein-Nascent RNA interactions in single cell using Proximity Ligation Assay (IPNR-PLA) in mammalian cells. IPNR-PLA is used for analysis of protein association with nascent RNA with single-cell resolution, which was highly sensitive, quantitative, efficient, handy, and required small experimental starting material. The method was validated by demonstrating known CDK9 and elongating RNA pol II interaction with nascent RNA.

### Total Chemical Synthesis of Hynic-PSMA

Using an indigenous protocol, Hynic-PSMA (a ligand) was synthesized for prostate cancer diagnosis. The ligand was synthesized by employing a multi-step process characterized by rigorous purification steps. All the intermediates produced were adequately characterized using LC, and MS analysis.  $^1\text{H}$  NMR analysis of the synthesized product is in progress, which would confirm the structural integrity of the product. The

final unmasked product with more than 99.9% purity was achieved on a small scale.



Chemical Structure of Hynic-PSMA.

### Novel Approach for Targeting Lysosomes in Pancreatic Cancer

Six novel Lysostilbenes (LS-1 to LS-6) compounds were synthesized in-house for deploying them in pancreatic ductal adenocarcinoma (PDAC) therapies as an alternative to autophagy and lysosome route for treating PDAC. Results showed that LS-3 was nearly 30-40 times more cytotoxic compared to the parent compounds against PDAC cells. The LS-3 specifically kills cancer cells without affecting the normal cells. Mechanistically, LS-3 causes lysosome membrane permeabilization (LMP), leading to mitochondrial depolarization and apoptosis at later time points. Lysostilbenes are the conjugates of pharmacophore from chlorquine and stilbene compounds where CQ targets lysosome while DHS inhibits the lysophagy (a subtype of autophagy for lysosome clearance) pathway.

### Development of Dual Inhibitor of TOP1 and PARP1 for Efficient Killing of Cancer Cells

A number of candidate molecules were synthesized in-house by combining pharmacologically relevant pharmacophores of Olaparib (a clinically approved PARP inhibition) and naphthalimide (a widely studied TOP1 inhibitor) in an effort to develop a dual TOP1-PARP1 inhibitor. The synthesized molecules were evaluated for

their efficiency and it was identified that PAR-3 compound showed significant anti-proliferative potential and was found to have the capability of inhibiting both PARP1 and TOP1. Also, PAR-3 inhibits PARP1 activity in vitro and inhibits the accumulation of cellular PARylation in response to a classical TOP1 poison like camptothecin. Further, PAR-3 does not trigger TOP1 degradation, which is a protective mechanism against TOP1 poisons.

### Metabolic Real Time Analysis of Different Cancer Cell Lines for Metabolic Target Determination

As a component of work on cancer metabolism, exploring the link between metabolic rewiring, stemness of cancer cells and chemo-resistance phenotype is being explored. The expression level of embryonic stem (ES) cell marker, Yamanaka factors (Oct3/4, Sox2, Klf4, c-Myc) in different cancers including lung, prostate, thyroid, liver, leukaemia and breast cancer cell of human origin were evaluated. Work is under way for understanding the levels of Monocarboxylate transporter 1 & 4 (MCT1/4), LDHA, PDK1, PDK3 and different key metabolic inhibitors for understanding the balance between the glycolysis dependent cancer cells and Stem cells.

### Anti-proliferative Action of Fo-F1 ATP Synthase Inhibitor (Bedaquiline) on Cancer Cell Lines

Autophagic induction and protein level expression of cell death associated genes were explored using Fo-F1 ATP Synthase inhibitor, Bedaquiline. Our study revealed a simultaneous activation of autophagy and apoptosis in <sup>131</sup>Iodine resistant thyroid cancer cell lines in vitro and in vivo.

### Development of Blood-based Prognostic Cancer Biomarkers for Non-iodine Concentrating Thyroid Carcinoma Patients

Experiments were carried out to understand transcriptomic, metabolomic and proteomic hallmarks of cancer using Peripheral blood cell and

plasma/serum sample for personalized management of non-iodine, concentrating poorly differentiated thyroid carcinoma patients. Standardization of isolation of plasma, RNA and peripheral blood cells towards transcriptomic and metabolomic analysis was completed.

### **Novel 2D Biphenylene as Carrier for Anti-cancer Drug Cisplatin**

Nanocarriers for application in cancer drugs is an important and challenging area of research. Carbon nanomaterials are well-studied in this field with promising results. Using Density Functional Theory, the suitability of the biphenylene (a newly synthesized member of the 2D graphene family), as a possible nanocarrier for the anti-cancer drug Cisplatin had been explored. Studies showed that Cisplatin can be absorbed on the surface of biphenyl with a charge transfer from Cisplatin to biphenylene and this system of carrier and drug is stable at room temperature. Its solubility in water and desorption temperature in acidic environment indicate possibility of dispersing the drug in the human body.

## **Mega Science & International Collaboration**

### **Indian Neutrino Observatory (INO)**

The Indian Neutrino Observatory project is aimed at constructing an underground laboratory to study neutrinos. Modern Iron Calorimeter (ICAL) detector with Resistive Plate Chambers (RPCs) are the active detector elements. The first stage of the project with 85 tons mini ICAL magnet with 11 layers, is operational at Madurai. The second stage Engineering module (E-CAL) having 8m x 8m x 3.1m size and 700 tons weight with 23 soft iron layers is aimed at establishing engineering process requirements and qualifications like plate machining and handling for assembly, automated loading and unloading of RPC detectors, gap measurement, coil cooling, etc. Copper coils for E-ICAL have been developed. The third stage of the project involves construction of main ICAL magnet

having 16m x 16m x 15m size (three modules) and 51,000 ton overall weight. The design for main ICAL has been completed.

### **Permeation of Hydrogen Isotopes through Silica Glass Membrane for ITER Applications**

MD studies were conducted to study the permeation of H<sub>2</sub> and isotopes through silica membrane of varied density. Results show increase in H<sub>2</sub> permeability from 5.93x10<sup>-6</sup> moles/m<sup>2</sup>-sec-Pa to 8.82x10<sup>-6</sup> moles/m<sup>2</sup>-sec-Pa while going from rigid to partial flexible model of membrane. PMF profiles were estimated as an effect of membrane density, temperature and pressure. While increasing membrane density from 0.6 g/cm<sup>3</sup> to 2.0 g/cm<sup>3</sup>, the potential energy barrier (PMF) for H<sub>2</sub> crossing of membrane increased from 1.52 kJ/mol to 7.52 kJ/mol, which resulted in decreased permeability of H<sub>2</sub> with increasing membrane density. With increasing temperature of the system, the density of H<sub>2</sub> molecules inside membrane pores as well as in permeate reservoir was also increased, which resulted into reduced energy barrier for membrane crossing of H<sub>2</sub> with increasing temperature. Further, the effect of thermostat coupling was analyzed and an increase in H<sub>2</sub> gas permeability was noted when thermostat coupling was changed from membrane + gas atoms to membrane atoms only. Because of liquid like permeation, the population distribution of H<sub>2</sub> gas molecules in membrane pores was not much affected by pressure gradient, therefore, the potential energy barrier for membrane crossing remained unaffected by pressure gradient. Nevertheless, with increasing pressure, a considerable difference in potential mean force of H<sub>2</sub> was observed for the feed and permeate reservoir, which resulted in differential permeability and diffusivity of H<sub>2</sub> gas with increasing pressure.

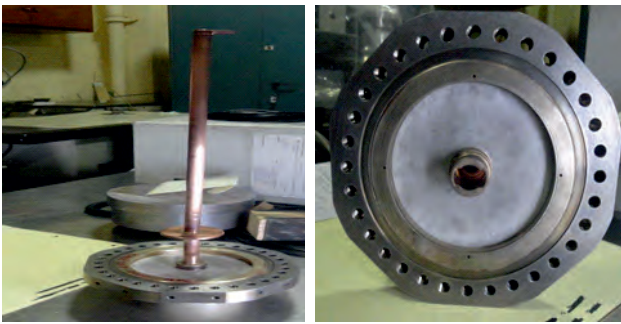
### **Indian Institutions Fermilab Collaboration (IIFC)**

Several DAE institutes, including BARC, RRCAT, and VECC, are contributing to the development of key

technologies for high-intensity proton accelerators through IIFC collaboration. Among them, BARC is involved in a wide range of technical areas, including spoke cavities, 325 MHz RF amplifiers, 325 & 650 MHz RF power couplers, superconducting magnets, low-level RF and RF protection systems, cryogenic test stands, and cryogenic plants. Significant progress has been made in many of these these technologies.

### RF Power Couplers

The components of 325 MHz and 650 MHz couplers were fabricated. Brazing trials were undertaken to ascertain vacuum leak tightness; testing of these components in Hydrogen Furnace were planned in the next stage.



Brazed cold part of 650 MHz coupler along with antenna; a view of cold part of the coupler from flange side.

### 325 MHz RF Amplifier

325 MHz, 7 kW RF amplifiers designed by BARC and developed by ECIL were installed in the PIP2IT facility. A prototype RF amplifier (325 MHz, 20 kW) has also been developed at BARC. The RF module had been integrated with revised water cooled DC supply and tested for up to 1,100 W.

### LLRF

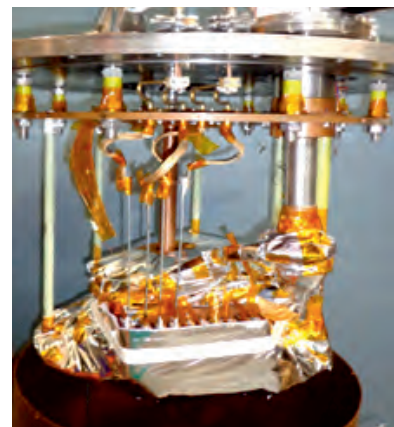
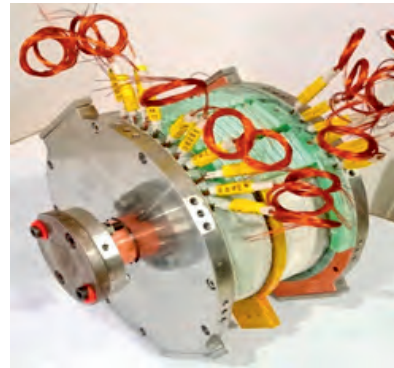
Low level RF (LLRF) system was tested on a Horizontal Test Stand (HTS). The test results were shared with the Fermilab, which is expected to receive the system at its plant site.

### Superconducting Solenoid Magnets

BARC has developed a Superconducting Solenoid Magnet called SSR2, which has undergone successful testing at a temperature of 2 K. The magnet was transported to the US-headquartered Fermilab. Three additional magnets will be delivered to Fermilab in the near future.

### Cryogenic Systems

As a part of its contribution to PIP-II (a multi-national collaborative effort), the Department of Atomic Energy intended to provide a liquid helium plant that would supply 2,000 W of power at 2 K. The design review work for the plant is currently underway, and the equipment installation and commissioning is scheduled to take place in February 2026. The development of the liquid helium plant is being carried out by Air Liquide, a company based in France.



Superconducting solenoid magnets dispatched to the US headquartered Fermilab.



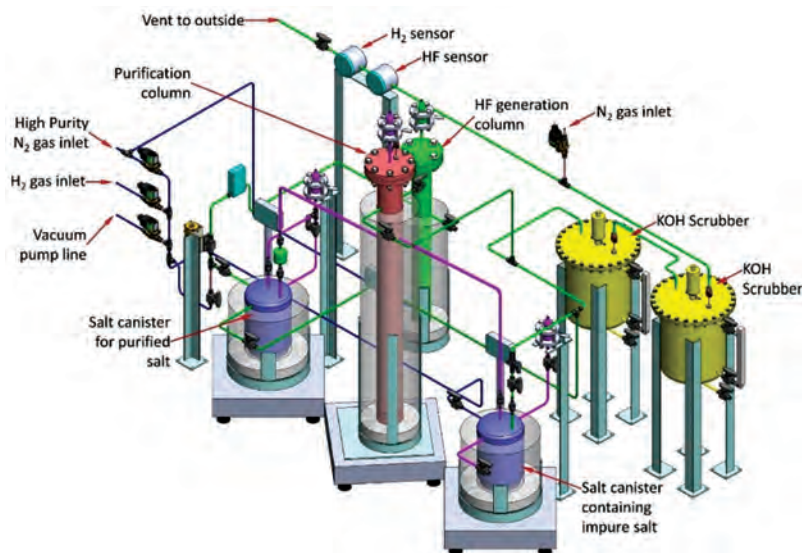
The Environmental Survey Laboratory of BARC at Visakhapatnam.

# BARC (Facilities) Visakhapatnam

## Fluoride Salt Purification Facility

The Fluoride Salt Purification Facility (FSPF) has been designed to meet the requirements of the experimental facilities for long term testing of IMSBR materials, components and salts in Long Term Test Facility (LTF) at BARCF(V). FSPF can

purify 8 kg of fuel salt or 5 kg of coolant salt in one batch by bubbling a mixture of hydrogen fluoride (HF) and hydrogen. Due to safety issues associated with long term storage of HF cylinders, a system for *in situ* generation of HF by decomposition of sodium bi-fluoride has been designed.



Layout of the Fluoride Salt Purification Facility.

## 9 MeV RF Electron LINAC as a Photo-Neutron Source for Neutron Radiography Applications

A project has been taken up at BARC Visakhapatnam to develop a 'Neutron Radiography Facility' using a 9 MeV RF Electron LINAC at ECIL, Hyderabad. The entire LINAC system is enclosed in a radiation shielded enclosure and operated remotely. At full rating, an X-ray dose rate of 24 Gy/min was produced at a distance of 1m from Tantalum target. The photo-neutron target assembly for neutron radiography has overall dimensions of 700mm (L) × 855mm (W) × 700mm (H) and a collimation ratio (L/D) of 28. To obtain a maximum thermal neutron fluence rate, two beryllium cylinders of 63mm diameter having lengths of 44mm and 84mm, have been used along with a 60mm HDPE moderator. The thermal neutron flux measured at image plane was  $\sim 6 \times 10^3$  neutrons/cm<sup>2</sup>/second/kW e-beam.



The 9MeV RF LINAC at ECIL.

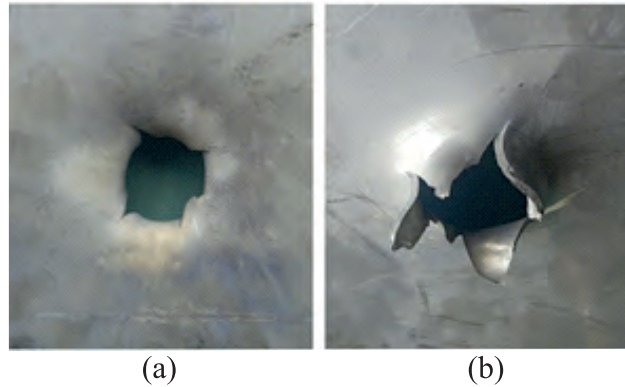


Neutron radiography set-up with gated ICCD camera for imaging.

## Rail Gun based Acceleration Facility

The impact and penetration capability of railgun based acceleration facility was tested *in situ* during a performance trial. The accelerated 8gm armature projectile pierced through the 3mm thick SS304

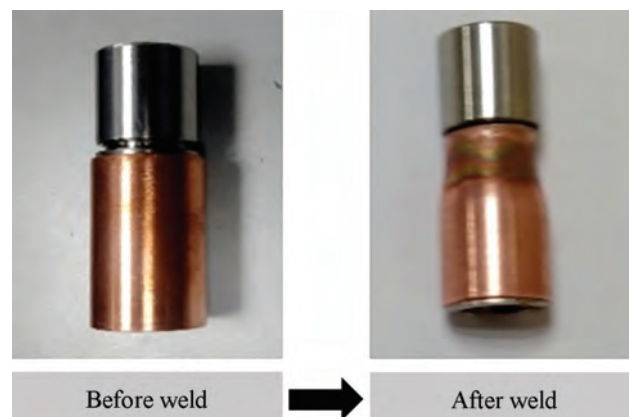
target plate placed at  $\sim 1.1$ m from the muzzle-end. Petalling signature was clearly evidenced on the penetrated target plate of SS304 material.



Front (a) and back (b) view of 3mm thick SS304 target plate after impact penetration by 8gm Al-7075 projectile.

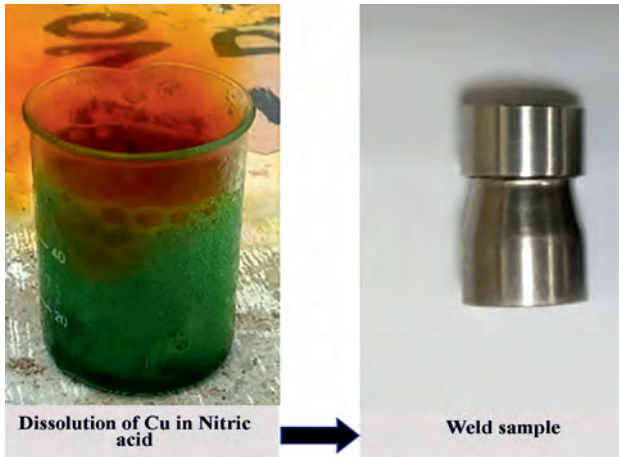
## Dissimilar Metal Joints by MPW

Magnetic Pulse Welding (MPW) is a solid-state impact welding technique wherein a conducting flyer is subjected to magnetic pressure generated with an electromagnetic tool coil. The deforming flyer gains velocity over the stand-off distance available and impacts on the target job at the critical velocity to establish a joint between them. High Velocity Impact Welding MPW technique was employed successfully in joining Ti tube to SS tube using a multi-turn and shaper tool coil at a peak magnetic field of 33T, 17 kHz frequency and impact velocity in the range of 300-400 m/s. The advantage associated with this technique is that there is no heat and no melting of bulk material involved, which eliminates the formation of Heat Affected Zones and undesired oxides and nitrides at the joints, thereby avoiding joint failures.



Ti & SS 304L job piece.

The copper driver from the weld samples was removed using nitric acid, following which the sample was checked for helium leak rate and other weld characterization techniques.



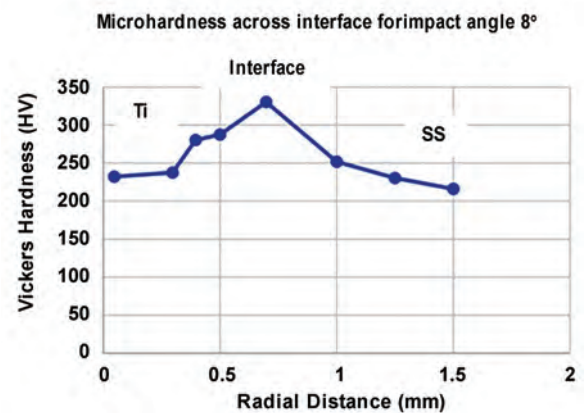
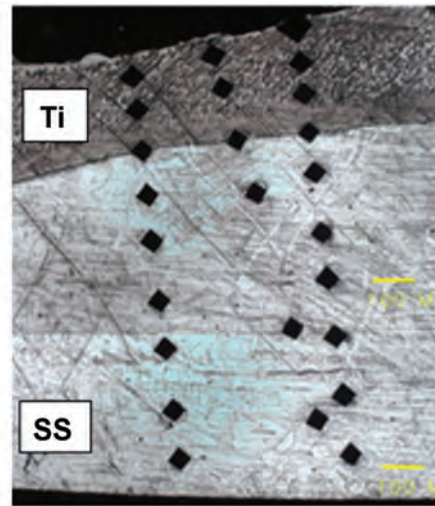
Removal of copper driver.

The welded joint was sealed from one side and the leak rate was measured with helium gas. The welded joint passed the leak rate upwards of  $10^{-10}$  mbar.ltr/s.

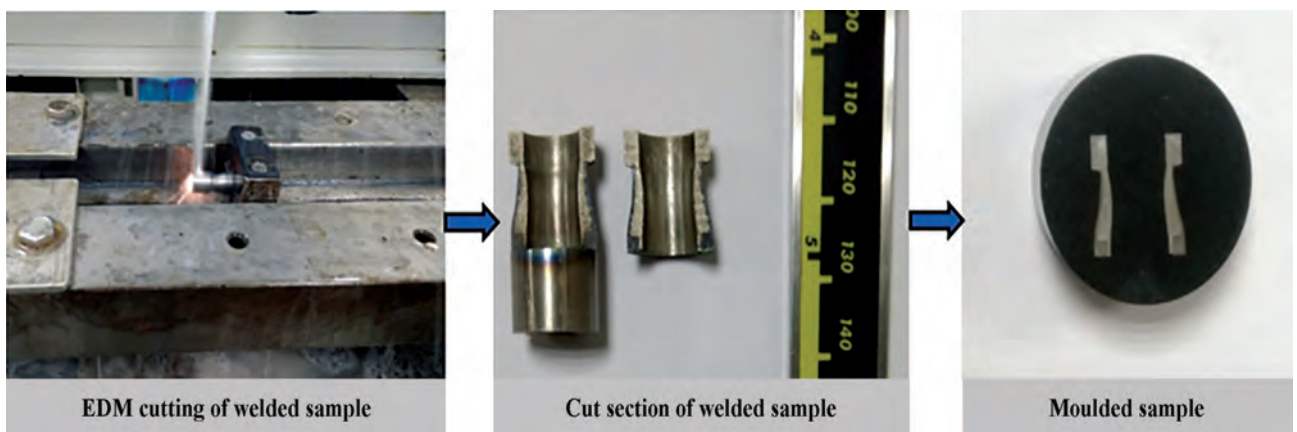


Helium leak rate measurement.

Microhardness measurements were done over an array of points along and across the weld interface. The hardness value was observed to increase more towards the interface than towards the Ti or SS side, being maximum at the interface which could represent the amount of deformation introduced into the flyer and the target tube during the welding process along the joint section.



Hardness measurement across weld interface.



Sample preparation for metallographic studies.



A Corrosion test was conducted at Corrosion Division, IGCAR. One Ti-SS304L weld sample was subjected to Practice C test i.e 65% boiling Nitric Acid test for 240 hours. The MPW weld sample survived the test hours without getting debonded.

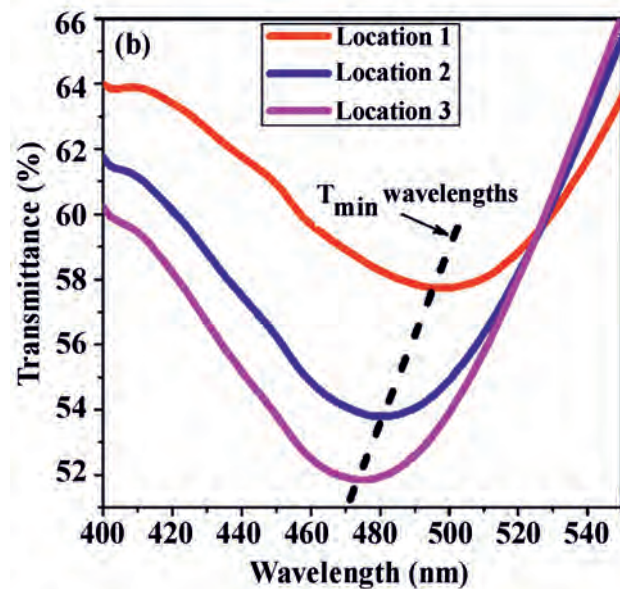
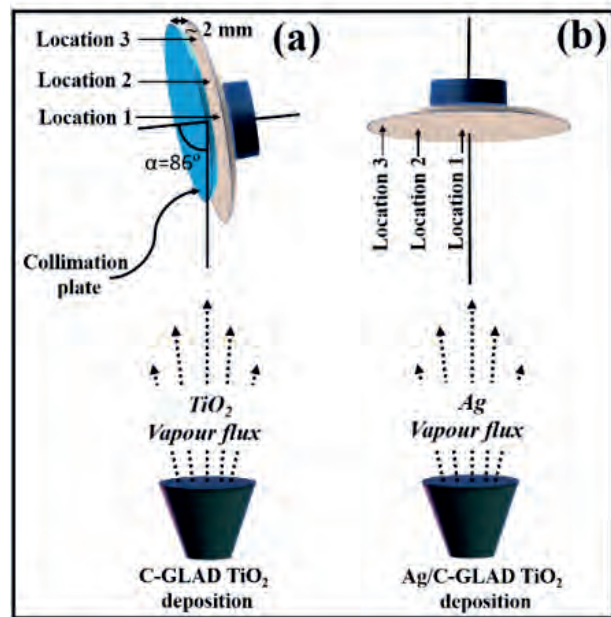
An Ultrasonic Test was conducted on Titanium to SS-304L weld samples welded at 35 T and 40T at Non-Destructive Evaluation Division, IGCAR . The results showed a bond length of 2 mm for sample welded at 35 T and a bond length of 3 mm for sample welded at 40 T. This was in confirmity " in place with the SEM micrographs observed for the weld samples.

## Photonics and Nanotechnology

### Investigation on e-beam Evaporated Plasmonic Metal and Metal/dielectric Nanocomposite Thin Films

In view of the high temperature applications of plasmonic metal nanostructures, an investigation on the evolution of the optical constants of plasmonic Ag nanostructures, as a function of annealing temperature, was performed. A set of plasmonic Ag nanostructures with varying thicknesses (5-25 nm) were fabricated using e-beam evaporation technique and subjected to temperature dependent *in situ* spectroscopic ellipsometry measurements at room temperatures (25°C) and at various elevated temperatures (80°C – 530°C). The results obtained were explained using the temperature induced alterations in grain morphologies of the films.

In another investigation, spatially selective nanoplasmonic behavior of Ag decorated TiO<sub>2</sub> film structure across the sample surface was studied. The spatially selective response was achieved by utilizing the tailored optical response of the underlying dielectric TiO<sub>2</sub> thin film produced using a novel collimated glancing angle deposition technique. The measured optical transmittance spectra of the device showed spatial selectivity in LSPR (Localized surface plasmon resonance) wavelength of ~22 nm across the sample surface.

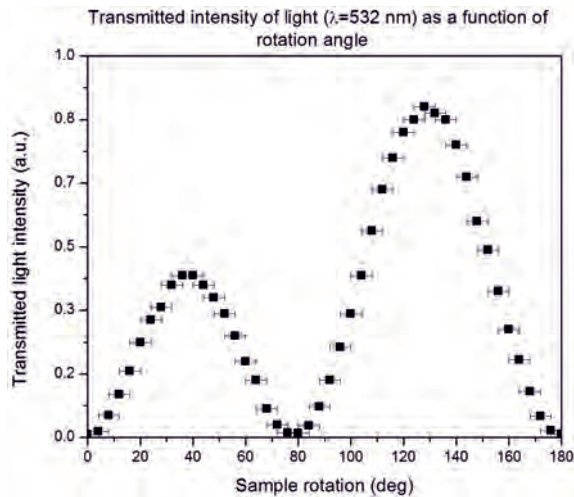


The deposition arrangement and the measured LSPR absorption region of the nanocomposite at various spatial locations.

### Fabrication of Quarter Wave Plate Device using Glancing Angle Deposition Technique

Electron beam evaporation thin film deposition technique equipped with glancing angle deposition (GLAD) arrangement was used to fabricate quarter waveplate device. The device was made using zig-zag deposition of TiO<sub>2</sub> by precise manipulation of azimuthal substrate rotation. The zig-zag structure consists of two arms deposited by flip-flopping the substrate between two oblique angles,  $\alpha = 70^\circ$  and

$\alpha = -70^\circ$ . The transmitted intensity from the device was measured at different rotation angles by placing the quarter waveplate in between two cross polarizers.



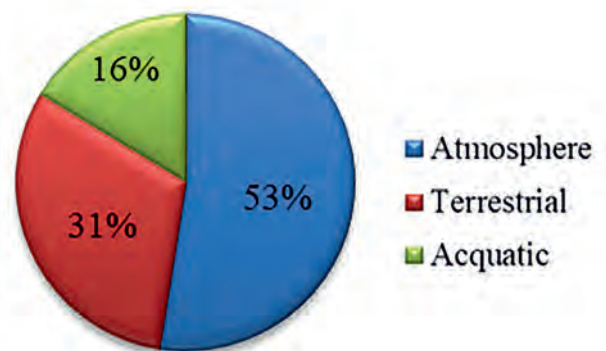
Measured transmitted light intensity as a function of sample rotation angle.



Job piece in the tool coil

## Environmental and Radiological Surveillance

Periodic collection and analysis of around 800 samples from atmospheric, terrestrial and aquatic domains within 30 km radius of the plant had been carried out during 2018. The sampling locations were selected taking into account such diverse factors as wind pattern, the local environment etc. The values observed are typical background values of a clean environment with the naturally occurring temporal variations. The monitoring parameters and details will be increased gradually with increase in development of infrastructure and other activities at the site. The results obtained from the study can be used further to find the sources for these elements (Natural or anthropogenic) and also will be useful for assessing the future impact of upcoming facilities in this region. Continuous atmospheric gamma radiation levels were measured using the Environmental Radiation Monitor (ERM) installed under the Indian Environmental Radiation Monitoring Network (IERMON) at Project site, BARCF(V), Visakhapatnam. It was observed that the variation shows a range of 70 to 120 nGy/h with a mean of around 90nGy/h. The values indicate normally observed background gamma radiation levels.



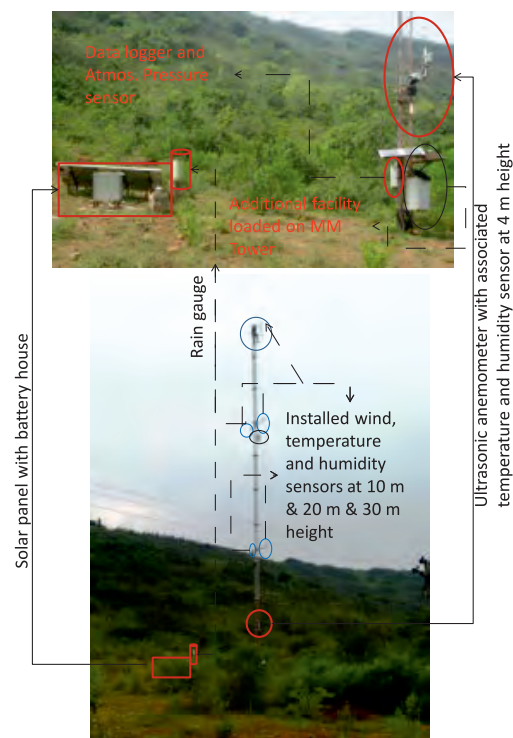
Distribution of samples collected in various environmental matrices.



Study of samples collected from different environmental matrices.

### Computation of Site-specific Meteorological Parameters

A meteorological tower (30 m high) equipped with diverse set of sensors has been erected at Gandivalaipalaem, project site, BARCF (V). Surface meteorological measurements for wind speed, wind direction, ambient temperature, relative humidity, solar radiation, net solar radiation, atmospheric pressure and rain fall parameters are being continuously monitored by meteorological station. The combined meteorological data would aid the efforts to study the climatology of project area, radiological dose apportionment for various upcoming units and in planning for emergency preparedness.



The 30m meteorological tower erected at Gandivanipalem situated near BARC Visakhapatnam.

### Site-specific Transfer Factor Studies for Nuclear Emergency Preparedness

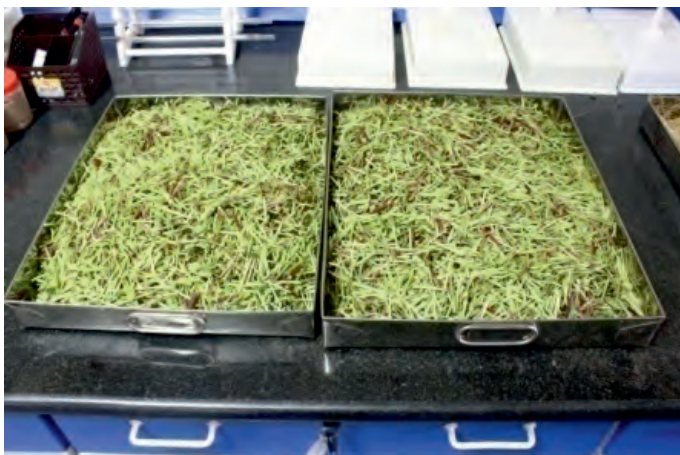
Critical paths for radionuclides and the critical foods in India differ from those in other countries because agricultural products and diets are different. Consequently, safety assessments for a particular place must consider their critical food. Rice, vegetables, fruits especially banana and sea food are the critical food of the people of Visakhapatnam. In the present work, the activity concentrations of naturally occurring and anthropogenic radionuclides deposited in the soil and soil to plant TF of various food items are to be studied. Transfer factors of various plants can be compared with other parts of the country and world.

Activity on “Site Specific Transfer/ Translocation Factors for BARC site, Visakhapatnam” in vegetative

crops, soil and water etc., was initiated. Trace, micro and macro elements in different vegetative crops starting from the stage of sowing to harvest were studied at the Environmental Survey Lab.

### Radiation Dose Estimation among Local Population

Using gamma spectrometry, the extent of ingestion of radiation dose to the population living in the vicinity of the site, are assessed regularly. It is necessary to carry out public dose evaluation during the pre-commissioning and operational stages of the plant activities. The radioactive concentrations due to naturally present radionuclides in food crops cultivated in the vicinity of the site and within the produce procured locally were determined.



Activities taken up at BARC Visakhapatnam as part of transfer factor studies.



# HUMAN RESOURCES, SCIENTIFIC INFORMATION RESOURCES 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.



BARC Training School Facility in Anushaktinagar, Mumbai.

# Human Resources, Scientific Information Resources and Technology Management

## Human Resources

### BARC Training School

Dr. Homi Jehangir Bhabha strongly professed that in order to achieve self reliance in the nuclear energy sector, it is imperative to build a sustained pool of highly skilled human resources from the ranks of talented workforce, which is readily available within the country. In line with this philosophy, Dr. Bhabha conceptualized the creation of specialized Training Schools in the Department of Atomic Energy (DAE), and the first BARC Training School was established in Trombay in 1957, as a centre for training of professionals in-house. Over the years, it has grown into an

internationally acclaimed school of excellence with more 9000 scientists and engineers graduating from it with flying colors.

BARC Training School runs two flagship programs – OCES (Orientation Course for Engineering Graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme) for which it picks young graduates from across the country through a carefully crafted selection process.

### Recruitment

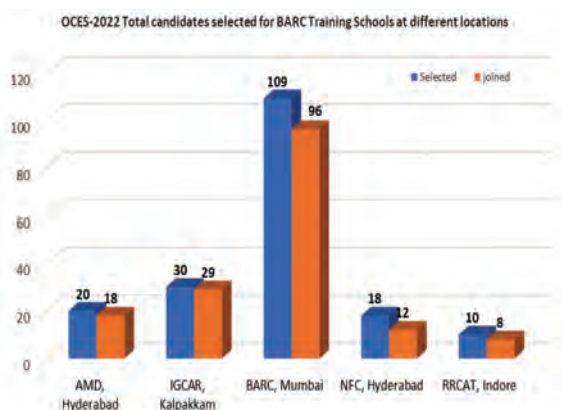
The Human Resources Development Division of BARC provides highly skilled human resources to DAE through its two flagship programs, OCES and DGFS. The linkage of BARC Training School

programs with HBNI ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various DAE units.

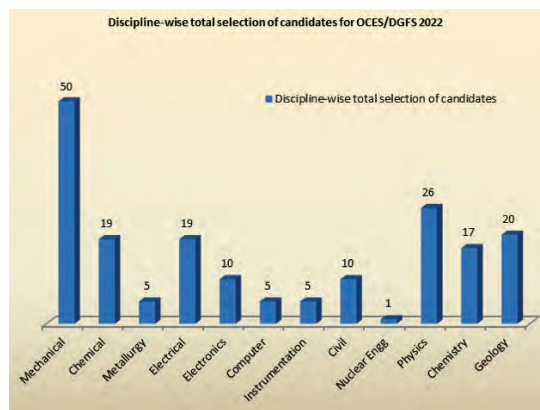
A total of 101 graduating TSOs of the 65<sup>th</sup> batch of OCES/DGFS-2021 (75 in Engineering, 10 in Physics, 7 in Chemistry, 3 in Biosciences and 6 in Radiological Safety and Environmental Science), after successful completion of training, were placed in various units of DAE. There were also 8 Trainee Defence Officers, who passed out with

this batch and were assigned to different Divisions/Units for undertaking projects for M.Tech under the aegis of HBNI.

While the academic programme of the 65<sup>th</sup> batch was underway, screening examination for 9 engineering and 3 science disciplines for the 66<sup>th</sup> batch was organized successfully at 58 venues in 47 cities of India. The number of applicants for OCES/DGFS-2022 was 85,588. Of them, 44,793 candidates appeared in the online examination. A total of 187 candidates were selected for OCES/DGFS-2022.



Total number of selected and admitted candidates in various BARC Training Schools in the 2022 batch of OCES/DGFS.



Discipline-wise total number of selected candidates for OCES/DGFS 2022.



Meritorious Trainee Scientific Officers of OCES-2022 batch along with Shri K.N. Vyas, Chairman AEC, Dr. A.K. Mohanty, Director, BARC and senior officers of BARC during the Graduation Function.



Trainee Scientific Officers of OCES-2022 batch during Graduation Function in BARC.

## Upskilling of Scientific and Technical Manpower

The Human Resources Development Division of BARC also conducts the QUEST program under DAE's Continuing Education Programme (CEP). During the year, it offered four advanced courses on Signal Conditioning & Recovery, Advanced Concepts in Finite Element Method, Catalysis and Surface Engineering Chemistry and State-space approach to Reactor Control for PhD students and DAE employees. Certificates were issued to candidates who have secured more than 50 per cent in the passing examination.

HRDD coordinates for a 1-2 month practical training and also offers up to one year duration academic projects in BARC for students of BE/BTech/MTech/ME/MSc/MCA/JRF/SRFs from all over the country for promoting interactions between academia and scientists for wider benefits. HRDD facilitated 719 applicants from outside colleges to perform collaborative research/project work in BARC.

For upskilling of entry level young graduates, HRDD facilitated enrolment of 78 Trainee Officers of OCES-2021 and 69 TSOs of OCES-2022 of BARC Training School to M.Tech program of HBNI. Under its coordination, M.Tech project work was initiated for 52 officers of OCES-2020 and 45 of OCES-2021. HRDD processed 22 M.Tech theses of OCES-2019 and 16 of OCES-2018 M.Tech degrees from HBNI.

## Human Resources Capacity Building

Radiation Medicine Centre conducts various academic courses for science graduates viz., M.Sc. (Nuclear Medicine and Molecular Imaging Technology (NMMIT) and Hospital Radiopharmacy (HRP). 19 candidates took admission in these two programs. Besides, it has coordinated with HBNI for successfully conducting student examination for MD (Nuclear Medicine). Two MD post-graduates have completed the mandatory 1-year post-MD residency and have joined regular services.

## Scientific Information Resources

### Trombay Colloquium

Established in 1957 by pioneering scientist Dr. Homi Jehangir Bhabha, Bhabha Atomic Research Centre (BARC) is committed towards development of advanced technologies that contribute to the expansion of nuclear energy generation capacity in India. Since its inception, BARC was instrumental in developing several important nuclear technologies, including power reactors ranging from capacities 220 MWe to 700 MWe capacity. True to its multi-diversified nature of R&D activities, BARC encourages wide ranging exchanges and interactions regularly between its scientific community and their peers spread across geographies with an aim to fuel scientific research in newer and exciting domains. The Trombay Colloquium is a key window of opportunity for the BARC community to brainstorm with eminent individuals belonging to a wide spectrum of science and allied domains. Prominent scientists visited BARC Trombay to deliver captivating talks on emerging domains of science, and the transformative effect on the technology landscape.

### Vice Chancellor of ICT Visits BARC

Professor Aniruddha Bhalchandra Pandit, Vice Chancellor of Mumbai headquartered Institute of Chemical Technology, who is popularly known for



Professor Aniruddha Bhalchandra Pandit receiving a memento from Director, BARC.



his outstanding achievements in intensification of physical and chemical processing applications in Hydrodynamic Cavitation among others delivered a talk titled '*Cavitationally Induced Physico-chemical and Biological Transformations*'.

## Veterans of Nuclear Energy Speak in One Voice

Noted senior nuclear energy experts Dr. R.K. Sinha (Former Chairman AEC), Dr. A.K. Nayak (Head, Nuclear Control & Planning Wing) and Dr. Birijalaxmi Das (Bio Science Group, BARC) have jointly delivered a talk entitled '*The Unreasoned Fear of Radiation*' touching upon major driving factors leading to the irrational fear of radiation, effects of low dose and low dose-rate radiation on the health of living beings, and associated targeted scientific research requirements.



Dr. R.K. Sinha, Former Chairman AEC, speaks during his Trombay Colloquium talk in BARC.

## Vice Chancellor of BIT Visits BARC

Professor Indranil Manna, Vice Chancellor of Ranchi headquartered Birla Institute of Technology and a reputed materials engineer-cum-educationist, delivered a talk titled '*Laser Assisted Additive Manufacturing and Surface Engineering*' to draw the attention of BARC audience towards the key concepts and issues governing laser assisted additive manufacturing, including repair and refurbishment using laser assisted surface engineering and appropriate correlation among microstructure, properties and process parameters.



Professor Indranil Manna addressing the audience present for Trombay Colloquium in BARC.

## Information Resources Management

The Home Office Anywhere (HoOA) facility of BARC provides secured remote access to important information resources. Around 100 new members have registered for availing this service during the year.

## Digitization Activities

Digitization of printed copies of proceedings of conferences sponsored by Board of Research in Nuclear Sciences (BRNS) was continued in BARC Central Library during the year.

## BARC Newsletter

Six issues of newsletter on important and interesting themes, with articles mostly on research and development work in BARC, were edited and published during the year. These include Waste Management and Reprocessing, Beam Technologies, Astrophysics (on MACE Telescope), Materials for Sustainable Energy, and Artificial Intelligence & Robotics.



BARC Newsletter Issues published in 2022.

## Publishing of New Books

BARC has officially published 03 books with ISBN recognition. These books cover R&D work over the years in the field of beam technologies in BARC. Besides, it has assisted Homi Bhabha National Institute (a deemed to be university) in its efforts for publishing a book - *Atomic Energy in India: Achievements since Independence* - as a part of Azadi ka Amrit Mahotsav (1947-2022) activities in the department.



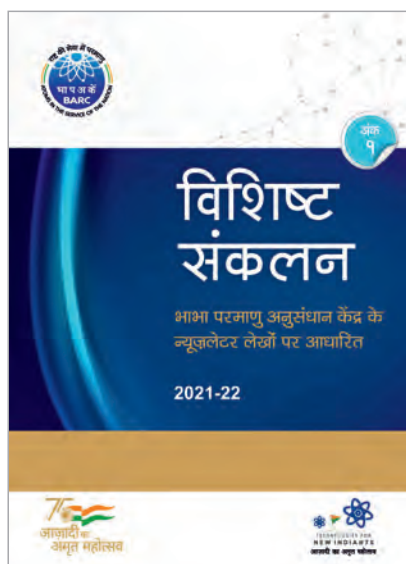
Books published by BARC during the year 2022.

## BARC Annual Report

R&D activities during the calendar year 2021 were compiled and published in the form of BARC VISTA Annual Report 2021.

## Publications in Hindi

Interesting articles on advancements in nuclear reactor technologies in India were prepared and published during the year. The special issue (Vishisht Sankalan-1) was released during an event held in BARC to mark 2023 edition of World Hindi Day.



## Nuclear News Web Digest

Nuclear energy related information of credible nature, published across several media by multiple agencies, is collated and published regularly in the weekly Nuclear News Web Digest with the intention of keeping BARC scientific community abreast of global developments.

## BARC Reports

Internal, External and Restricted reports were prepared and published regularly during the year. These reports comprise specific scientific and technology outcomes of R&D work in BARC. Pulse - a magazine on hospital practices, clinical procedures - edited and published jointly by BARC Scientific Information Resource Division and BARC Medical Division - was prepared and published.

## Central Library Book Collection

Interesting books on varied topics of science and technology as well as on general subjects both in Hindi and English were acquired for BARC Central Library. The total collection of books of all kinds across all formats in BARC Central Library stands at over 190,000.

## Journals

BARC Central Library subscribed to 389 journals in electronic form and 53 print based journals besides several popular magazines. It is working proactively for the implementation of One Nation One Subscription (ONOS) initiative floated by the Government of India for enhancing the accessibility of wide spectrum of journals. BARC Central Library subscribed to 389 journals in electronic form and 53 print based journals besides several popular magazines. It is working proactively for the implementation of One Nation One Subscription (ONOS) a GoI initiative. Originality of BARC scholarly manuscripts for more than 850 articles, 95 PhD thesis and many book chapters were checked for similarity. Besides, online gateway Lakshya were updated regularly.

## Technology Management

### Technology Sharing

BARC has inked 178 agreements with small-to-big industry players for transfer of 87 technologies besides renewing licenses for 14 technologies during the year.

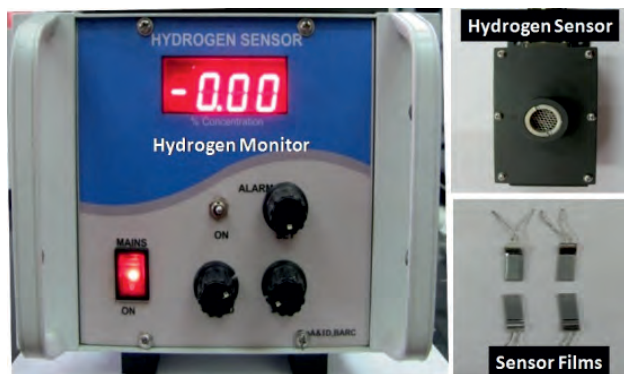
The technologies transferred for commercial use were in the domain of agriculture & bioscience, radiation technology, advanced instrumentation, medical equipment, engineering, environment, chemical sciences and water.

Additionally, 26 new technologies conceived in BARC have been released into public domain during the year. The new technologies released into public domain are as follows.

1. Aluminium Visual Detection Kit (AVDK) for Rapid Detection in Dialysis Fluids and Ground water, developed in NCCCM, a unit of BARC.
2. Tungsten filament based Scanning Electron Microscope (SEM) with imaging resolution of 20nm.
3. Cumulative automatic air moisture collection sampler using Peltier cooling technology.
4. High Coulomb Spark-gap Switch.
5. Induction Levitation Melter (ILM).
6. A process for synthesis of o-Tolylbenzotrile (OTBN), an advanced intermediate for anti-hypertensive –sartan group of drugs.
7. Environmental Gamma Spectroscopy System (EGSS).
8. Air Plasma Incinerator.
9. Hydrogen gas Sensor.
10. DC Accelerator for Radiation Processing Applications.
11. Electron Gun for Linear Accelerator.
12. Scan Magnet and Power Supply for Electron Beam Accelerator.
13. Type IE CRISPR system based microbial gene silencing kit.
14. ANU-CHAITANYA: A versatile bioregulator for sustainable crop production.
15. A novel universal multi-nutrient soil extractant for assessing bio-availability of nutrients in soil.
16. Nutritious Ready-to-Eat (RTE) fish spread.
17. Visual Detection kit for melamine content in adulterated milk.
18. Bonding and Packaging, and Testing Technology of High Power Laser Diode Arrays for Diode Pumped Solid State Laser Module, developed by RRCAT Indore.
19. Laser additive manufacturing system using powder fed Direct Energy Deposition, developed by RRCAT Indore.
20. Process for Synthesis of Poly-Acrylamide-Hydroxamate (PAH) Resin for Recovery of Selective Metal Ions.
21. Isolated Multi-channel DAQ for Multi-cell Stack System.
22. Shelf Stable Luscious and Nutritious Chiku Fruit Bites.
23. Synthesis of High Purity 1, 3-Dioctylxycalix [4] arene-18-crown-6 (Calix-Crown-6).
24. Process system for cleanup of dissolved oil and salt contaminated waste water.
25. Agni Rakshak - Raman optical fiber based distributed fire sensor system.
26. Naturally Fermented fibre fortified Rice/ Millet Idli using Moong as an alternative to Urad.



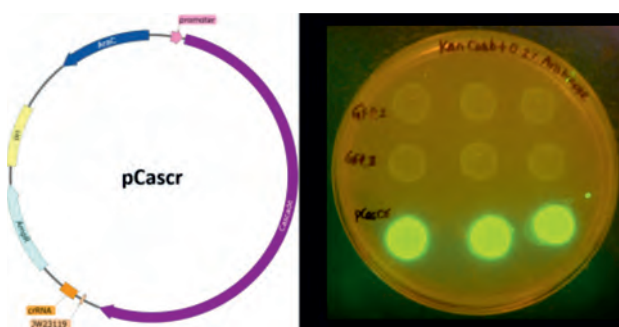
The Technology of High Coulomb Spark-gap Switch with Applications in Large Charge Transfers Associated with High-energy Pulsed Power Systems.



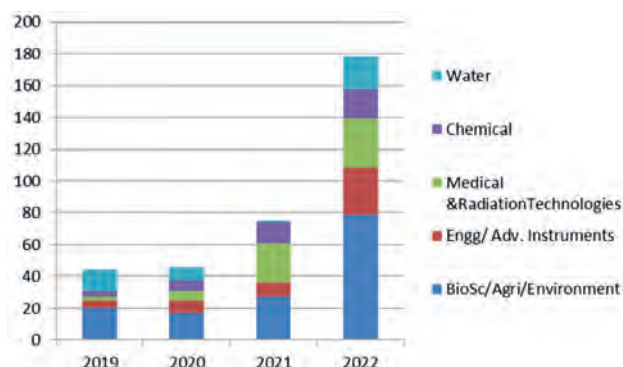
Hydrogen Gas Sensor.



Induction Levitation Melter.



Type IE CRISPR System based Microbial Gene Silencing Kit.



Agreements Signed in the Last 4 Years for Commercialization of BARC Technologies.

## Renewal of Technology Licences

Licences for 14 technologies were renewed during the year. These include

1. Nanocomposite Ultrafiltration Membrane Device for Domestic Drinking Water Purification from arsenic, iron, and microbial contaminations.
2. On-line Domestic Water Purifier based on Ultrafiltration Polysulfone Membrane.
3. 70kj, 25kv Electromagnetic Manufacturing Equipment(EME).
4. Membrane assisted Defluoridation process for safe drinking water.
5. Nanocomposite Ultrafiltration Membrane Device for Domestic Drinking Water Purification from arsenic, iron, and microbial contaminations.
6. Membrane assisted De-fluoridation process for safe drinking water.
7. Preparation of Composite Polyamide Reverse Osmosis Membrane for Brackish Water (BWRO) desalination.
8. FDK- Fluoride Detection Kit for Ground Water.
9. Preparation of Composite Polyamide Reverse Osmosis Membrane for Brackish Water (BWRO) Desalination.
10. TLD Badge for Personnel Monitoring.
11. Production of Dysprosium Doped Calcium Sulphate powder.

## New Patents

Patents have been sought for three new innovations conceived in BARC.

1. Antihypertensive and cardio-protective property of allylpyrocatechol (APC), a dietary molecule derived from piper betel leaves.
2. Deinoxathin intermediate uses in the detection and quantification of creatinine in human biofluids.
3. Deuterated-3, 3'-diselenodipropionic acid (D-DSePA) and its use as an anticancer or radioprotective agent.

## Technology Entrepreneurship through AKRUTI Program

Through its Advanced Knowledge & Rural Technology Implementation (AKRUTI) program, BARC is propagating deployment of 17 spin-off technologies. During the year, 3 agreements were signed and 9 licences were granted for deployment of AKRUTI technologies in rural and semi-urban areas. The licensed technologies are:

1. A Rapid composting technology for decomposition of Dry Leaves, Kitchen waste and Temple waste
2. Process for Long Lasting Ready-To-Eat Intermediate Moisture Fruit Cubes.
3. Solar Dryer (25 kg capacity).
4. Foldable Solar Dryer.
5. Banana Tissue Culture.
6. Nisargruna Biogas Plant based on biodegradable waste (one ton per day capacity).
7. Soil Organic Carbon Detection & Testing Kit.
8. Mass Multiplication Medium of Biofungicide *Trichoderma spp.*

## Training Programs

Around 30 entrepreneurs from various parts of India joined a training program on BARC technologies, organized by AKRUTI.

Training program in AKRUTI technologies was organized in two phases during 28-29 June and 9-11 November, 2022 for 18 resource persons of Punyashlok Ahilyabai Holkar Solapur University. Senior officers of BARC demonstrated important aspects of BARC societal technologies for the benefit of participants.

## New AKRUTI Centres

Four new AKRUTI Centres are coming up at various DAE locations viz., Heavy Water Plant Manuguru, BARC(Facilities) Visakhapatnam at Dibbapalem, Institute of Physics at Bhubaneshwar, and Special Material Facility at Chitradurga.

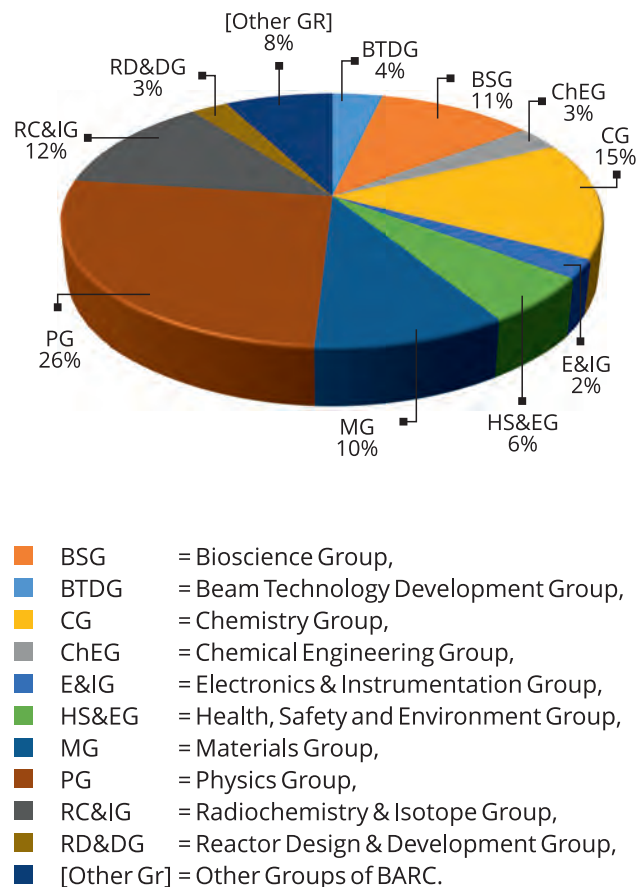
## Journal Publications

Journal articles published by BARC scientists across various disciplines during the calendar year 2022.

Sr. No.	Discipline	J. Articles
1	Biology	218
2	Chemistry	336
3	Engineering	233
4	Materials Science	272
5	Physics	413
6	Multidisciplinary	93
<b>All</b>		<b>1565</b>

Source: Scopus database (accessed on 26 Apr. 2023)

Group-wise percentage of journal articles published in the calendar year 2022 by BARC scientists.



S. No	Name of the Journal	Impact Factor	Total journal articles published
1	Journal of High Energy Physics	6.38	31
2	Journal of Radioanalytical and Nuclear Chemistry	1.75	28
3	Journal of Alloys and Compounds	6.37	25
4	Journal of Molecular Liquids	6.63	25
5	Physical Chemistry Chemical Physics	3.95	22
6	Physical Review C	3.20	22
7	Applied Radiation and Isotopes	1.79	21
8	New Journal of Chemistry	3.93	21
9	Transactions of the Indian Institute of Metals	1.39	19
10	Current Science	1.17	17
11	International Journal of Hydrogen Energy	7.14	16
12	Physical Review D	5.41	16
13	Journal of Physical Chemistry C	4.18	15
14	Journal of Applied Physics	2.88	14
15	Physical Review B	3.91	14
16	Physics Letters, Section B	4.95	13
17	Langmuir	4.33	12
18	Materials Chemistry and Physics	4.78	12
19	Radiation Physics and Chemistry	2.78	12
20	Journal of Instrumentation	1.12	11
21	Journal of Molecular Structure	3.84	11
22	Journal of Nuclear Materials	3.56	11
23	Materials Today Communications	3.66	11
24	Materials Today: Proceedings	--	11
25	Physical Review Letters	9.19	11
26	Annals of Nuclear Energy	1.81	10
27	Colloids and Surfaces A	5.52	10
*28	[Other Journals]	--	1124
<b>Total</b>			<b>1565</b>

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

Compared to last year (BARC VISTA 2021), BARC scientists and engineers published 237 more articles i.e. a total of 1,565 journal articles in the calendar year 2022. These articles attracted immediate attention from scientific community across the world.

BARC has high number of research collaborations with international R&D centres. The most favoured collaborating countries include, United States (144), United Kingdom (106), Germany (99), South Korea (96), and, France (82). This demonstrate the expertise and thought leadership of BARC scientists in the field of nuclear science and technology.



## 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.



Shri K.N. Vyas, Secretary DAE and Chairman AEC, addressing the students of JNV Vadnagar in Mehsana, Gujarat, through a recorded video as part of Parmanu Jyoti program.

# Outreach

## Students of Gujarat visit BARC

Students of Gujarat along with their teachers visited BARC (June 17-18, 2022) during which they interacted with the scientists and visited prominent facilities situated in Trombay campus to gain first-hand knowledge of diversified R&D activities in

BARC. The students were presented with certificates of appreciation at a special program. These students have excelled in a state-wide STEM Quiz conducted by the Gujarat State Council of Science and Technology.



Dr. A.P. Tiwari, Director, KMG, Dr. S. Adhikari, Head SIRD, Shri Manoj Singh, SIRD, Dr. Narottam Sahoo of Gujarat Council on Science and Technology pose for a group photograph with the students of Gujarat during an event organized in Anushaktinagar as part of a 2-day visit to BARC Trombay in 2022.





### Outreach Program in Kolkata

As part of an exclusive outreach program, senior officials from BARC and other constituent units of DAE visited prominent higher educational institutes, including colleges situated in the vicinity of Kolkata during April 26-30, 2022.

### Mega Exhibition in Dehradun

BARC participated in a Mega Exhibition in Dehradun (July 7-9) promoted by the Government of Uttarakhand. Students of prominent schools and engineering colleges across the state visited the DAE-BARC exhibition. The chief minister of Uttarakhand, Shri Pushkar Singh Dhami, and senior cabinet ministers of the state government also visited the stall.



BARC-DAE exhibition on nuclear technologies held in Dehradun.

### Rajbhasha Divas 2022

BARC participated in the 2022 edition of the Annual Rajbhasha Divas Samaroh (Hindi Day) held during September 13-14 in Surat, Gujarat.

### Exhibition on BARC Technologies for Societal Benefit

BARC and Atomic Minerals Directorate, a constituent unit of DAE, have jointly organized 'AKRUTI-ARUNODAY' event in Arunachal Pradesh's Mushai during 25<sup>th</sup> of August for the benefit of locals. At the event, various products developed across India using AKRUTI technologies were showcased with the aim of propagating the benefits of BARC technologies to the remotest regions of the country.

At an event held during 24-26 April in Samba Palli Gram Panchayat in Jammu to mark the National Panchayat Raj Day-2022, team AKRUTI and DAE

have jointly organized an exhibition to reach out to local farmers and women self-help groups for potential deployment of BARC spin-off technologies. Around 70,000 farmers participated in the event.



BARC-DAE exhibition at Samba Palli in Jammu, India.

Officials of BARC Visakhapatnam have been organizing public awareness programs regularly as part of sustained efforts to improve public perception of nuclear energy activities, particularly among students of schools and colleges, general public and academia by engaging the IARP, print and electronic media and AKRUTI Technology team of AKRUTI, BARC.



BARC officials addressing the audience present at a public awareness program organized at an educational institute near BARC, Visakhapatnam.

## Parmanu Jyoti Program

Parmanu Jyoti is a novel school-outreach initiative, aligned with the Scientific Social Responsibility, where the young scientists reach out to the students in remote areas. Mooted by the Department of Atomic Energy, it aims to inspire the next generation and spread awareness about the contributions of atomic energy to nation-building. BARC has joined hands with the DAE for implementing the activities planned under the program across various Jawahar Navodaya Vidyalayas (JNVs) during the year 2022.

### Glimpses of Parmanu Jyoti-2022



Commissioner of JNVs calls on Secretary, DAE to discuss the way forward for implementation of Parmanu Jyoti program.



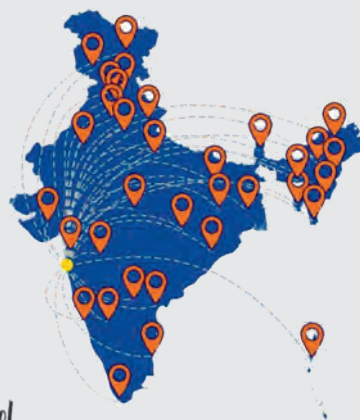
Dr. A.K. Mohanty, Director, BARC addressing a gathering of high level officials during a consultative meeting on implementation of Parmanu Jyoti program in DAE.



Team Parmanu Jyoti

### परमाणु ज्योति

- 50000+** STUDENTS
- 100+** SCHOOLS
- 80+** SCIENTISTS
- 34** STATES & UTs
- 4** MONTHS
- 1** MISSION



#BackToSchool





BARC scientists with the students of JNV Thoubal in Manipur.



Students of JNV interacting with a young scientist of BARC Trombay.



With the students of JNV Paota at Jaipur in Rajasthan.



Students of JNV Bemetara, Chhattisgarh share a lighter moment with a young scientist of BARC.



With the students of JNV at Valpoi Sattari in North Goa.



Students of JNV listen carefully to a BARC scientist addressing their queries.



A young BARC scientist explains an interesting point to the students of JNV.



Chairman, AEC and Director, BARC honour Dr. S. Adhikari for his coordination in organizing the Parmanu Jyoti Programme.

## Science & Technology Events in BARC

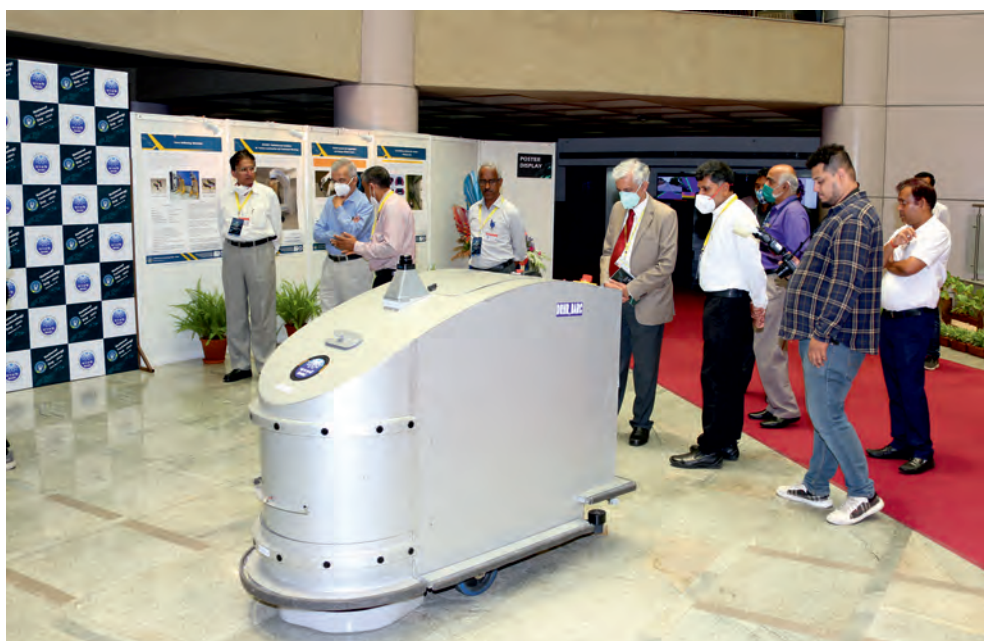
Events of significant national prominence such as National Science Day, National Technology Day are celebrated in BARC regularly. Eminent individuals belonging to science and technology domain are invited to BARC to deliver lectures for the benefit of BARC community. Students of schools and colleges are encouraged to visit BARC during such high profile events where they can make full use of the opportunity to network with the visiting scientists.



**National Science Day 2022:** Dr. A.K. Mohanty, Director, BARC and Dr. R. Chidambaram, Former Chairman, AEC alongside senior officers of BARC present during the event.



**National Technology Day 2022:** Shri K.N. Vyas, Chairman, AEC and Dr. Anil Kakodkar, Former Chairman, AEC alongside senior officers of BARC and the organizing team of the event.



**National Technology Day 2022:** Shri K.N. Vyas, Secretary DAE and Chairman AEC, paying attention to a new technological innovation of BARC, which was showcased during the event.



## 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 joint drill in BARC

# Safe and Secured Workplace

## Information Security

BARC has been pursuing proactively the development of technologies and systems as part of its measures to address deterrence, avoidance, prevention, detection and reaction to events, which

may pose potential threat to its physical and virtual infrastructure. New innovations in high-performance computing and cyber / information security solutions are being implemented to ensure safe and secure culture at workplace.

### Effective Deterrence and Information Security

- ✧ To facilitate smooth entry of private contractors and laborers into BARC Trombay campus, the TVS Gate entry equipped with the state-of-art Identity Validation System (IVS) has been made operational. Safety and security issues have been addressed through deployment of access control systems, baggage scanning systems and CCTVs.
- ✧ A new user-friendly visitor management portal is in works for deployment in management of visitors to DAE office at OYC, Mumbai.
- ✧ Attendance management of BARC staff stationed at remote locations has been simplified through implementation of an android based application.
- ✧ A new simplified Smart Vehicle Entry Permit system is in the process of implementation for proper monitoring of various government and contractual vehicles plying inside BARC campus.
- ✧ A new server was commissioned with HTTPS and reverse proxy front-end, which meet Govt. of India revised norms for hosting of websites.
- ✧ BARC has put in place a new front-end software that facilitates integration of DAE system with the National Single Window System for issuing of vendor licenses.

## Safety Measures

The BARC Safety Council Secretariat (BSCS) conducts short term training courses for scientific and technical personnel of BARC facilities regularly.

Important topics addressed in the safety courses include regulatory framework of BARC, radiation basics and natural radiation, radiological safety in front-end and back-end nuclear facilities, electrical safety, occupational health care, biological effects

of radiation, industrial hygiene and safety, safety in storage and handling of chemicals, industrial safety aspects in fuel fabrication facilities, safety aspects of material handling equipment, regulatory aspects of radioactive waste management, regulatory inspections, event reporting, emergency preparedness and response to nuclear & radiological emergencies, and improvement of safety culture in the facilities.



Participants of the 43<sup>rd</sup> course on "Safety and Regulatory Measures for BARC Facilities" held at DAE Convention Centre, Anushaktinagar during June 22-25, 2022.

## Fire Safety

Fire safety is given due attention in BARC campus through implementation of various training programs regularly. Knowledge on prevention and mitigation of fire related incidents at workplaces, high duty engineering plants is imparted to the

scientific community through organizing practical training sessions periodically. Fire Safety Awareness campaign is organized each year within the campus as well as the residential campus in Anushaktinagar to improve public awareness on standard operating procedures for preventing the occurrence of fire mishaps.

## Glimpses of Fire Safety Awareness Campaign-2022 in BARC



Fire safety drill underway as part of annual Fire Safety Awareness program in BARC Trombay.



Display of new systems and equipments acquired for dealing with potential fire emergencies in BARC Trombay.



A view of fire safety preparedness exercise in BARC.



Preparedness for Response to Radiological Emergency





Radiation Medicine Centre coming up at Rajarhat, Kolkata.



Plasma Incinerator Facility in BARC.



Inside view of Ahmedabad Sludge Hygienisation Plant.

# INFRASTRUCTURE DEVELOPMENT



Ahmedabad City Sludge Hygienisation Plant established with BARC know-how.

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

- ✧ New developmental works were initiated at KRUSHAK facility at Lasalgaon in Maharashtra for cold storage of fruits and vegetables (onion, garlic, banana and mango). These include –
  - ❖ A 250 metric ton (MT) capacity storage chamber for onion.
  - ❖ Two storage chambers of 10 MT capacity for potato/ onion equipped with varying relative humidity (RH) and temperature conditions.
  - ❖ One pre-cooling/ re-heating chamber of 50MT storage capacity.
  - ❖ One ripening chamber of 5MT storage capacity for banana/mango/papaya.
  - ❖ A quality control laboratory and a discussion room for organizing workshop/outreach activities has been planned at the facility.
- ✧ A new Radiation Medicine Centre is coming up at DAE Campus located at Rajarhat in Kolkata to cater to the growing demand for nuclear medicine services in eastern and northern states.
- ✧ Work on installing a Pre-conditioning System of Sludge Hygenization plant of Ahmedabad Municipal Corporation completed.
- ✧ Work is underway on a project for capacity enhancement of RAPCOFF facility at Kota in Rajasthan for handling absorber rods of 700 MWe reactors and hotcells for fabrication of sealed radiation sources.
- ✧ A 1 ton per day capacity Plasma Incinerator, which employs advanced plasma technology for carrying out the process of burning of solid wastes, was commissioned.
- ✧ Work on Agro Irradiation Facility for processing of food grains using Cesium-137 source completed.



@IRMS, SIRD, BARC