सत्यमेव जयते

GOVERNMENT OF INDIA

ANNUAL REPORT 2019-20

DEPARTMENT OF ATOMIC ENERGY

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EXECUTIVE SUMMARY

The Department of Atomic Energy's vision is to empower India through technology, creation of more wealth and providing better quality of life to its citizens. DAE is engaged in the design, construction and operation of nuclear power/ research reactors and the supporting nuclear fuel cycle technologies to achieve these objectives.

Advanced technologies such as accelerators, lasers, supercomputers, advanced materials and instrumentation are developed to encourage transfer of technology to industry which contributes to the national prosperity.

The Department is also engaged in the development of radiation technologies and their applications for better crop varieties, techniques for crops protection, radiation based post-harvest technologies, techniques for radio-diagnosis and radiotherapy of diseases particularly cancer, technologies for safe drinking water, better environment and industrial growth.

DAE also contributes to the enrichment of knowledge domain by way of support to basic research in nuclear energy and related frontier areas of science; Interaction with universities and academic institutions; Support to research and development projects having a bearing in DAE's programmes, and international cooperation in related advanced areas of research.

During the year 2019-20, the programmes of the Department achieved impressive growth in all the segments and domains. These are described below.

NUCLEAR POWER PROGRAMME: STAGE 1

PRESSURISED HEAVY WATER REACTORS

Nuclear Power Corporation of India Limited (NPCIL), formed in 1987, is a Public Sector Enterprise under the administrative control of Department of Atomic Energy (DAE). NPCIL is a dividend paying company with highest credit rating of AAA by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. Safety is given overriding priority in all facets of nuclear power reactors. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. TAPS-1&2 reactors have registered 50 years of safe and reliable commercial operation in October 2019. These units were the first nuclear power units in Asia and presently are the oldest operating nuclear power generating units of the world. First pair of indigenously designed 700 MW Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (KAPP-3&4) followed by second pair at Rawatbhata in Rajasthan (RAPP-7&8) and second pair of Light Water Reactors (LWRs) at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Various preparatory/ pre-project activities are in progress for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP)-1&2 (2x700 MW PHWRs), KKNPP-5&6 (2x1000 MW LWRs) and for 10 PHWRs (10x700 MW) in fleet mode towards commencement of construction of these projects. In addition, various activities including Techno commercial discussions are in progress for setting up of large size LWRs with international cooperation as an additionality. NPCIL, in all its endeavors, is committed towards up-gradation and continuous improvements in Quality Management, Quality Assurance (QA), Quality Surveillance, Pre-Service Inspection/ In-Service Inspection, Software Quality Assurance (SQA) and interface with regulatory body.

Power Generation

During the Calendar Year (CY) 2019, NPCIL registered highest ever commercial generation of 45163 Million Units (MUs). In the previous CY 2018, the generation was 39051 MUs.

During the Financial Year (FY) 2019-20, the actual generation up to December 31, 2019 is 35808 MUs and expected total generation for the FY 2019-20 is about 45000 MUs. Actual generation during the previous FY 2018-19 was 37813 MUs.

During the Financial Year 2019-20, the overall Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2019 for all the reactors in operation were 91% and 85% respectively. These figures for FY 2018-19 were 73% and 70% respectively.

During the Financial Year 2019-20, four reactors i.e. NAPS-2, KAPS-2, KGS-4 and TAPS-4 achieved continuous operation of more than a year. NAPS-2 and KAPS-2 continued operating and registered continuous operation of 493 days and 465 days respectively till December 31, 2019. KGS-4 and TAPS-4 registered continuous operation of 370 days and 365 days respectively after which these units were shut down for carrying out planned maintenance activities.

TAPS-1&2 (2x160 MW)

Release of 'My Stamps' and 'Special Covers' by Department of Posts on commemoration of 50 Years of Commercial operation of TAPS-1&2 on December 28, 2019

Department of Posts released 'My Stamps' and 'Special Covers' on setting a World Record of 962 days of continuous operation of KGS-1 on November 28, 2019

So far, the continuous operation of more than a year has been achieved 32 times by various reactors operated by NPCIL. Out of these, three reactors KGS-1 (962 days), RAPS-3 (777 days) and RAPS-5 (765 days) have operated continuously for more than two years. The continuous operation of 962 days registered by KGS-1 is a world record.

Commemorating the achievement of Kaiga Generating Station-1 (KGS-1) for establishing the world record of 962 days of continuous operation and achievement of TAPS-1&2 on completion of 50 years of operation, Department of Posts, Govt. of India has released 'My Stamps' and 'Special Covers' on November 28, 2019 and December 28, 2019 respectively.

Nuclear power reactors in operation registered 517 reactor years of safe operation by the end of CY 2019.

Renovation & Modernization works at KAPS-1

At Kakrapar Atomic Power Station (KAPS) Unit-1, the En-Masse Coolant Channels Replacement (EMCCR), En-Masse Feeders Replacement (EMFR) and other safety upgrades, which were undertaken in project mode since August 1, 2016, were completed successfully and the unit re-started and synchronized to Grid at 06:44 hrs. on 24th May 2019.

Projects under construction

Kakrapar Atomic Power Project (KAPP) Unit-3&4 (2x700 MW PHWRs)

Unit-3 is in commissioning phase. A major milestone i.e. 'Primary Heat Transport (PHT) Hot Conditioning' was successfully completed in August 2019 after obtaining regulatory clearance and this will be followed by Initial Fuel Loading and approach to first Criticality. The physical progress of the unit is about 98% as on December 31, 2019.

In Unit-4, with completion of Outer Containment (OC) Dome, main plant civil construction works are completed. In reactor side, coolant channel installation has been completed and feeder fabrication work is in progress. The physical progress of the unit is about 86% as on December 31, 2019.

View of Main Plant construction area – KAPP-3&4

Rajasthan Atomic Power Project (RAPP) Unit-7&8 (2x700 MW PHWRs)

In Unit-7, construction of Inner Containment (IC) Dome and OC Dome has been completed. Erection of feeders is completed. Primary Heat Transport (PHT) system main loop piping has been completed. Physical completion and testing of various circuits are in progress towards start of PHT Hydro test. The physical progress of the unit is about 86% as on December 31, 2019.

In Unit-8, construction of IC wall is completed along with ring beam. Construction of Steam Generator (SG) vaults is completed. Installation of Calandria Tubes is in progress. Balance construction and equipment erection works are in progress. The physical progress of the unit is about 72% as on December 31, 2019.

RAPP-8 Reactor Building

Kudankulam Nuclear Power Project (KKNPP) Unit-3&4 (2x1000 MW LWRs)

Civil works like construction of Reactor Building, Reactor Auxiliary Buildings, Emergency Power Supply Buildings, Turbine Buildings, Common Services Buildings, Switchyard Buildings, Hydro-technical Structures etc.; Manufacturing and supply of equipment and components; and Development of Working Documentation (WD) is in progress.

Lowering and alignment of Catcher Vessel of Core Melt Localization Facility (CMLF) in Reactor Cavity, an important milestone on critical path of Unit-3, was successfully completed in November 2019. The physical progress of Unit-3 and Unit-4 was about 38% and 36% respectively as on December 31, 2019.

Overview of Unit-3 of KKNPP

Sanctioned Projects

Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) Unit-1&2 (2X700 MW PHWRs):

Excavation & ground improvement in Main Plant area has been completed. Main Plant civil package has been awarded. Various tests required for qualification of foundation are completed at site and it is planned to commence First Pour of Concrete (FPC) after receipt of clearance from Atomic Energy Regulatory Board (AERB). Water Treatment Plant for construction water, domestic water and fire water supply has been commissioned. Purchase orders are placed for major equipment/ components like Primary Coolant Pumps, Steam Generators, Calandria, End-shields, Reactor Headers, extra in Fueling Machine Heads, Moderator and D_2O (Heavy Water) Heat Exchangers, etc. Manufacturing of these equipment/ components are in progress. Process of tendering for other major packages like Primary Piping Package, Plant Water Package, Turbine Island Package, and Main Plant Electrical Package is in progress.

GHAVP-1&2 –site activities in progress

Kudankulam Nuclear Power Project (KKNPP) Unit-5&6 (2x1000 MW LWRs)

Pit excavation for main plant buildings and structures is completed. Ground improvement by consolidation grouting and concrete levelling course is in progress. Confirmatory geo-technical investigation works at founding level has been completed. Application for AERB consent for First Pour of Concrete (FPC) submitted and is under review by AERB.

Ten 700 MW PHWRs in Fleet Mode

Land: Land is available for GHAVP-3&4 and Kaiga-5&6. Possession letter issued for all types of land for Chutka site in Madhya Pradesh. Land acquisition is in advance stage at Mahi Banswara site in Rajasthan.

Rehabilitation & Resettlement (R&R): R&R colony for the Project Affected Persons (PAPs) is under construction as per approved architectural plan in respect of Chutka site. In respect of Mahi Banswara site, land is identified for R&R colony and payment is made, demarcation work and topography survey for R&R colony land is completed.

Ministry of Environment, Forest and Climate Change (MoEFCC) Clearance: MoEFCC clearance is available for GHAVP-1 to 4, Chutka site and Kaiga-5&6. Application for Environmental Clearance (EC) is under consideration of MoEFCC for Mahi Banswara site.

Site Activities: Geo-technical investigation works are completed for GHAVP-3&4 and tender for Main Plant Excavation & Ground Improvement is under evaluation process. All the scope of work of Geo-technical and Geo-physical investigation is completed for Kaiga-5&6 and excavation tender for main plant civil works is under evaluation process. At Chutka and Mahi Baswara sites, Geo-technical investigation works are at stand still due to public/ villagers agitations.

Siting consent from AERB: Siting consent from AERB is available for GHAVP-3&4. Siting consent applications are submitted for Kaiga-5&6 and Chutka-1&2 and same are under review by AERB.

Procurement activities: Bulk purchase Orders are placed for various quantities of Forgings for Steam Generators, Lattice Tubes and Plates for End Shields, Pressurisers forgings, Bleed Condensers forgings and tubes for 40 Steam Generators. Tendering process for balance Steam Generators, Reactor Headers, Primary Coolant Pump (PCP) motor units, etc. is in progress.

New Project / Sites

Light Water Reactor (LWR) Projects

Jaitapur, Maharashtra: Land has been acquired. Techno-commercial discussions with Électricité de France (EDF), France are in progress.

Kovvada, Andhra Pradesh: Land acquisition process is in progress. Techno-Commercial discussions with Westinghouse Electric Company (WEC) are in progress.

Mithi Virdi, Gujarat: Land is to be acquired as per the new Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013.

Haripur, West Bengal: Land acquisition is contingent to initiative by State Government.

Pressurized Heavy Water Reactors (PHWRs)

Bhimpur, Madhya Pradesh: Commitment for water is to be confirmed by State Government.

Quality Assurance

NPCIL, in all its endeavours, is committed towards up-gradation and continuous improvements in Quality Management, Quality Assurance (QA), Quality Surveillance, Pre-Service Inspection/ In-Service Inspection, Software Quality Assurance (SQA) and interface with regulatory body. Quality Assurance/ Surveillance (in India and overseas) activities have

been carried out expeditiously for projects and stations. Pre-Service Inspection/ In-Service Inspection (PSI/ISI) activities of Projects/ Stations have been completed successfully. Corporate Peer reviews of operating stations have been conducted based on WANO guidelines. Audits of suppliers for major nuclear items are carried out in planned manner. Corporate QA audits of KKNPP-3&4, KAPP-3&4, RAPP-7&8, PSI audits of KAPP-3&4, RAPP-7&8, ISI audits of RAPS 3&4, KGS 1&2 and KGS-3&4 have been completed in a planned way. NPCIL continued to provide QA consultancy services to BARC and BHAVINI.

FRONT END FUEL CYCLE

Front-End Fuel Cycle comprises operations such as mining, milling and processing of ore, and fabrication of fuel. In addition, production of heavy water, used as moderator and coolant in pressurized heavy water reactors, also constitute a major segment of the Nuclear Power Programme.

DAE has wide-ranging capabilities in uranium mining and mineral processing, and is self-sufficient in the production of heavy water, zirconium alloy components and other materials and supplies, for pressurised heavy water reactor. The Nuclear Fuel Complex at Hyderabad manufactures fuel assemblies for pressurised heavy water reactors and boiling water reactors.

Heavy Water Production

Heavy Water Board (HWB), a constituent unit of DAE, is recognized as benchmark of excellence in production of nuclear grade Heavy Water and isotope separation technologies. HWB has gained expertise in commissioning and operation of large scale industrial Heavy Water Plants (HWPs) having varied complexities in design and operation. At HWB, a series of modifications aimed at process parameter optimization and energy conservation have resulted in substantial reduction in production cost over the years. HWB has been entrusted with the development and demonstration of technological feasibility of various processes for products required at the 'front end' as well as 'back end' of the nuclear fuel cycle. HWB has successfully achieved these tasks and accordingly, in April 2019 AEC has enlarged the mandate of Heavy Water Board as "Managing the projects of DAE for production of heavy water and specialty materials".

On May 01, 2019, HWB organised the "Golden Jubilee Celebrations" of its formation. It was on this day in 1969 that 'Heavy Water Projects' was set up as a separate unit under the leadership of Shri S. Fareeduddin, the eminent chemical engineer and one of the earliest Padmashree Awardees of the Department. Later it was renamed as Heavy Water Board (HWB) on February 17, 1989. Highlights of the celebration was the release of Coffee Table Book on HWB and release of Special Cover on HWB by Post Master General Ms. Swati Pandey.

Celebration of Golden Jubilee of formation of HWB– Dr. Anil Kakodkar, Dr. Sekhar Basu, Shri K.N. Vyas and Dr. U. Kamachi Mudali along with former Chief Executives of HWB

Release of special cover by Department of Posts during Golden Jubilee celebration of formation of HWB

Heavy Water Board has achieved the production targets set for the year for heavy water as well as for other products such as Boron, organo-phosphorus solvents and synthesis of D-labelled compounds. HWP, Hazira carried out Major Turn Around in May – June 2019 and HWP, Thal took annual turnaround of both streams in November 2019. While HWP, Kota operated

excellently during the period, operations at HWP, Manuguru was affected in the second week of May 2019, due to very low water levels in river Godavari. Such unprecedented constraint of raw water supply was witnessed for the first time in last 25 years. Subsequently, on May 29, 2019, main Cooling Tower of HWP, Manuguru was severely damaged due to wind storm forcing the plant to operate partially for prolonged period.

At HWP, Tuticorin, revamping jobs for targeted restart up of the plant are in full swing. IOCL Natural Gas pipeline laying job from Ramanad - Tuticorin sector is in progress. Civil work related to Solvent Production Plant is in an advanced stage of completion. Work order has been placed for detailed EPC activities. At Solvent Extraction Plant, land development, boundary wall and peripheral road for securing newly acquired land was completed.

Diversification Activities

HWB continued demonstrating Solvent Extraction technologies for nuclear hydrometallurgy; producing stable isotope products like ^{10}B enriched boron carbide pellets for control & safety mechanisms in Fast Breeder Reactors; production of nuclear grade Sodium for FBRs and production of O-18 for societal applications. New initiatives taken in some of the key areas in these activities during the period are as follows:

Solvent Technology

HWB has the mandate for production and fulfilling the requirement of solvents in DAE for sustaining the Indian Nuclear Power Program. The existing solvent production facilities at Baroda and Talcher continued to meet the demand placed by various DAE units for organo-phosphorus solvents. HWP, Tuticorin, has been building experience in synthesis of new organo-phosphorus solvents and an industrial scale Solvent Production Plant is being set up there for synthesis of solvents.

Technology Demonstration Plant at Mumbai has successfully demonstrated the solvent extraction technology in industrial proto-type scale for various nuclear hydrometallurgical operations. Based on this, a Solvent Extraction Plant of industrial scale (25 MT) for the production of rare materials is now being set up at HWP, Tuticorin. Currently, HWB is working towards extraction of rare material from Indian phosphate rocks. After getting clearance from Forest Department, prospecting work will be taken up through AMD.

Boron Enrichment

HWB has taken up indigenous production of B-10 enriched Boron. Enriched Boron Carbide pellets are being produced for applications in control & safety systems for fast breeder reactor program and enriched BF_3 gas for neutron detector systems. HWB has already delivered the entire quantity of enriched Boron for the first core of PFBR. The 50% IP B_4C was made for the first time based on the request from IGCAR. At HWP, Manuguru Elemental Boron Plant and Boron Carbide Palletisation Plants are in operation for production of enriched Boron Carbide powder/ pellets of various isotopic purities.

BF_3 detector based on thermal neutron absorption by B-10 is one of the best thermal neutron flux measurement devices for nuclear reactors. At HWP, Talcher, B-10 enrichment by exchange distillation route generates BF_3 ether complex which is converted to KBF_4 for further processing and Boron Carbide production. The enriched BF_3 ether complex generated can be converted to enriched boric acid and in the next step to enriched BF_3 gas. The process has been taken up at the Boric Acid Conversion & Purification unit and BF3 Gas Generation unit installed at HWP, Talcher.

Sodium Metal

Nuclear grade Sodium metal is used as coolant for PFBRs. There is no manufacturing unit for Sodium metal in the country and its demand is met by import. Hence, DAE decided to indigenously produce Sodium. As per the roadmap, development of cell technology using test cell of 2 kA with different configurations and operating parameters have been operated to collect the data and fine tune the technology. Subsequently, scaled up 24 kA proto type cell has been designed which will be operated prior to setting up of 600 MTPA plant at HWP, Baroda. Foundation stone of Sodium Metal Plant was laid on January 5, 2020 by Shri K. N. Vyas, Secretary DAE & Chairman, AEC. He also inaugurated bench scale Sodium Purification Unit installed at HWP, Baroda for purification of raw Sodium.

Foundation stone laying ceremony of Sodium Metal Plant by Shri K. N. Vyas, Secretary DAE & Chairman, AEC at HWP, Baroda on January 5, 2020

Mineral Exploration and Mining

Atomic Minerals Directorate for Exploration and Research (AMD) has accelerated the pace of exploration activities by integrated, multi-disciplinary methodology and judicious utilisation of man power with a focused approach for augmentation of uranium, thorium, rare metals and rare earth resources.

This resulted in the augmentation of additional uranium oxide (U_3O_8) reserve of over 24,966 tonnes in the areas of Andhra Pradesh, Jharkhand, Rajasthan, Karnataka and Meghalaya.

Significant uranium anomalies were located in Uttar Pradesh, Chhattisgarh, Madhya Pradesh, Andhra Pradesh, Arunachal Pradesh and Rajasthan. About 2,56,034m reconnoitory, exploratory and evaluation drilling was carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of uranium and mineralization in the new promising areas. Significant uranium mineralized intercepts / bands have been identified in boreholes drilled at Uttar Pradesh, Himachal Pradesh, Karnataka, Andhra Pradesh, Jharkhand, and Rajasthan. New Potential/significant blocks have been identified at Madhya Pradesh, Karnataka, Rajasthan and Andhra Pradesh.

Geochemical surveys (4,695 sq km) have been carried out in different parts of the country for delineating targets for detailed investigations. Ground geophysical surveys (Regional: 652 sq km and Detailed: 399 sq km) have delineated potential high chargeability- low magnetic zones in Rajasthan; anomalous chargeability zones and deep seated faults along Andhra Pradesh and extensions of potential fracture zones in Karnataka and Chhattisgarh. Airborne survey and remote sensing surveys over 26,966 line km have been carried out in parts of Rajasthan where discrete conductors and subsurface structural elements were delineated in parts of Alwar Basin.

Rare Metal and Rare Earth (RMRE) investigations surveys were carried out in parts of Odisha, Chhattisgarh, Karnataka, Rajasthan and Gujarat.

Beach Sand and Offshore Investigations (BSOI) resulted in establishing potential heavy mineral zones mainly along the east coast of India. Significant zones of Total Heavy Mineral (THM) concentration have been located at Andhra Pradesh and Odisha.

Uranium Corporation of India Limited (UCIL) is mandated to engage in mining and processing of uranium ore in the country and has the sole responsibility to meet the nuclear fuel needs of the growing indigenous nuclear power programme.

UCIL continues to perform satisfactorily in all its operating units in Jharkhand and Andhra Pradesh with seven mines and two ore processing plants in the State of Jharkhand and one mine and one processing plant in Andhra Pradesh.

Tummalapalle plant has achieved highest ever production during 2018-19, despite severe socio political disturbances in the region.

In a major breakthrough in Industrial relations, for the first time in UCIL history, the wage revision settlement in respect of workmen (due from April 1, 2018) has been concluded for a period of 10 years (earlier always 5 years). The same is under the process of approval at DAE.

The Project Appraisal Committee (PAC) of department has given its recommendation for approval of Musabani Uranium Recovery Plant Project, Jharkhand. Govt. land has been transferred to UCIL. Consent to Establish (CTE) from Jharkhand State Pollution Control Board (JSPCB) has been received. Construction of boundary wall and other enabling work will be taken up soon.

Exploratory mining activities are in progress at Rohil uranium project. The development of 8^0 decline has progressed up to 105 meters (16.5meter vertical).

UCIL has signed a MoU with 'Sikar Muncipal Council' for supply of water to the project. Technical design of water supply pipe line and pump has been submitted by Sikar municipality which is under review by consultant.

At IREL, production of Nuclear Grade Ammonium di-Uranate (NGADU), Mixed Rare Earths Chloride (MRECL) increased by 6.4% and 29% respectively compared to similar period during previous fiscal.

Production of minerals increased by 30% compared to similar period during previous fiscal.

IREL implemented flow sheet developed by BARC and has produced 50 kg Nuclear Grade Gadolinium Oxide (99.99%). Same can be converted into Gadolinium Nitrate which is used by NPCIL.

Established Brownfield Private Freight Terminal (PFT) on existing railway siding at OSCOM, Odisha as per Ministry of Railways' guidelines and an agreement with M/s Gopalpur Ports Limited is signed for commercial utilization.

Environment Clearance and Consent for Establishment received for the Rare Earth Permanent Magnet Plant in BARC Campus, Vizag. Detailed Engineering in progress and clearance from Design Safety Review Committee (DSRC) and Safety Committee (SC) of BARC are awaited for preparing the final drawings. Agency shortlisted for taking up procurement, construction, erection and commissioning of the plant on LSTK basis. Selection will be carried out after receipt of clearance from DSRC & SC, BARC.

At BARC, using Alkyl Phosphine Oxide solvent, 99% pure hafnium oxide was recovered from scrub raffinate obtained from Zirconium Oxide Plant, NFC. 25% of the hafnium present in the scrub raffinate was recovered.

Fuel Fabrication

Nuclear Fuel Complex (NFC), an ISO 9001, ISO 14001 & OHSAS 18001 organisation under Department of Atomic Energy (DAE), remained engaged in the production of natural Uranium fuel bundles for Pressurized Heavy Water Reactors (PHWRs), enriched Uranium fuel assemblies for Boiling Water Reactors (BWRs), Reactor Core Structurals (calandria tubes, coolant tubes, square channels etc.), Reactivity Control Mechanisms and special materials like Tantalum, Niobium etc. In addition, for Fast Breeder Reactors, NFC produced all the core sub-assemblies and other critical components like fuel cladding tubes, hexagonal wrapper tubes etc. made out of special stainless steels/D9 materials. NFC also catered to the demand of high quality stainless steel tubes/pipes and titanium half alloy products for critical and strategic applications in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

About 30 tons of nuclear grade Uranium metal was produced in a reaction vessel established recently and supplied for research reactor fuel fabrication. Further, about a ton of Uranium was recovered by processing 20 tons of MgF_2 Slag – a byproduct of Magnesio- Thermic Reaction. An automated guided vehicle, material handling conveyors and supervisory software modules were installed at the New Uranium Oxide Fuel Production Plant in NFC, Hyderabad for fabrication of PHWR fuel pellets.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

The process of recovery of pure ^{90}Sr (free from radio-chemical contaminants) from HLLW (High Level Liquid Waste) using multi-step separation processes was standardised. Carrier-free radiopharmaceutical grade ^{90}Y was successfully milked from ^{90}Sr-^{90}Y solution. Using Supported Liquid Membrane (SLM) generator, more than 15 batches of 150 mCi of ^{90}Y were produced for radiopharmaceutical applications.

About 350 kg Uranium was recovered from 22,000 litres of acidified HLLW through a three-step separation process. Di-tertiarybutyl dicyclohexano-18 crown-6 ether (DTBDCH18C6), used for separating strontium from HLLW was synthesised.

The Induction skull melting facility was regularly operated to produce 200 kg of Aluminium-Silicon alloy taking the cumulative production of the alloy more than 600 kg.

A 60 m long waste transfer trench was built for transfer of High Level radioactive Liquid Waste (HLLW) from pump house in Waste Immobilisation Plant to AWTF and vice versa. The trench was hot-commissioned on 22nd Nov 2019 by transferring 1500 litres of HLLW from Plutonium Plant to AWTF via Pump House tank after obtaining necessary safety clearances.

R&D OF POWER SECTOR

The Research and Development support to the Nuclear Power Programme is provided by the research centres of DAE.

Under off-site fuel management services, evaluation of control rod patterns for mid-cycle sequence change at various power levels and core follow-up calculations were carried out for TAPS 1 & 2 reactors. Extensive safety analysis has been done to obtain control rod withdrawal sequence.

New versions of PREssure tube SAg Measurement (PRESAM) inspection system for 220 and 540 MWe PHWRs were developed to ensure increased service life and greater ease of operation. Structural integrity of the dump tank in old design PHWRs like RAPS/MAPS was studied to understand Severe Accident conditions at temperatures in excess of 2500 °C.

HEALTH SAFETY & ENVIRONMENT

Probabilistic Safety Assessment (PSA) Level-3 for 220 MWe PHWR at Kakrapar were carried out to estimate risk, development of protection strategy and emergency planning in early phase of nuclear accident using site-specific meteorological and demographic data.

Post-Accident Monitoring of Electrical Systems (PAMES) was developed for examining the health of power supply cables in an operating power plant.

Radiation Protection and Environmental Surveillance around Uranium Corporation of India Ltd (Jharkhand & Andhra Pradesh), Indian Rare Earths Ltd. (Kerala, Tamil Nadu, Odisha) and Nuclear Fuel Complex (Hyderabad) was carried out. Around 8260 occupational workers were monitored for external and internal radiation exposure in front-end operations of nuclear fuel cycle.

A Geographical Information System using open source data from Spatialite and PostGres was developed to visualise spatial and temporal trends around Nuclear Power Plants, for emergency response during extreme conditions. Occupational radiation doses to workers in underground Uranium mines and Thorium handling facilities were well within the regulatory limit of 20 mSv per year.

Environmental Surveillance at Trombay and Nuclear Power Plant Sites was conducted. Environmental Gamma Spectrometry System (EGSS) was developed for in-situ identification of radionuclides in atmosphere.

Radiation Monitoring Watch (RMW) powered by a 3V cell CR2450A was developed for gamma radiation monitoring. Quality audit of I-131 activity measurements was carried out for 242 Nuclear Medicine Centres (NMCs). Mobile Radiological Assessment Lab (RAL), designed for monitoring of ambient Gamma dose rate, has started operating for Integrated Centre for Crisis Management (ICCM).

NPCIL has recorded about 517 reactor years of safe operation by the end December 2019. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by Atomic Energy Regulatory Board by following the principles of As Low As Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB. NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001:2015 and Occupational Health and Safety Management System (OHSMS) as per IS-18001:2007 are maintained and regular audits

(internal, external and management) were carried out for continual improvement.

Overall safety management was excellent at all Heavy water Plants and there was no unusual occurrence during the period. HWPs Manuguru, Kota, Baroda, Thal, Hazira and Tuticorin were felicitated through awards by reputed organizations like National Safety Council, ICC, FICCI and AERB, for their endeavours to excel in the fields of safety, energy conservation and environment management.

NUCLEAR POWER PROGRAMME: STAGE 2

FAST BREEDER REACTORS

For the second stage of the Nuclear Power Generation Programme, the Indira Gandhi Centre for Atomic Research (IGCAR) is pursuing development of sodium cooled fast breeder reactors and associated fuel cycle technologies. Breeder reactors produce more fuel than they consume.

The Fast Reactor Programme of IGCAR is supported by its research and development endeavour in a range of disciplines such as reactor engineering, metallurgy, materials science, instrumentation, safety, and others. The Fast Breeder Test Reactor (FBTR), operating at Kalpakkam for over 25 years, also caters to technology development related to fast reactor.

Based on the fast breeder reactor technology developed by IGCAR, a 500 MWe Prototype Fast Breeder Reactor (PFBR) is coming up at Kalpakkam. The project is being executed by the Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), a public sector undertaking of DAE.

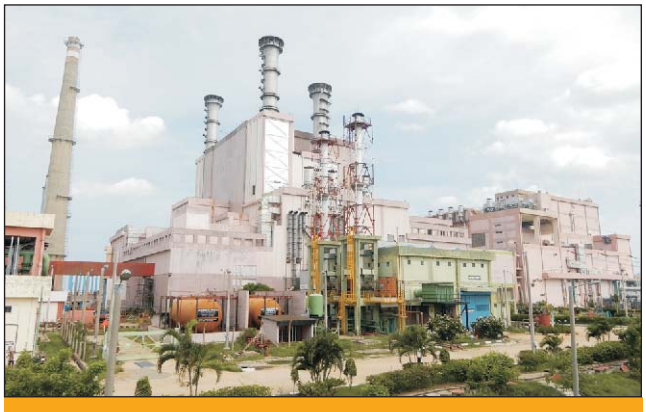
BARC contributes to the research & development and manufacture of fuels for fast reactors, technology for reprocessing of fuels, waste management and health and safety of the work force.

Fast Breeder Test Reactor

Fast Breeder Test Reactor (FBTR), the flagship of India's second stage Nuclear Power Programme continues as test bed for irradiation of fuel & structural materials in fast neutron flux, besides serving as a training hub for fast reactor operators and has completed 34 years of successful operation. In the current year, FBTR was operated at the highest reactor power level of 32 MWt with the turbo generator synchronised to the grid delivering an output of 7 MWe during the 28^{th} irradiation campaign. Operational life of FBTR has been re-assessed and towards extending life of grid plate, replacement of axial steel shielding in fuel subassemblies with tungsten carbide has been recommended. Towards this, high-density tungsten carbide pellets have been synthesised using spark plasma sintering technique for incorporation into carbide fuel sub-assemblies. 64 m^3 of sodium in two tanks of the FBTR flooding circuit has been successfully purified using the newly installed mobile sodium purification circuit. Servo Manipulator for remote cell applications has been successfully designed, fabricated, tested and qualified, in collaboration with industry.

Prototype Fast Breeder Reactor

Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is a 500 MWe (1250 MWt) liquid sodium cooled, pool type reactor using mixed oxide of uranium and plutonium as fuel.The plant is located 500 m south of the existing Madras Atomic Power Station. After completion of construction, installation & erection of all the systems / components of PFBR, commissioning of the individual systems and the integrated commissioning are in progress.



West Side view of PFBR

The major activities that have been completed during the report period are:

In sodium systems, secondary sodium pumps in both the loops were run for about eight months continuosly and the stable operation of secondary sodium loops was established. Subsequently, these pumps were shut down and the loops were completely drained as a preparatory step towards taking up the job on opening, inspection and rectification of bearing in Large Rotatable Plug (LRP). Preparatory works are under way for rectification of LRP bearing.

With respect to Fuel handling system, Gripper assembly of Transfer Arm (TA) was modified and room temperature tests were carried out at test station. TA was erected on pile and tested at preheated condition (150^{o}C) of reactor assembly.

In power evacuation system, commissioning of three nos. of 230 kV / 21 kV 200 MVA Generator Transformer from 230 kV Switchyard was completed successfully.

IGCAR is continuing to provide necessary support for the 500 MWe Prototype Fast Breeder Reactor (PFBR) which is in the advanced stage of commissioning. The first batch of 42 fuel sub-assemblies for PFBR has been shifted from Interim Fuel Storage building to BHAVINI site.

FBR Fuels

An autonomous robotic solution for loading PFBR fuel pins into transport magazines at Fuel Fabrication Facility, Tarapur was commissioned. As a part of the automation, deep learning-based algorithm and hardware were developed for autonomous reading of fuel pin number and for preparing a computerised data base. The system not only increases the throughput but also protects the operators from radioactive hazards.

Fast Reactor Fuel Reprocessing

Campaigns for reprocessing the spent fuel discharged from the Fast Breeder Test Reactor have been carried out at the COmpact Reprocessing of Advanced fuel in Lead cell (CORAL) facility, with excellent recovery and low dose expenditure. At the Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP), penultimate test runs (acid – solvent runs) are in progress ahead of commissioning.

Design and development of Plutonium Continuous Air Monitor (PuCAM), indigenous design & development of numerical protection relays, development of indigenous wireless sensor network to enhance avalanche forecasting capability and indigenous simulator platform for FBRs are some of the other notable achievements.

The construction and process equipment manufacturing activities for the Fast Reactor Fuel Cycle Facility (FRFCF) continue to make steady progress. Training Centre of FRFCF, the first green building in DAE, obtained Gold rated Green Building Certificate from Indian Green Building Council (IGBC). In the nuclear island, civil constructions of seismically qualified nuclear plant buildings are reaching the finished floor level.

Experimental facilities like measuring the contact angle of sodium, cavity-ring down spectrometer facility for the precise detection of trace level impurities in cover gas mixture have been commissioned.

FBR Related Technologies

Explosive welding trials have been carried out to plug the defective Steam Generator Tubes of PFBR, at Terminal Ballistic Research Laboratory (TBRL), DRDO, Chandigarh. IGCAR, in association with M/s MIDHANI and M/s NFC, Hyderabad produced for the first time, ten-meter long Alloy 617M boiler tubes for the Indian AUSC (Advance Ultra Super Critical) project. A novel high- performance nanophase-modified fly-ash concrete with inhibitor has shown promise for extending the life span of concrete structures of nuclear installations. The Fire-side Corrosion Test Rig (FSCTR), the first of its kind facility in India, was commissioned by the Indian AUSC consortium consisting of IGCAR, BHEL and NTPC at the 210 MWe Dadri Thermal Power Plant and is in operation for testing boiler tubes to various damage conditions at ultra-supercritical steam parameters. A high-temperature (720°C) thermal mixer made of stainless steel, an essential component of this facility, has been designed, fabricated, qualified under Indian Boiler Regulations (IBR) and delivered by IGCAR, for operation for a target duration of three years.

Future FBRs

As part of continuing endeavour towards development of metallic fuel, 1000 kg LiCl-KCl eutectic salt for electro-refining of uranium has been prepared. Facilities for fabrication of U-Pu-Zr metal fuel by injection casting method and pyro-processing studies of uranium and its alloys have also been commissioned.

Health, Safety & Environment

Effective Health Physics surveillance and radiological protection has been provided to all the active facilities of IGCAR. The online Decision Support System for radiological and nuclear emergencies developed by IGCAR called ONERS-DSS has been operationalized. Industrial Safety, Fire Safety and First Aid training programmes were organized periodically in addition to safety promotional activities to promote safety culture among the IGCAR employees. In addition, well equipped Occupational Health Centre (OHC) is made available to provide medical assistance for occupational injury / illness.

NUCLEAR POWER PROGRAMME: STAGE 3

THORIUM BASED REACTORS

Nuclear power employing closed fuel cycle is the only sustainable option for meeting a major part of the world energy demand. World resources of thorium are larger than those of uranium. Thorium, therefore is, widely viewed as the 'fuel of the future'. The Indian Nuclear Power Programme Stage-3 aims at using thorium as fuel for power generation on a commercial scale. In the thorium fuel cycle, thorium-232 is transmuted into the fissile isotope uranium-233 which is a nuclear fuel. As a part of this programme, BARC has been developing a 300 MWe Advanced Heavy Water Reactor (AHWR). Fuelled by thorium and using light water as coolant and heavy water as moderator, this reactor will have several advanced passive safety features.

Advanced Heavy Water Reactor

BARC is developing a 300 MWe Advanced Heavy Water Reactor (AHWR) with several advanced passive safety features for utilization of thorium abundantly available in India. A special experimental cluster with AHWR fuel consisting of 7 pins of (Th, 1%Pu) MOX was designed to carry out void reactivity measurements in AHWR-Critical Facility for validation of safety parameters.

Kalpakkam MINI (KAMINI) Reactor

The U-233 fueled Kalpakkam Mini Reactor (KAMINI) has continued its successful operation at a maximum power level of 30 kWt. It is serving as a unique facility for neutron activation studies and testing of indigenously developed neutron detectors.

Research Reactors

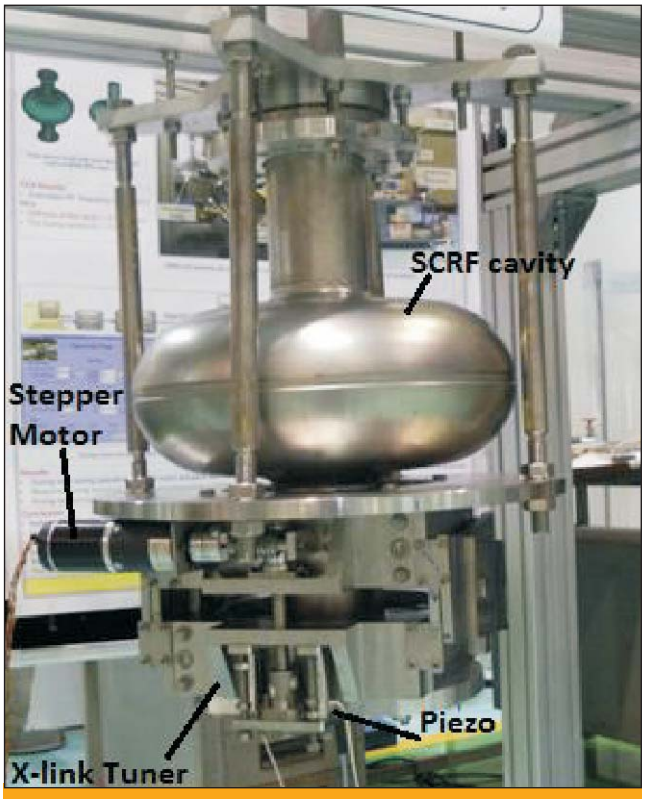
The newly commissioned Apsara-U reactor was operated at up to 90% of its full rated capacity of 2 MW after achieving the first approach to criticality on September 10, 2018. Trial production of radioisotopes has commenced. Research reactor Dhruva operated at its full rated capacity of 100 MW with high availability factor. Radioisotope production was on full stream with more than 700 samples irradiated during the year. Safe decommissioning of various facilities in Cirus reactor is in progress by minimizing various radiological and industrial hazards.

ADVANCED TECHNOLOGIES

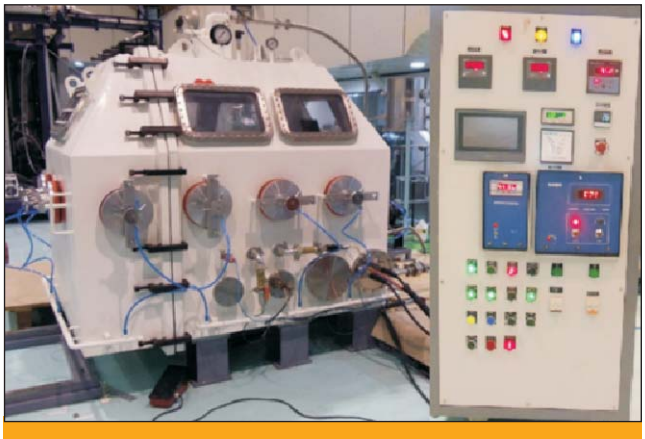
The research centres of DAE are engaged in developing advanced technologies such as accelerators, lasers, advanced materials, robotics, supercomputers, instrumentation and others. BARC, RRCAT, VECC and BRIT are also engaged in the development of radiation technologies and their applications for better crop varieties, techniques for crops protection, radiation based post-harvest technologies, techniques for radio-diagnosis and radiotherapy of diseases particularly cancer, technologies for safe drinking water, better environment and industrial growth.

Accelerators

Tuner for Superconducting Radio Frequency (SCRF) cavity plays an important role for resonance control during accelerator operation. RRCAT is developing x-link tuning mechanism for this purpose. This x-link tuner is tested at room temperature as well as at cryogenic temperature up to LN_2 along with its control system using single-cell Nb SCRF cavity. This tuner has been granted three international patents from Japan, Europe and USA.



X-link tuner with single-cell SCRF cavity



Environment-controlled glove box for dressing of the cavity and its control panel

Dressing of Superconducting RF (SCRF) cavities requires an important infrastructure known as environment-controlled welding glove box. The Glove Box (GB) has been designed and developed indigenously. The GB has been recently commissioned conforming to Titanium welding, maintaining oxygen level < 10 PPM and relative humidity (RH) level < 2%. This is an important milestone towards the development of dressed SCRF cavity.

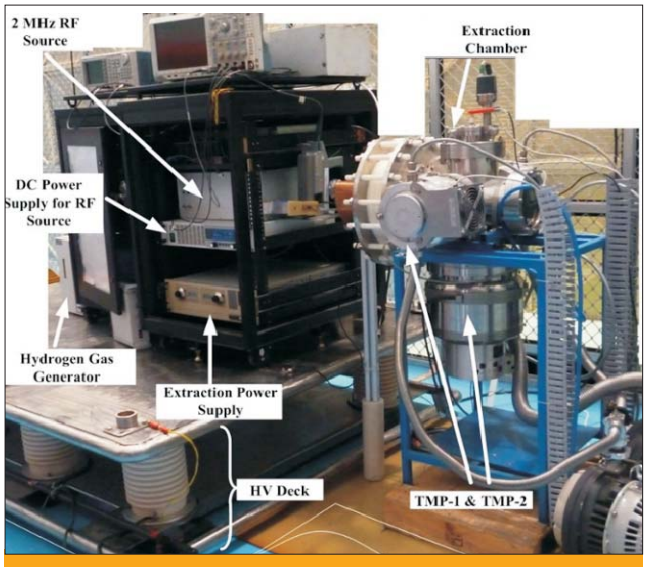
A Horizontal Test Stand (HTS) facility for testing of superconducting RF (SCRF) cavities at 2 K is being set up at RRCAT. The facility comprises of a 2 K cryostat, cryogenic transfer lines, a 40 kW 650 MHz RF amplifier with associated Low-Level RF (LLRF) system, control system etc. The cryostat is housed in a radiation shielded vault. The facility has been installed, sub-systems integrated and initial tests for transferring Helium has been successful. This facility shall be useful in high power RF testing of SCRF cavities being developed at RRCAT and other DAE units.

Horizontal test stand (HTS) cryostat with cryogenic transfer lines

For operation of HTS, the sub-systems like Radio Frequency (RF) high power stage, Low Level RF (LLRF) system, RF Protection Interlocks (RFPI), cryogenics, vacuum, radiation monitoring, personnel

and machine safety interlock etc. are integrated in centralised data acquisition and control system for machine operation and carrying out cavity characterization. An overall data acquisition and control system was designed and the testing is in progress.

An external RF antenna based multi-cusp H negative (H^-) ion source has been developed and operated in pulsed mode. H negative ion beam of 16 mA is extracted at 50 keV energy at repetition rate of 2 Hz with 2 ms pulse width. This ion source is developed for capacity building for proton linac. The work is in progress to test this ion source at high duty ratio of 10 %.



RF antenna based multi-cusp H negative ion source

A methodology has been developed to re-tune the lattice of the linac to compensate for the failure of solenoid or quadrupole magnets of the 1 GeV, H negative (H^-) accelerator proposed for Indian Facility for Spallation Research (IFSR). This makes the design of the accelerator robust. Also, a new design of β_g = 0.11 Superconducting Spoke Resonator (SSR) has been worked out by carefully optimizing the end-wall shape to make it completely free from multi-pacting at operating gradient. The work on physics design is in progress.

100 kW pulsed power solid state RF amplifier system operating at 325 MHz is designed and developed. It was tested up to 100 kW from 1 ms to 5 ms pulse width and 50 Hz pulse repeating frequency at 325 MHz. This is the first prototype; the work is in progress on modular stacking to derive a total power of 500 kW solid state RF power for energizing the RFQ to achieve 3 MeV pulsed H negative output required for IFSR.

100 kW, 325 MHz pulsed solid-state RF amplifier for RFQ

13 kV/5A Capacitor Charging Power Supply

A compact prototype, 13 kV, 5 A, Capacitor Charging Power Supply (CCPS) has been successfully designed, developed and tested for partial discharge capacitor charging applications. The developed CCPS is a substitute for costly imports. The CCPS has been tested with the high voltage modulator system at 300 Hz pulse repetition rate. Regulation and efficiency less than ± 1% and 94%, respectively, have been achieved at full load.

A prototype 10 kV, 1 kA water cooled IGBT based switch has been developed to evaluate the possibility for using it as a main pulsing switch in hard switch type pulse modulator of 6 MW peak power microwave system. The solid switch is an import substitute for the costly life limited thyratron switch. The switch has been tested at 10 kV, 1 kA, 200 Hz in a pulsed modulator system which generates 130 kV pulsed voltage of 12 μs pulse width for the klystron.

Test set up of high voltage solid state switch with the klystron

At VECC, a full scale prototype RFQ LINAC having unmodulated vanes has been fabricated. Low power RF measurements have been performed to find out dipole component and quadrupolar asymmetry in the fabricated structure and were validated with the simulation results.

A superconducting Heavy-ion Linac Cryomodule is being built for the VECC RIB project, jointly with TRIUMF Canada under a MoU. This cryomodule will be used for accelerating heavy ions with a high acceleration gradient of around 5 MV/m. In recently conducted preliminary tests acceleration gradient has been measured and matches with the design value.

An indigenous RF power meter along with Dual Directional Coupler (DDC) with monitoring electronics is designed, developed and tested successfully jointly by RIB and C&I Group at VECC that offers low cost import substitution for the indigenous linear accelerators at the centre.

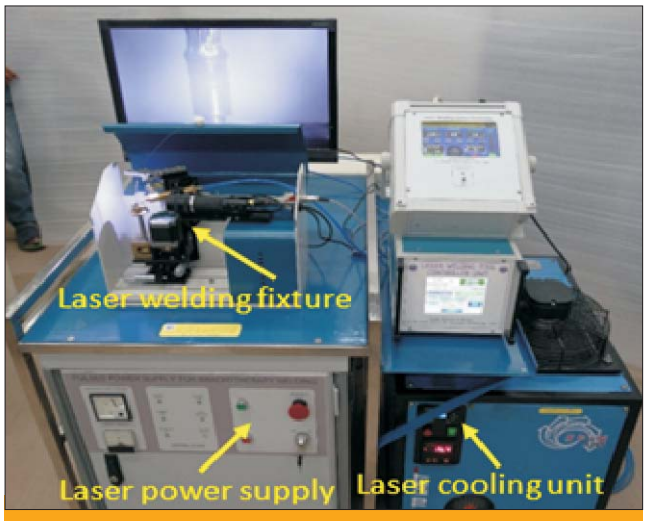
An indigenous 10kW, 75.6 MHz, Solid-State RF power amplifier has been designed and developed and successfully tested with load.

Laser Technology Development and Applications

The following lasers and laser based systems have been developed by RRCAT during the period of report for industrial, nuclear applications and applied R&D:

A fiber coupled pulsed Nd:YAG laser of 500 W average power and 10 kW peak power has been developed using dual flash lamp ceramic reflector pump chamber for welding of fuel pins at AFFF, Tarapur. Laser pulse duration can be varied in the range of 2-40 ms and pulse frequency in the range of 1-100 Hz. Laser output has been efficiently delivered through a 400 mm core diameter optical fiber for welding of PFBR and BWR fuel pins.

In-house developed Nd:YAG laser average 500 W power and peak 10 kW power



In-house developed Nd:YAG laser system for welding of Ir-192 brachytherapy assembly

A compact Nd:YAG laser system providing a maximum of 12.5 J pulse energy at 12 ms pulse duration was developed and installed at BRIT, Mumbai for welding of 1 mm diameter and 150 micron wall thickness iridium-192 brachytherapy assembly. Now the system shall be used in the hot cell at BRIT, Mumbai.

A table top 20 W average power all-fiber Yb-doped Q-switched fiber laser with 220 ns pulse duration at repetition rate of 20 kHz has been developed using Master Oscillator Power Amplifier (MOPA) configuration for marking application.

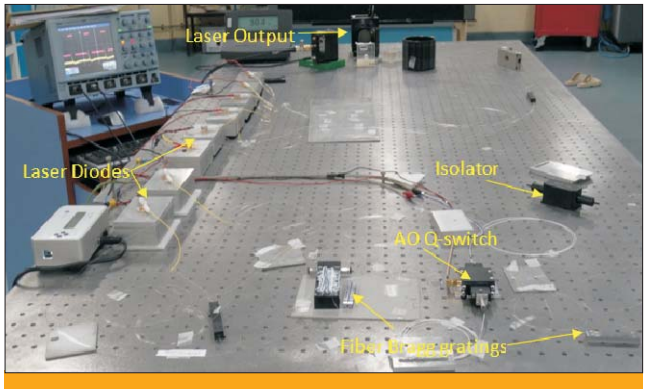
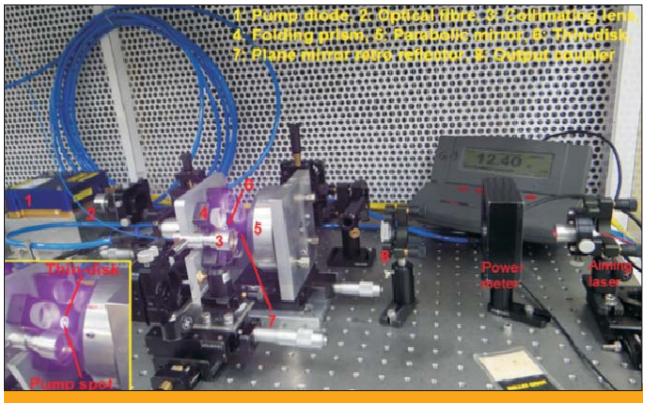


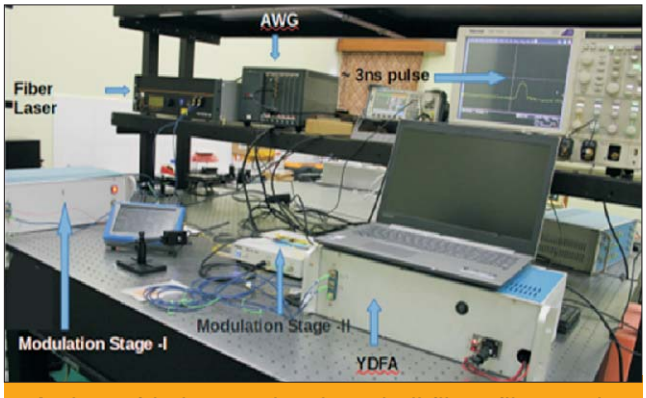
Table-top set up of 20 W Yb-doped Q-switched fiber laser

A multi stage Ytterbium doped all-fiber amplifier setup is developed for amplification of narrow linewidth seed source delivering 20 mW output power at wavelength of 1064 nm, with linewidth < 2 MHz to scale the power to 10 W level. Second harmonic generation of the amplifier output is carried out in periodically polled crystal to generate narrow linewidth at 532 nm with output of 350 mW. This laser is being developed to serve BARC requirement.

A 12 W CW Yb:YAG thin-disk laser, based on diode pump with 24-pass pump-head, has been designed and developed. Thin-disk laser is an advanced variant solid state laser to deliver high power/energy with excellent beam-quality. This work will continue to achieve 100 W CW power.



Developed CW Yb:YAG thin-disk laser in operation



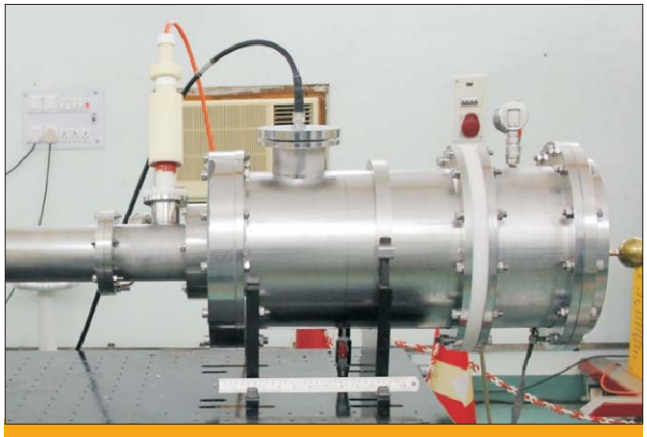
A view of in-house developed all-fiber, fiber optic front end system

An all-fiber, fiber optic front end system for high energy Nd:Glass laser, that delivers laser pulses with a pulse width of 3 ns and pulse energy of 20 nJ at 1053 nm has been developed.

A non-contact type and remotely operated laser-based sag measurement system LASMART (Laser based sag measurement application for reactor tubes) an alternative probe to LVDT and inclinometer has been indigenously developed. This system is capable of measuring the maximum sag with an accuracy of

0.5 mm and typically, the sag is of the order of 10 - 20 mm in the calandria tubes of PHWR. LASMART was used for sag measurements of three calandria tubes in the vault of KAPS-1 during EMCCR.

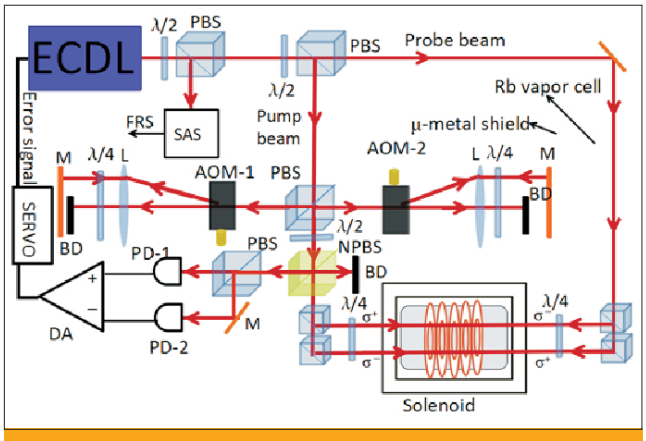
Laser system LASMART in the vault



Capillary discharge x-ray laser system emitting at 46.9 nm

The table-top capillary discharge soft x-ray laser operating at 46.9 nm wavelength has achieved significant enhancement in its energy. The gain medium of this laser is hot and dense plasma column with Ne-like Ar ions- in abundance. To increase the energy, the length of this gain medium was increased from 15 cm to 45 cm inside an alumina capillary of 3.2 mm inner diameter. This was subjected to a discharge current ranging from 25 to 35 kA with 90 ns quarter period. This has resulted in the increase in the energy per pulse from 4 μJ to 70 μJ.

A new frequency stabilization technique for External Cavity Diode Laser (ECDL) at 780 nm has been developed, where an enhanced symmetric dispersion like reference locking signal is generated using polarization enhanced absorption technique in presence of magnetic field. The schematic of setup is shown in where oppositely circularly polarized pump and probe beams overlap in Rb-vapor cell. The dispersion like PE-DFDL signal obtained from difference of two probe spectra from ^{87}Rb atoms was shown. The higher slope obtained in the dispersion like signal is useful for tight frequency locking of lasers.



Schematic of polarization enhanced Doppler-free Dichroic Lock (PE-DFDL) set-up

IR-FEL setup installed inside a 60 m long radiation shielded area

An Infra-red Free Electron Laser (IR-FEL) designed to lase in the 12.5 – 50 μm wavelength band is presently in an advanced stage of development at RRCAT. The injector system of the IR-FEL has recently been upgraded to ultimately deliver up to 50 W average electron beam power, which is planned to be achieved in stages. In first stage of commissioning of the IR-FEL, the electron beam qualification experiments have been performed in the low energy (6 W) section of the machine and the RF conditioning of all accelerating structures are in progress to operate

at electron rated beam power. Electron beam trials and lasing experiments will continue over the next quarter leading to lasing with laser peak power 1.5 MW and laser average power 10 mW at a wavelength of 30 μm.

The other Laser technologies developed at RRCAT for various applications includes Development of ion-chamber electrometer for radiation monitors; Development of high temperature (800 ^{O}C) fiber Bragg grating sensor based temperature monitoring system for use in Microwave heated chamber; Design and development of a spatially offset Raman spectroscopy system using optical fibre based ring illumination; Development & deployment of laser cutting technology for removal of single selected coolant channel L-8 of 540 MWe TAPS-4 reactor; Laser based removal of three selected coolant channels from KGS-1 reactor; Development of underwater laser cutting technology for retrieval of pressure tube stubs of 540 MWe TAPS-3&4 reactors; Development & deployment of laser cutting technology at PRPD, Kalpakkam and Laser Additive Manufacturing of Tungsten Carbide clad layers on SS304L tubes for BARC project.

Electronics & Instrumentation

A new version of "ANU NISHTA" was developed with enhanced hardware features for ensuring cyber security of instrumentation and control systems in Nuclear Power Plants. A Distributed Control System (DCS) integrated test facility comprising of 32 Node and 9 Node based NUCON-1000 PLCs interfaced with SCADA servers was set up at ECIL, Hyderabad.

A digital lock-in amplifier to detect and measure very small AC signals and to eliminate phase dependency of the output was developed. The amplifier has a bandwidth of 250 kHz, dynamic reserve of over 100 dB, time constant of over 400 seconds and roll-off of up to 80 dB.

Digital lock-in amplifier

RADIOISOTOPES & RADIATION TECHNOLOGY AND THEIR APPLICATIONS

DAE has been playing a significant role in the development and applications of various radioisotopes in healthcare, industry, agriculture and research. India is one of the leading countries in the isotope technology today as a result of the consistent efforts of DAE.

Radioisotopes are produced in the research reactors at Trombay, accelerator at Kolkata and the various nuclear power plants of NPCIL. During the report period, a wide variety of radioisotopes for medical, industrial and research applications were produced and supplied by BARC. The Board of Radiation and Isotope Technology (BRIT) produced and supplied a wide range of radioisotope products, and radiation technology equipment for medical and industrial uses. BRIT's plants for radiation sterilization of medical products and radiation processing of spices and allied products continued to offer services to medical and agro-industry. Radiation technology based tools and techniques benefitted variety of industries and social sector.

Agriculture

Three Trombay crop varieties, viz., Trombay Chhattisgarh Dubraj (rice) Mutant -1 (TCDM-1), Trombay Mustard TBM-204 and Trombay Linseed Genotype TL 99 have been released and Gazette notified for commercial cultivation by Ministry of Agriculture & Farmers Welfare, Government of India. As a part of the breeder seed programme, 251 quintals of Trombay groundnut seed, 20 quintal seeds of TKR Kolam rice variety BARCKV-13 and 10 quintal seed of various pulses were produced and distributed to 24 seed agencies in Bihar, Gujarat, Jharkhand, Karnataka, Maharashtra, Madhya Pradesh and West Bengal for foundation seed production. Breeder seed multiplication of blackgram variety TU-40, Cowpea variety TC901 and Pigeonpea variety TT401 was

carried out at Vizag. BARC Btk biopesticide technology was recommended for inclusion in the "package of practices" by University of Agricultural Sciences, Dharwad. A Biosensor Kit for detection of Organophosphate and Organocarbamate pesticides has been developed.

Nucleus seed production of 'TCDM-1', a mutant rice variety released & notified for Chhattisgarh state

Food Technology

A radiation processing facility based on indigenously developed 10 MeV, 5 kW electron linacs, has been setup by DAE at Devi Ahilyabai Holkar Fruit and Vegetable Mandi Indore. Two linacs have been installed at the facility. The linacs for the facility were developed indigenously by RRCAT in progressive manner.

Electron accelerator based radiation processing facility set up at Fruit and Vegetable Mandi, Indore

A technology was developed and transferred for preparation of shelf-stable dehydrated preservative-free Jamun strips. The technology is a solution to minimise post-harvest losses of Jamun fruits. Shelf life of onions was extended to 10 months by treating with 60 Gy of gamma radiation, followed by storage at ambient temperature (25±2°C RH 60-65%) under ample ventilation.

Combination processing, including gamma irradiation, was developed for ensuring safety and shelf life of legume sprouts and shelled sweet corn kernels. Prawns and different vegetables were combined to prepare RTE pulao and its shelf life extended using irradiation and chilled storage. Recipe for low glycaemic chapati was standardized by fortifying 10-14% (dry weight basis) Radiation Processed Psyllium (RPPs). A better score for softness and chewability was observed with RPPs chapati compared to controls.

Ready to Eat prawn pulao with extended shelf-life using Radiation processing

Development of low glycaemic chapati using radiation-processed psyllium

Nuclear Medicine and Healthcare

Regular Production & Supply of new radiopharmaceutical, ^{177}Lu-PSMA-617 was launched in September 2019 for the treatment of Prostate Cancer. The product is prepared using peptide, PSMA-617, which is synthesized in-house at BOD, BARC. More than 50 treatment doses of the therapeutic product has been produced and supplied to various nuclear medicine hospitals so far.

More than 200 Ci of I-131 products in 6000 consignments have been supplied to various hospitals in the form of capsules and solution for both, diagnosis and treatment of thyroid disorders including the treating thyroid cancer. This data also includes I-131 radiolabelled mIBG which is being used for diagnosis and therapy of Neuro Endocrine Tumors (NET).

Nearly 17 Ci in 160 consignments of therapeutic products, other than I-131 based radioactive products, such as ^{153}Sm, ^{177}Lu and ^{32}P for bone pain palliation and ^{68}Ga PET RPhs (^{68}Ga-DOTA-TATE for NET imaging and ^{68}Ga-PSMA for Prostate Cancer imaging) and ^{177}Lu-DOTA-TATE injection for the treatment of positive neuroendocrine tumors, were supplied to nuclear medicine hospitals and PET Centres.

1345 consignments containing approximately 120 Ci of ^{99}Mo in the form of Sodium Molybdate solution for Coltech Generators, Geltech Generators and Solvent Extraction Generator for obtaining Technetium-99m at hospital end, have been supplied to various hospitals in India in the financial year 2019-20.

More than 5600 consignments of Technetium-99m cold kits (19 Products; BRIT Code: TCK) for imaging various organs have been supplied to nuclear medicine centres in India including, ^{99m}Tc-cold kit for the preparation of ^{99m}Tc-Macro Aggregated Albumin (MAA) injection, useful for lung perfusion imaging and ^{99m}Tc-Ubiquicidine (Tc-UBI), used for infection imaging, during the reported time.

A total of 850 consignments of Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits were supplied to various pathology laboratories and nuclear medicine centres throughout the country for in-vitro diagnosis of thyroid disorders.

Around 600 batches of radiopharmaceutical samples (which includes TCK kits, ready-to-use radiopharmaceuticals injections and oral solution and capsules) and 48 batches of ^{99}Mo-^{99m}Tc COLTECH Generators were routinely analysed and certified by QC during this period.

Regular Quality Assurance was performed before the batch release of all the radiopharmaceuticals which were supplied during the reported period. Batch release certificates were issued for a total of 570 batches of TCK cold kits, ready-to-use radiopharmaceuticals injections, oral radiopharmaceuticals. This also includes recently launched radiopharmaceuticals based on Lu-177, Ga-68 and ^{99}Mo-^{99m}Tc COLTECH Generators.

The Medical Cyclotron Facility (MCF) of BRIT continued the synthesis and supply of Positron Emission Tomography (PET) radiotracers, the maximum being [F-18]-FDG. Other PET radiopharmaceuticals include [F-18]-NaF, [F-18]-FLT, and [F-18]-FET, which are produced in smaller scales. So far ~215 Ci of [F-18] FDG in 270 consignments have been supplied to various hospitals in Mumbai for PET imaging. More than 15,000 patients were benefitted with PET investigations in the reported year 2019-20.

New automated F-18 radiochemistry module has been installed inside the new lead hotcell for production of non-F-18-FDG based radiopharmaceuticals (F-18-DOPA & F-18-PSMA) during the reported period of 2019-20.

Production of other medically useful isotopes (a) ^{64}Cu in the indigenously developed solid target irradiation system via irradiation of 95% enriched ^{64}Ni, and (b) ^{68}Ga via irradiation in the liquid target system via irradiation of highly enriched ^{68}Zn was carried out during 2019-20.

Production of Fluorine-18 isotope for the preparation of Fluorodeoxyglucose (FDG) was carried out successfully using Medical Cyclotron, CYCLONE-30, at Radiopharmaceutical Facility of Regional Centre (Kolkata) of BRIT located at VECC.

BRIT continued the synthesis and supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products and various types of Tritium-filled self-luminous sources

(TFS). It is also involved in the production and supply of C-14 Urea Capsules. The —Urea Breath Test using these capsules is useful in the diagnosis of the infections caused by microorganisms named, Helicobacter pylori, a spiral bacterium, which may be responsible for gastritis, gastric ulcer, and peptic ulcer disease.

For societal application VECC has set up a 30 MeV H^- cyclotron-facility for the production of radioisotopes for medical applications, i.e., application in Positron Emission Tomography (PET), specifically ^{18}F, which is used in Fluorodeoxyglucose (^{18}FDG), as well as in Single Photon Emission Computed Tomography (SPECT). Already several batches of FDG produced through automated system and the test report sent to Radiopharmaceutical Committee (RPC) for obtaining clearance for human applications.

Radiation Medicine Centre of BARC provides diagnostic and therapeutic Nuclear Medicine services to a large number of cancer patients. During the year, 14,651 patients were provided diagnostic services using ^{68}Ga-, ^{99m}Tc- and ^{18}F- based radiopharmaceuticals and 3206 patients were treated for thyroid, prostate and neuroendocrine cancer using radionuclide therapy. Various thyroid function tests (TSH, T_4, fT_4, AMA and Tg) were performed using RIA for 10,936 patients.

RMC produced 8980GBq activity consisting of ^{18}F based PET radiopharmaceuticals and supplied to 14 Nuclear Medicine Centres across Mumbai. The new mini Lead hot cell housing an automated ^{18}F-radiochemistry module will be used for radiosynthesis of PET agents like ^{18}F-DOPA, ^{18}F-PSMA and ^{18}F-choline. A new therapeutic regime using ^{90}Y - DOTATATE was cleared by the Radiopharmaceutical Committee (RPC) and Institutional Ethics Committee of RMC. Till date, 10 patients with neuroendocrine tumour and liver metastasis were treated using ^{90}Y-DOTATATE. RMC developed ^{177}Lu-DOTA-Rituximab and ^{177}Lu-DOTA-Trastuzumab for radioimmunotherapy of non-Hodgkin's lymphoma and breast cancer respectively. 300 patients, diagnosed of metastatic castrate resistant prostate cancer, were treated using atheranostic pair of radiopharmaceuticals consisting of ^{68}Ga-PSMA and ^{177}Lu-PSMA.

BARC produced 50,000 Ci of ^{192}Ir and 3,185 Ci of medical radioisotopes. 612 consignments of various types of sealed radioactive sources were supplied through BRIT for medical and industrial applications. 19 consignments of ^{125}I brachytherapy seeds were supplied for treatment of eye and prostate cancers.

Alternative Applications of Heavy Water

Based on MoU between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers. All the solvents supplied had >99.8% Deuterium abundance.

To extend DAE's contribution towards societal benefits, HWB is shouldering responsibility for production and supply of ^{18}O enriched water ($H_2{}^{18}O$) of 95.5% ^{18}O enrichment required for PET scanning and 10% ^{18}O enrichment for metabolic studies. Nuclear grade Heavy water is used as raw material in the first indigenously developed ^{18}O production plant at HWP, Manuguru. The unit is under steady operation and has reached the enrichment of ^{18}O up to 85% during the report period.

HWB has now ventured in to new technology demonstration initiatives viz. recovery/ production of Cobalt, Gallium, Helium gas and Hydrogen. Facilities for the same are set up at the Technology Demonstration Plant, Mumbai.

Cancer Diagnostics & Treatment Services

The Tata Memorial Centre (TMC) continued to implement successfully the Hub-and-Spoke cancer care models across India. The current and future expansion of TMC would increase the number of new cancer patients being treated from 70,000 to 1.5 lakh per year. The bed capacity would be augmented from the current 700 to 3300 beds.

The year 2019 saw the inauguration of the 9th Cancer centre, the second in Varanasi, the Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC) of 350 beds by the Honourable Prime Minister of India Mr. Narendra Modi. In April 2019, foundation stone for the Annex Building at Homi

Bhabha Cancer Hospital, Varanasi was laid by Secretary DAE, Dr. KN Vyas in presence of Director TMC, Dr. RA Badwe.

The 10th satellite cancer centre is proposed to be set up in Muzaffarpur, Bihar on the 15-acre land given by the Bihar government in the campus of Sri Krishna Medical College in Muzaffarpur.

At the Dr. Bhubaneswar Borooah Cancer Institute (BBCI) in Guwahati, a state-of-the-art Linear Accelerator was inaugurated by Shri K N Vyas, Chairman, AEC and Secretary, DAE. The Buildings of the Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) in Mullanpur were almost complete and the centre is expected to be commissioned by May 2020. The HBCH, Sangrur was growing rapidly with plans to procure newer diagnostic equipment and to introduce more surgical facilities.

There were seamless patient referrals that ensured that patients did not have to re-register on being referred / or opt for treatment at any TMC satellite cancer centre. The costs of diagnostic investigations, treatment and cancer related drugs & consumables for patients in TMC and all its satellite centres were substantially cheaper than the private sector and significantly lower than the Maximum Retail Price (MRP). The unique and uniform aspect of the cancer services offered across TMC and its satellite centres were based on Disease Management Groups (DMGs) that bridged all medical disciplines, including those of prevention, diagnosis & treatment to focus on the specific anatomic region of cancer origin. Educational facilities in the satellite centres are also being implemented. The commissioning of the above centres resulted in marginal reduction of patient registration at TMH, Mumbai to around 72,000 from about 74,000 of last year; however, the new patient registrations at the satellite centres increased to over 30,000 in year 2019.

On 17th September 2019 in Vienna on the sidelines of 63rd General conference of International Atomic Energy Agency (IAEA), Shri K. N. Vyas, Secretary DAE & Chairman AEC launched the “NCG-Vishwam Cancer Care Connect” (NCG-Vishwam 3C). The NCG was thus made open to the cancer hospitals and other relevant institutes from foreign countries. Dr. RA Badwe, Director, TMC gave the details of NCG and how it could be extended to the foreign hospitals and the benefits which they shall accrue. This global cancer network would share best practices of the NCG and will work towards eliminating disparities in cancer care worldwide by creating uniform standards of patient care, developing human resource for cancer prevention and management globally and collaborate multicentric cancer research. Countries like Sri Lanka, Bangladesh, Russia, Kazakhstan, Vietnam, Nepal, United Arab Emirates, Afghanistan, Jamaica, Myanmar and Zambia agreed to have their premier hospitals to be part of NCG-Vishwam.

The demand for the popular TMC-Navya second opinion cancer services grew, and, their services were availed of from 68 countries and they guided over 38,000 cancer patients.

Industrial Applications of Radioisotopes & Radiation

BRIT supplied nine Co-60 teletherapy sources (CTS) of activity within the range of 151 and 206 RMM to different cancer hospitals in India and abroad during 2019-20. Co-60 teletherapy source of 206 RMM was exported to Joseph Ravoahangy Andiavavalona Hospital, Madagaskar, South Africa, through Panacea Medical Technologies Pvt. Ltd., Bengaluru. Fifty three W-91 Irradiator sources of industrial grade & 83 BC-188 Irradiator sources with 2109 kCi activity in 13 consignments were supplied to 11 radiation processing plants within the country during the year 2019-20. Supply of Irradiator sources with total strength of 650 kCi for four radiation processing plants is planned upto March 31, 2020.

A total of 693 consignments (with total activity of 26,896 Ci) of ^{192}Ir & ^{60}Co Radiography sources were supplied to NDT user’s during the year 2019-20. About 17 nos. of Co-60 Custom Made Reference (CMR) sources in 427 consignments with total activity of 1.47 Ci were supplied to various users. Another 5 nos. of CMR sources with 250 mCi is planned to be supplied soon.

Four absorber rods from NAPS (Narora Atomic Power Station) Utter Pradesh and 02 absorber rods from KAPS (Kakrapar Atomic Power Station), Gujarat, were successfully transported to RAPPCOF. It is planned to transfer six Adjusters rods from RAPS-6.

During the Year 2019-20, more than 13000 TFS sources of various sizes, shapes were supplied by BRIT to defence establishments and used for illumination of various types of gadgets and instruments.

At BARC, a prototype tomography scanner based on gamma ray beam generator and discrete nucleonic scintillation detectors and associated data acquisition system was developed for low-resolution cross-sectional imaging of columnar structures for Non-Destructive Evaluation (NDE). Laboratory experimental data was found satisfactory confirming to the prescribed design criteria for NDE under certain special conditions. A process for large scale production of super-absorbent cotton using gamma and electron beam radiation was developed. The super cotton was found to selectively absorb organic compounds from different kinds of organic-water mixtures such as water-crude oil, water-kerosene, water-benzene, water-xylene, water-toluene, etc. A patent was filed on the process and the technology was transferred to M/s Welknit Fab LLP, Surat, Gujarat for large-scale production of the super-absorbent cotton.

Radiation Processing

Gamma Radiation Processing Plant at ISOMED, BRIT is being revamped and is under renovation during 2019-20. Radiation Processing Plant extended their services to irradiate about 4340 MT of spices, pet feed, ayurvedic & healthcare products were processed during the reported time period. Radiation Processing Plant Facility at Vashi was certified for ISO 22000:2005 (Food Safety Management Systems). Surveillance audits for ISO 9001:2015 (Quality Management System) were also carried out by the certifying agency and found in full compliance with standard's requirement.

Plant commissioning dosimetry for M/s Avantee Megafood Park, was completed during the reported period. Plant re-commissioning dosimetry was carried out in eight Gamma Radiation Processing Plants in India for low, medium and high dose applications. Dose rate certification was provided to four blood irradiators and two gamma chambers which were supplied to various cancer hospitals and research universities respectively. Production & supply of ~1.9 Lakhs Ceric-Cerous Sulphate Dosimeters were done for various gamma irradiators in the country for the measurement of absorbed dose. About 1500 nos. of Ceric-Cerous Sulphate Dosimeters were exported to Atomic Energy Regulatory Board, Sri Lanka.

BRIT signed three MoU's for setting up Gamma Radiation Processing Plants (GRPF) at various places within the country for disinfestations, shelf-life extension of food products and sterilization applications of healthcare products during the reported year 2019-20. Gamma Radiation Processing Plant of M/s Avantee Mega Food Park Pvt. Ltd., Indore, M.P., was commissioned.

BARC and Ahmedabad Municipal Corporation have jointly setup a pilot project "Sewage Sludge Hygienisation Plant" at Shahwadi, Ahmedabad. The plant was inaugurated in March 2019. About 350 tons of sludge was hygienized.

Radiation Technology based Equipment & Services

BRIT supplied about 37 numbers of Radiography Cameras, ROLI-2 model, to various NDT users within India and services were provided for 588 numbers of BRIT and imported radiography cameras. Four Blood Irradiators – 2000 (BI-2000) units with 8972 Ci of Cs-137 source in 24 pencils were supplied to hospitals in India during the year. Two Gamma Chamber–5000 units with 27,866 Ci of Co-60 in 12 nos. of source pencils have been supplied in India, and another one was exported to Vietnam for research purposes during 2019-20. The GC-5000 unit was installed and commissioned at Dong Nai Irradiation Centre, Dong Nai Province, Vietnam and training was imparted to the users in terms of its operation and maintenance aspects. 127 nos. of decayed sources were unloaded from various types of units and stored for disposal.

Water Purification, Water Desalination & Isotope Hydrology

At BARC, a 600 litre/hour Advanced Effluent Water Treatment Plant (AEWTP) was piloted to demonstrate the feasibility of a process for treatment of industrial effluent water to cater to irrigation needs.

Work is in progress on integrating reverse osmosis system and others in the pilot plant.

A pilot scale Advanced Effluent Water Treatment Plant (AEWTP)

A 1000 litres/hour Reverse Osmosis (RO) based drinking water facility was commissioned at Somthana Village in Maharashtra's Nanded district in November, 2019. The facility would effectively treat beyond permissible levels of nitrate (140-150 ppm) and high salinity (1200-1400 ppm) in ground water to supply clean and safe drinking water of Indian Standard 10500 quality to the village of 2500 households. The facility was implemented as part of DAE sanctioned project 'Deployment of Water Purification Technologies in 50 Villages in India'.

Isotope hydrological investigations were carried out to identify water recharge sources and deep aquifers in the semi arid Patan district of Gujarat. Isotope hydrology of geothermal areas of Odisha and Himachal Pradesh were also carried out.

BASIC & APPLIED RESEARCH

Basic and applied researches relevant to DAE's programme are carried out in the research centres of the department. The autonomous research institutes supported by the grant-in- aid applied sciences. Following were the notable developments in the fields of basic and applied research carried out during the report period, by these research institutes.

Mathematics & Computational Sciences

The celebrated conjecture of Parthasarathy-Ranga Rao-Varadarajan from the 1960s and its extensions by Kostant, Verma, Kumar and Montagard were the subject of recent research by members of the mathematics group at IMSc.

At TIFR, work was carried out on several questions and problems in Algebra, Analysis, Lie Groups, Number Theory, Algebraic and Differential Geometry and Combinatorics. At the TIFR Centre for Applicable Mathematics, Bengaluru, researchers studied the structure of solutions for the Balance Laws in one space dimension with a source term. In Numerical Methods for Differential Equations, a new adaptive order scheme blending quartic, cubic and quadratic polynomials was developed. These techniques were applied to solve compressible flow problems where their superior performance was shown. Some of the research works that were pursued in the areas of computer science as well as systems science includes the design of a new state-of-the-art deterministic algorithm for the combinatorial problem of approximately counting proper colourings of graphs.

At HRI, Prof. Manoj Yadav and his collaborators used their work in group theory to enumerate skew left braces of small orders, which in turn provided them a number of set theoretic solutions of the quantum Yang-Baxter equation, arising in Physics. Prof. Umesh Dubey and his collaborators have obtained a number of results on moduli spaces as a part of their programme of resolving questions of V. Balaji and C. S. Seshadri related to functorial construction of moduli of parabolic bundles.

Physics

Installation of the MACE telescope with 356 mirror panels and 68 CIMs has been completed by BARC. Engineering trials are currently underway. A portable Digital Holography Microscope based on miniaturized laser interferometer coupled to a pathological microscope and a smartphone camera has been developed for 3D imaging of biological cells. The system will be deployed at BARC-Vizag for 2D & 3D imaging purposes. Small Angle Neutron Scattering (SANS) facility at Dhruva reactor has been upgraded

with multi Position Sensitive Detectors (PSDs) based on ^{3}He to improve the length scale and measuring time. A 3.65T, 100ms pulsed electromagnet was developed for 95GHz Gyrotron system.

At VECC, the effect of liquid drop model parameters on nuclear liquid gas phase transition within the ambit of canonical thermodynamical model and the formation of fission fragments in case of spontaneous fission using microscopic nuclear energy density functional theory have been studied. Various aspects of strong interactions in the presence of intense magnetic fields have been extensively investigated. Formulations for the thermal field theory of Tsallis statistics have been developed. New high precision study on the decay width of the Hoyle state in 12C, Giant Dipole Resonance for deformed odd-odd nucleus and Structure 197Tl using Gamma ray Spectroscopy have been investigated. Fabrication of detectors for the neutron time-of-flight array has been completed and several experiments have been performed using beams from cyclotron.

Indigenously developed neutron detector array at VECC

TIFR Balloon Facility, Hyderabad extended its support to launch various types of balloons with different types of aerosol payloads to NASA-Langley Research Centre (USA), ISRO-National Atmospheric Research Laboratory (Gadanki) and French National Center for Scientific Research (CNRS) during the 2019 monsoon season (July 2019). This was the fifth successful balloon campaign conducted from the TIFR Balloon Facility to study the Asian Tropopause Aerosol Layer (ATAL) over Indian (Hyderabad) region using various balloon-borne aerosol instruments. At the National Centre for Radio Astrophysics, Pune**,** **t**he Giant Metrewave Radio Telescope (GMRT) completed a major upgrade that had been ongoing for the past six years, and the upgraded facility was released to the world-wide user community from the GMRT observing cycle starting April 2019. In Theoretical Physics at TIFR, new, previously unknown, shapes of CMB spectral distortions were discovered. It was shown that the amplitude of the spectral distortions is sensitive to the energy injection mechanism.\

At the Institute of Physics (IOP) research were continued in the areas of physics, namely, theoretical high energy physics, theoretical condensed matter physics, theoretical nuclear physics, experimental condensed matter physics, experimental high energy physics, and quantum information.

In Condensed Matter Physics at HRI, works on three aspects: topological materials, strongly correlated systems and materials for applications were continued. The astrophysics group at HRI continued to work in the field of astrophysics, general relativity and gravitation, and dynamical systems phenomena. At HRI several contributions of significance have come from High Energy Phenomenology in the context of beyond standard model physics search at present and future accelerator experiments, dark matter experiments as well as Astrophysics experiments such as the Square Kilometre Array (SKA1).

Facility for Research in Nuclear Astrophysics (FRENA), a national facility at SINP is built around a high current 3MV Tandetron Accelerator. The machine is equipped with three ions sources that can deliver Hydrogen (H), Helium (3,4He) and other heavy ions, respectively. The machine can also deliver pulsed H- and He-beams. The terminal voltage can be varied from 200 kV to 3 MV with a resolution of 10^{-5}. Nitrogen gas is used as stripper for anion to cation exchange at the terminal. The machine is now being prepared

for commissioning. Optimization of muon telescope design parameters through numerical simulation based on Geant4 and CRY was continued at SINP. The area of application has been identified to be discrimination among materials among different Z values. Once validated, such a telescope can be used to carry out non-destructive testing of any static large structures, such as buildings, bridges, monuments of archaeological interest etc. The Underground Science Laboratory is operational at 555m of UCIL, Jaduguda mines. The laboratory has been continuously working round the clock and scientists and students from SINP and BARC have been visiting the facility on regular basis. The nuclear physics group members of SINP have been successfully continuing their activities in Accelerator-based Nuclear Physics (In-Beam gamma spectroscopy and Reaction studies) using National and International Accelerator Facilities as well as in their in-house laboratories.

The School of Physical Sciences, NISER Bhubaneswar has discovered the superconductivity in Silver-ion implanted in Au film. This work was performed with a team of scientists from NISER, IOP and Institute of Minerals and Materials Technology (IMMT), Bhubaneswar. The team has observed superconductivity below 2K.

Synchrotrons and their Applications

Synchrotron Radiation Sources Indus-1 and Indus-2 are being operated as national facility. Indus-1 is operated at 450 MeV energy, 125 mA current, and Indus-2 is operated at stored current up to 200 mA at 2.5 GeV energy. During the period between April 2019 and March 2020 both the machines operated round-the-clock for 323 days. The operational performance of Indus machines has significantly improved as compared to previous years because of the improvement in beam life time. As a major upgradation, a vertical pinger magnet has been installed in Indus-2. This will help in carrying out advanced beam dynamics studies in the machine. Installation of IOT-based RF amplifier is in progress and will be commissioned with beam operation in Indus-2 in Jan 2020. The number of user experiments at Indus beamlines has also increased further as compared with previous years.

For the Upgradation of Indus-2 and other developments many activities have taken place at RRCAT these includes Design, installation, testing and commissioning of an Inductive Output Tube (IOT) based high efficiency RF p; ower system; Development of power supply to energise vertical pinger magnet; Development, installation and commissioning of power converters for quadruple magnets in Indus-2; Design and development of ultra-high vacuum compatible twin beam position indicators for Indus-2; Installation and

IOT amplifier as set-up in Indus-2

Magnet ready for magnetic measurement

commissioning of new precision cooling station for the fifth and sixth RF cavities of Indus-2; Development of processing electronics for single pass digital beam position monitor for IRFEL; Development of software for performance enhancement of booster synchrotron in Indus; Development of energy ramping verification system for indus-2 synchrotron radiation source at RRCAT; Enhancement of Indus-2 Timing Control system for pinger magnet control; Design, development and characterization of 270º achromatic dipole magnet for linac-3; Low momentum compaction mode of operation for reducing electron bunch-length in Indus-2; Development of process of Titanium coating on ceramics for storage ring application; Development of high-stability (±10 ppm) power converter for electromagnets; Design and development of a high stability, ultra-low ripple HV dc power supply for scanning electron microscope; Development of power converters for FAIR, Germany and Commissioning and operation of electron accelerator based radiation processing facility at Indore.

Cyclotrons & their utilisations

N2+ beam has been extracted through the deflectors up to the magnetic channel #3 and now the beam has been extracted out of the machine and measured (around 2nA) on the Faraday cup (FC#01) in the external beam line of the K500 Superconducting Cyclotron. Further optimization is in progress.

A High Temperature Superconductor (HTS) based cryocooler assisted steering magnet operating at 20 K temperature has been developed at VECC for the extraction beam line of K500 cyclotron for beam steering of ± 3 degree in horizontal plane and ± 1.5 degree of vertical in vertical plane for maximum rigidity of 3.3 T-m.

The room temperature cyclotron (RTC) has been operating in round the clock shift basis and delivering ion beams to various experimental research programs. The facility has been utilised by the experimentalists of VECC, SINP, Materials Division/BARC, ACD/BARC/VECC, RPD/BARC, RCD/BARC, HPU/BARC/VECC, etc. with beam availability of 3140 hours till December 15, 2019.

Fusion and Other Plasma Technologies

Experiments done on the Aditya-Upgrade Tokamak related to disruption mitigation using electromagnetic pellet injection have yielded encouraging results, with rapid decrease of plasma temperature and density. In the Steady-State Superconducting Tokamak (SST-1), the experimental campaign has been extended to a record 15 days, with plasma pulse durations upto 650 milliseconds, 30% higher than the best achieved ever before, and better reproducibility of plasma parameters.

An indigenously-developed prototype Helicon plasma thruster system has been operated at 10 milliNewton thrust, with an input RF power level of 1500 W. A water-repellent Super-hydrophobic PTFE Surface has been produced by low energy ion beam irradiation. Such surfaces have can be used for several applications, such as self-cleaning, anti-scratch, anti-icing, anti-corrosion and fog harvesting. Collaborations are underway with several institutions to explore the use of plasma-jets for cancer treatment, based on in-vitro as well as in-vivo studies. Development of multilayer (TiN, TiAlN) coatings on zirconium alloy tubes which are used in nuclear power reactors are being explored to reduce waterside corrosion by the coolant water.

Chemistry

At BARC, Metal Organic Framework materials, capable of adsorbing inert gases Xe and Kr released during fuel reprocessing, were developed. Studies on Iodine chemistry relevant in a nuclear accident scenario were undertaken. A Spectrophotometric method to detect ammonia in 10-500 ppb range was developed for use in Nuclear Power Plants. The causes for the foam formation in the discharge region of the Kudankulam Power plant were identified and remedies suggested. A pilot scale photo-bioreactor was established in Kalpakkam for waste water treatment and carbon dioxide sequestration. Research was also undertaken to determine physico-chemical characteristics of salt mixtures relevant for futuristic Molten Salt Breeder Reactors. An irradiation facility has

been established to understand the mechanism of formation of organic iodides from iodine released during a nuclear accident.

At TIFR, the researchers have developed an improved computational description to provide a complete analysis of UV-vis photoexcitations in the new band for Lysine-Glutamate dimers.

At SINP, the scientists have come up with a new mechanism of ozone depletion by taking into consideration of degradation of sulphuric acid.

Biology

Boron Neutron Capture Therapy (BNCT) is an efficient technique to treat radiation resistant melanoma cancer cells. Gemcetabine (2,2-difluoro-2-deoxycytidine) is a known anti-cancer drug which has been successfully used for different types of cancer. At BARC, fluorescent labelled gemcetabine hydrochloride (which can act both as protecting agent against deamination as well as a bio-imaging agent) was made into sugar borate ester enriched with B-10 isotope to 90%, which can be used for the treatment of melanoma.

Synthesis of the Copper tetraMIBItetrafluroborate $[Cu(MIBI)_4].BF_4$ was to the tune of few milligrams per batch, due to high volatility and poor isolation yield, after a prolonged research, BARC has scaled it up to 4 g/batch. This is an important import substitute and was handed over to BRIT.

The researchers at TIFR showed that the neurotransmitter serotonin enhances the production and functions of neuronal mitochondria, the powerhouse of the cell, and protect against stress. This study identified a previously unknown role for serotonin in regulating neuronal energetics.

At SINP, newer initiatives have been taken up in the activities of the Biophysical Sciences group in the areas of synthetic biology, membrane proteins, epigenetic implications in cancer and trafficking of proteins inside cell.

Materials Science

In order to develop reactor core catcher materials to manage molten corium formed under severe reactor accident, model bricks made of red-mud in different sizes were made by BARC using appropriate additives and stepwise heating procedures. The bricks melt at around 1600 °C and do not ablate upto 1800 °C.

The main activities carried out in the field of Materials Science at RRCAT were Development and application of single crystalline Distributed Bragg Reflector mirror with reflectivity exceeding 99% for 1064nm and 1550nm; Development of polycapillary optics based focusing facility at XRF microprobe beamline (BL-16) Indus-2; Accelerated testing of Dixon ring-based catalyst for establishing long-term stability required for combined electrolysis & catalytic exchange(CECE) application; Setting up of an IR-THz frequency domain spectrometer for FEL utilization; Development of laser surface treatment for rejuvenation of inside surface of inter-granular corrosion (IGC) damaged type 304 stainless steel tube and Imprint of temporal envelope of ultra-short laser pulses on momentum spectrum of e^+ - e^- pairs.

IR-THz frequency domain spectrometer set up for the utilization of FEL radiation

At IGCAR, in the materials front, towards indigenous development of materials for FBR and Fusion Reactor, uniaxial creep testing facilities were augmented for developing the creep design data. A new 500 W power Nd-YAG Laser system capable of cutting through up to 15 mm thick stainless-steel tube, has been successfully interfaced with hot-cell for remote operations.

Research on Materials Science at VECC included microstructural evolution of proton irradiated Fe-

2.25Cr-1Mo characterized using synchrotron XRD (SXRD). Synchrotron GIXRD and slow positron beam characterization of Ar ion irradiated pure V and V-4Cr-4Ti alloy and characterization of ion induced damage as a function of depth in proton irradiated pure Ti and Ti-6Al-4V.

Cancer Research

G1-4A, an arabinogalactan polysaccharide was isolated from the plant Tinospora cordifolia. G1-4A treatment increased phenotypic and functional activation of splenic and bone marrow Natural Killer (NK) cellsG1-4A treatment activates NK cells directly as well as through NK-DC crosstalk and can be used as an immunomodulator in tumour bearing mice.

INTERNATIONAL RESEARCH COLLABORATIONS

The TIFR scientists participated in all aspects of the CMS experiment: data collection, monitoring, analysis, detector hardware construction and grid computing. The TIFR grid computing facility has played a major role in processing both collision and Monte Carlo data sets.

Two large size mini muon chamber modules (mMUCH), based on gas electron multiplier (GEM) technology having about 2000 readout channels, were fabricated at VECC and commissioned in the mini Compact Baryonic Matter (mCBM) experiment at GSI as part of FAIR phase 0 program. One 30 cm X 30 cm Bakelite based resistive plate chamber (RPC) module having resistivity 3.9X1010 ohm-cm has been tested at lower gain at VECC using free streaming DAQ for the same experiment. Radiation hard Low voltage power supply (LVPS) has been upgraded to 15 output channels each having dedicated DC-DC converter with over current sense and trip circuitry. Detailed simulation has been performed to finalize the realistic design of the first absorber of muon detector system in CBM experiment. Two parallel test-benches for common readout unit (CRU), a key component of ALICE- DAQ upgrade, has been set up at VECC. A prototype for muon tomography (MT) system using Bakelite based RPC is being developed. Six small size (30 cm X 30 cm) RPC detectors have been developed at VECC.

High Energy Nuclear and Particle Physics group of SINP is linked with the ALICE and CMS collaborative work at the Large Hadron Collider (LHC) of CERN. The group has built indigenously Second Muon Tracking Station of ALICE and is responsible for its maintenance and upgrade. The readout upgrade of High Granularity Calorimeter (HGCAL) of CMS detector has also been carried out by the group.

ITER-Project

As part of India's in-kind contribution to the ITER project, the sub-assembly of the Cryostat Base Section, weighing 1250 tons, was successfully completed and handed over to ITER Organization. This involved fabrication meeting strict tolerances, a first at this scale and magnitude. A handover ceremony was held on 23 July 2019, where India was represented by Dr. Anil Kakodkar and the Indian ambassador in France. The SPIDER test facility in Padua, Italy, produced the first SPIDER hydrogen beam using a 96 kV, 75 A Acceleration Grid Power Supply which was developed in the country and supplied as in-kind contribution to ITER.

RESEARCH EDUCATION LINKAGES

The Department of Atomic Energy supports the research education linkages mainly through grants-in-aid to institutes of national eminence, funding of extra-mural research, DAE-UGC consortium for scientific research and others.

Indus -1 and Indus-2 are national facilities with 14 beamlines in Indus-2 and 6 beamlines in Indus-1, which are available to users. Users from different universities, national labs and institutes are regularly engaging these Indus beamlines for experiments. About 930 user experiments were carried out in the calendar year 2019 leading to more than 175 research publications in peer reviewed international journals. Along with the above utilisation, there has been a continuous effort in improving the facilities at the

beamlines and other related aspects. These beamlines have been used for several work related to materials science, chemistry, health and medicines. A set of experiments have also been performed by scientists from ministry of AYUSH, Govt. of India on a few Ayurvedic medicines. There has been in increase in the number of users from industries, who have used the X-ray diffraction. X-ray absorption and small angle x-ray scattering beamlines for their product and process development. The engineering applications beamline BL-02 has been commissioned in Indus-2. The beamline has been recently used for the determination of strain at the SS-Zircaloy cold welded joints (samples from BARC).

Research reactor Dhruva continued to serve as a national facility for neutron beam research. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a Deemed to be University, is a grant-in-aid institute of the Department of Atomic Energy (DAE). It has completed a successful 14 years. During this period, it has established itself as one of the best research universities in the country, encouraging research in various facets of nuclear science and technology including mathematics. In the recently published result of 2019 Nature Index database, HBNI was placed at 16th position among Young Universities (less than 50 years old) in respect of publications in all science disciplines, whereas with respect to physical sciences, HBNI was placed at the tenth position, on a global level. Till December 2019, HBNI has awarded 1549 PhD degrees in a variety of disciplines. The total enrolment in the academic programs of HBNI in the academic year 2019-2020 is 879, which includes 320 for PhD,78 for MD, 27 for DM and 34 for MCh programme.

Training

BARC Training School and Homi Bhabha National Institute (HBNI) ensure continuous availability of professionally qualified scientific and technical manpower for induction into various units of DAE to fulfill its mandate to enhance the share of nuclear power in the country and to contribute to national security. A total of 74 graduating BARC Training School Officers (53 engineering, 3 Physics, 4 Chemistry, 5 Biosciences and 9 RSE) after successful completion of the training were placed in various units of DAE. As part of knowledge sharing, BARC will offer training programs for chemists of Central Ground Water Board (CGWB) for determination of ultra trace levels of uranium in groundwater.

Human Resources Development activities at RRCAT revolved around imparting training to Ph.D. Scholars and M.Tech. students from various Indian institutes. The stipendiary programme for CAT-I and CAT-II was conducted for the Scientific Assistants and Technicians. RRCAT has initiated "Trade Apprenticeship Scheme at RRCAT" abbreviated as TASAR from 15th October, 2018 to impart practical training to, ITI trained boys and girls to expose them to modern technologies and improve their proficiency, skill and employability. Thirty apprentices have been trained in first batch and 85 are being trained in current batches.

A draftsman apprentice making drawing

BARC Training School at IGCAR has successfully completed its 13th year, and twenty three young trained scientists and engineers graduated in a special ceremony that took place on July 29, 2019. The Trainee Scientific Officers have been placed in various units of DAE.

BARC Training School AMD Campus, Hyderabad continued its activity wherein 17 Trainee Scientific Officers (TSO) of the 9th batch (OCES-2018) completed orientation training on 31-07-2019. Twelve TSO's of the 10th batch (OCES-2019) are undergoing induction training.

NPCIL has strong and dedicated workforce of 11134 employees as on 30.11.2019 consisting of Engineers, Technicians and Supervisors, Non-Technical Executives, Staff and Auxiliary support staff who spearhead the activities of the organization. During the year 2019, 192 young talents were recruited in Group A, B & C and 17 young talents were recruited under Persons with Benchmark Disabilities Category. NPCIL's HR initiatives are directed towards fulfilling the NPCIL's mission and vision by attracting, motivating and retaining the right talent and intellect. While developing the strategic and incremental packages for employees, the individual goals and aspirations are encouraged by way of training, culminating in achievement of goals of NPCIL.

Administrative Training Institute (ATI) with the motto of "Prashikshaneshu Dakshaprayate – Training Empowers" continued to offer wide range of programmes starting from induction to post retirement and periodic in-service programmes and subject specific workshops ensuring depth and range. Some of the major highlights of the ATI training programmes included a programme on GeM for Head of Divisions of BARC, Four programmes on Retirement Benefits and Life Management post retirement; One programme on Heart of Effective Leadership and three programmes on Effective Living & Leadership at Initiatives of Change, Panchgani. All the programmes were well received. Under the Management Development Programme, a one week programme for Group-A & B Officers is planned to be conducted at Jamnalal Bajaj Institute of Management Studies, Mumbai.

SPONSORED RESEARCH

Promotion of Extra-mural Research in Nuclear Science

Board of Research in Nuclear Sciences (BRNS) continued to provide the funding for the national research institutes and universities for various research projects and scientific events which are relevant to DAE programmes. Proposals for research projects were invited, scrutinized by expert committees and selected through a critical review process for financial and technical support. Over the years, sponsoring such projects has not only promoted research activities in various academic and research institutes in the country but also provided important scientific inputs to the DAE programmes. During the calendar year, 74 new research projects with corresponding total grants amounting to ₹ 2044 Lakhs were sanctioned. Most of the projects have implementation periods of 2 to 3 years, during which the grant is utilised. The total grant of ₹ 3816 Lakhs has been released during this year for pursuing new and on-going research projects, supporting scientific events /workshops and financing the Olympiad Programme of training the Indian students contingent by Homi Bhabha Centre for Science Education (HBCSE). BRNS also provided financial assistance for organising symposia/ conferences/ workshops on topics relevant to the programmes of DAE. Financial support to the tune of ₹189 Lakhs was extended for conducting 89 scientific events. Out of these, sixteen fully funded symposia were organised by the DAE fraternity. BRNS has also been providing financial support to educational activities of Homi Bhabha National Institute. Funding from BRNS also supports Dr. K. S. Krishnan Research Associateship and the DAE Doctoral Fellowship Scheme (DDFS) Programme. During the current year, 21 new students were inducted under DDFS Programme, bringing the total number of Ph.D. students enrolled under this scheme to 173. A total of 66 DDFS students have completed their Ph.D., since the inception of this scheme. Out of these, 11 students have been awarded Ph.D degree by HBNI this year. The International Science Olympiad Programme is fully funded by the Government of India through the Board of Research in Nuclear Science, Department of Atomic Energy (BRNS, DAE), Department of Science and Technology (DST), Ministry of Human Resource Development (MHRD) and the Indian Space Research Organisation, Department of Space (ISRO, DoS). Relatively higher scale grants are provided by BRNS by entering into MoUs with Research Institutes and Universities.

Promotion of Mathematics

The National Board of Higher Mathematics (NBHM) was set up by the Government of India under the Department of Atomic Energy (DAE), in the year 1983, to foster the development of higher mathematics in the country, to formulate policies for the development of mathematics, help in the establishment and development of mathematical centres and give financial assistance to research projects and to doctoral and postdoctoral scholars. Major activities of NBHM involved Financial Support to Mathematical Institutions; Travel Grant/Conference Support/Research Project Grant; Mathematical Olympiad/Madhava Mathematics Competition (MMC); Mathematical Training and Talent Search Programme (MTTS); Undergraduate/Postgraduate/PhD Scholarships, PD(F) Fellowship; Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes.

In 2019, a total of 3023 candidates had applied for the Postgraduate Scholarship for M.A/M.Sc outh of which 1912 had appeared in the examinations, and 40 of them were benefitted from NBHM M.Sc. Scholarship. During the year 2019, 36 candidates were awarded NBHM Post Doctoral Fellowships.

NBHM continued to provide Institutional Support to Chennai Mathematical Institute, Chennai; Kerala School of Mathematics, Kozhikode; National Centre for Mathematics, Mumbai; Bhaskaracharya Pratishthana, Pune and Institute of Mathematics and Application, Bhubaneswar.

GRANTS-IN-AID

Grants to Aided Institutions

The aided institutions of the DAE are an integral part of the Department in as much as there is a growing synergy between these institutions and the Research and Development Units of the Department. Several joint projects have been undertaken between the Units and Aided Institutions and there is frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. The Department has eleven aided institutions fully funded in terms of their recurring and non-recurring expenditure and these institutions are growing at a faster pace in terms of the projects undertaken by them.

Grants to Cancer Hospitals

The Department extends financial assistance to Cancer hospitals located in other parts of the country. The grant released for the year 2019-20 for such partial financial assistance is to the tune of ₹10 crores.

Olympiad Programme

The major highlight during this period was India's continued success at the International Olympiads. 24 Indian students at the International Olympiads (held during July–August 2019) returned with medals.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The Computer Division of IGCAR has developed an in-house E-Procurement Software to make the entire procurement workflow online with the implementation of digital signature. The software is meant for use by DAE units, Purchase Units and Stores. The software has been deployed in Anunet and is being effectively used by IGCAR, GSO and DPS/MRPU. Various network services such as Email, Internet, DNS are provided to users of IGCAR on round the clock basis.

The various IT infrastructure development activities taken place at RRCAT includes Design, development and deployment of scientific computing resources; Commissioning of secure ARPFNet for ARPF site; Design, development and deployment of centralized file sharing facility e-साझा; Design, development and deployment of various Information Management Systems; Revamping of telephone exchange of RRCAT colony area and Upgradation of network security monitoring infrastructure.

A new High Performance Computing (HPC) facility named "Antya" has been commissioned at IPR and is operational on 24x7 basis. This has a theoretical peak performance of 1 Petaflop and sustained performance 0.65 Petaflop.

TECHNOLOGY TRANSFER

The spin-off technologies evolved out of the core Research and Development programmes of DAE were packaged and transferred to industries for commercial exploitation. Over a period of time, a number of technologies have been transferred to industries. During the year, 33 technologies were transferred to 44 parties, 24 new technologies were introduced in public domain. Bio-based technologies such as composting, microfine neem bio pesticides, Trichoderma mass multiplication medium, Bt biopesticide, Nisargruna and anti-cancer drug camptothecin production have been transferred to different private companies.

COLLABORATIVE PROGRAMMES

BARC signed a Memorandum of Understanding with the Indian Oil Corporation Ltd (IOCL) for development of Magnetic Flux Leakage – Ultrasonic combo (MFL-UT) Instrumented Pipeline Inspection Gauge (IPIG) for 18 inch pipeline and MFL IPIG with built-in speed control mechanism for 30 inch gas pipelines for its 40,000 km underground pipeline network for transportation of crude oil, natural gas and petroleum products.

SOCIETAL INITIATIVES

DAE Technology Display & Dissemination Facility (DTDDF) centres at Manipur Science and Technology Council became functional during the year and a DAE outreach centre at Utkal University was established in Bhubaneshwar. Total 12 agreements were signed with 5 educational institutes, private firms, individuals and a woman entrepreneur under the Advanced Knowledge & RUral Technology Implementation programme AKRUTI to promote rural entrepreneurship.

INTELLECTUAL PROPERTY RIGHTS

DAE-IPR Cell constituted by the Department, works as a nodal agency for all Intellectual Property Rights (IPR) related matters including filing of patents within India and abroad for all the Units including Public Sector Undertakings and Autonomous Institutions under DAE. During the financial year 2019-20, four DAE-IPR cell meetings were held, which reviewed fifteen new patent proposals. DAE filed ten new patent applications which includes; six in India, two in USA and one in Europe. One application was filed under the Patent Co-operation Treaty (PCT). During this period, seven of the previously filed patents were granted to the Department. These includes; four in USA, two each in Europe and one in India.

PUBLIC SECTOR UNDERTAKINGS

(Financial Performance)

Financial performance of DAE's public sector undertakings namely, the Nuclear Power Corporation of India Ltd., Uranium Corporation of India Ltd., Indian Rare Earth Ltd. and Electronics Corporation of India Ltd. are given below. (BHAVINI is yet to commence commercial operations).

NUCLEAR POWER CORPORATION OF INDIA LTD.

The provisional profit (Total Comprehensive Income) up to December 31, 2019 in the current Financial Year 2019-20 is ₹ 3650 Cr. and the expected profit for the year is around ₹4000 Cr. The profit (Total Comprehensive Income) for the last Financial Year 2018-19 was ₹ 2779 Cr.

URANIUM CORPORATION OF INDIA LTD.

The total income of the Company during the year 2018-19 was ₹ 2034.79 Cr as against ₹ 1793.98 Cr in the previous year. In terms of performance of the Company for the year 2018-19, UCIL is provisionally rated as "Excellent" by Department of Public Enterprises (DPE) as per Memorandum of Understanding (MoU) signed by the Company with

Department of Atomic Energy. For the first time UCIL has achieved "Excellent" MoU rating for second year in a row.

INDIAN RARE EARTHS LTD.

During the period upto December 2019, the company registered growth of Sales Turnover by 33% as compared to corresponding period of previous year. Profit Before Tax (PBT) for the period upto December, 2019 is increased by 79% as compared to corresponding previous year.

ELECTRONICS CORPORATION OF INDIA LTD.

The Company achieved a landmark turnover of [1] 2663 crores in FY 2018-19 because of its time bound supply of Electronic Voting Machines (EVMs), Voter Verifiable Paper Audit Trail (VVPATs) for General Elections 2019. The Company successfully manufactured 3.3 lakhs of latest model (M3 version) EVMs and 5.8 lakhs of VVPATs at the newly established Secure Manufacturing Facility (SMF) and supplied them for 2019 Loks Sabha Elections. ECIL also provided extensive support to Election Commission of India (ECI) for smooth conduct of Elections.

OTHER ACTIVITIES

INTERNATIONAL RELATIONS

India, a founding member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA), continued to take active part in policy management and programmes of the IAEA. India was represented on a number of IAEA Committees, including those on safety, safeguards, nuclear radiation, nuclear engineering and application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings etc., and offered the services of its experts under the IAEA Technical Cooperation programme in a number of fields. India made contributions towards Innovative Nuclear Reactors and Fuel Cycles (INPRO), Technical Cooperation Fund (TCF) and Regular Budget of the IAEA.

In addition to participation in the Annual General Conference of the IAEA in September 2019, India is actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combat Nuclear Terrorism, and India's own Global Centre for Nuclear Energy Partnership (GCNEP). Secretary, DAE led the Indian delegation comprising of Director, BARC, Chairman, AERB and Joint Secretary (ER) to the IAEA 63rd General Conference which was held at Vienna, Austria from 16-20 September 2019. Chairman, AEC had a number of bilateral meetings on the sidelines of the conference.

The Global Centre for Nuclear Energy Partnership (GCNEP) conducted multiple International & National programs on various topical issues. GCNEP Phase-II construction works of three new packages has been started. Augmentation of Lab and Infrastructure facilities was carried out.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and is actively participating in their programs for enhancing the safety and reliability of its nuclear power plants. NPCIL is one of the founding members of WANO. Almost all nuclear power plants operating or under construction in the world are its members. NPCIL representatives are in the governing board of WANO Tokyo Centre and WANO Moscow Centre. During the year, WANO Restart Review of KAPS-1, WANO Pre-Start Up Review of KAPP-3 and WANO Peer Reviews of RAPS-2 and RAPS-3&4 were conducted. These reviews provided the opportunity to benchmark our plants against the best international standards and practices. NPCIL continued to submit Performance Indicator data and WANO Event Reports (WERs) to WANO for IAEA safeguarded reactors. NPCIL participated in some of the COG meetings held thru' audio conferences to discuss the issues of mutual cooperation. NPCIL participated in the information exchange programme of COG and had access to its website which contains large database of useful operating experience information related to PHWR plants. NPCIL continued to provide information for IAEA PRIS database.

SCIENCE RESEARCH COUNCIL

DAE-Science Research Council that comprises eminent scientists, continued with the peer reviews of basic research to ensure that highest possible level of excellence is maintained.

BARC-SAFETY COUNCIL

BARC-Safety Council continued its regulatory function to ensure the safety of all the plants and facilities under its purview.

To comply with the requirement of licensing/ authorization for operation of the variety of radiation installations in BARC, the BARC- Safety Council Secretariat had earlier prepared Regulatory Guidelines, which specify the requirements to be fulfilled for reauthorization of existing old facilities of BARC. It also addresses the requirements for new radiation installations in BARC.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), which is the standing Committee of senior officials of the Department of Atomic Energy (DAE), carries out the function of overseeing the Department's emergency preparedness for responding to any radiation emergency in the public domain and coordinating response actions with state or national level public officials / agencies. Testing of the formal emergency response systems on a regular basis was ensured during the year with an objective to check its efficacy. Also, CMG continued to function as the contact point of DAE to provide its expertise in the field of nuclear / radiological emergency management at various National and International fora. During the year 2019-20, India participated in five numbers of International Convention Exercises, known as "ConvEx", conducted by IAEA, which are designed to test various aspects of the International Emergency Preparedness and Response (EPR) framework. As the Competent Authority, Crisis Management Group (CMG) coordinated India's satisfactory participation in these exercises. To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and heavy water plants periodically carried out variety of emergency exercises. CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Kalpakkam and Kaiga NPP sites. The exercises were found to be effective and satisfactory.

VIGILANCE

The overall responsibility for vigilance in any unit of DAE rests with its Vigilance Officer/Chief Vigilance Officer (CVO). To ensure effective functioning of the vigilance machinery a senior officer in each of the Constituent Unit and Aided Institution of the Department has been designated as part time Vigilance Officer/Chief Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time Chief Vigilance Officer discharges these responsibilities. The Vigilance functions were continued at DAE. As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2019" was observed in DAE during October 28th to November 02nd, 2019 on the theme of "Integrity - A way of life (ईमानदारी - एक जीवन शैली)". Various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were also held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC continued to provide seamless access of information to BARC and DAE scientists and engineers in their day-to-day R&D activities. BARC continued to subscribed to periodicals, Standards and Databases and added books and CD-ROMs to the Library collection. During Jan-Dec 2019, a total 3539 bibliographic records of various journals, conference proceedings and technical reports published in India were submitted to International Nuclear Information System (INIS) database on Nuclear Science and Technology in addition to 8 full text Non-Conventional Literature. Foreign language translations from foreign language journals, technical guides and manuals, etc., were undertaken in addition to Interpretation services.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a host of Public Awareness programmes on a mission mode to alleviate unwarranted fears, misconceptions, to address apprehensions harboured against nuclear energy. Across the nation there exists a void of any real understanding, on the part of the general population, of anything related to nuclear energy and technologies that have actually been developed for better quality of life. To keep the public abreast of the latest developments and contributions of atomic energy towards societal welfare, DAE participated in and organized a spectrum of events comprising exhibitions, seminars, workshops, essay and quiz contests in different parts of the country which were well received by the targeted audience.

DAE participated in the 107th session of the Indian Science Congress (ISC) held from 03-07 January, 2020 at GKVK University, Bengaluru. The Hon'ble Prime Minister of India Shri Narendra Modi inaugurated the Indian Science Congress on 3rd January, 2020. The occasion was graced by Eminent Scientists, Nobel Laureates, Dignitaries, former ISCA General Presidents, Industry Leaders, Policy Makers, Innovators, Academicians and thousands of national/ international delegates. DAE put up a five day exhibition along with the units viz. BARC, IGCAR, UCIL, ECIL, NFC, AMD, BRIT, IPR, HWB, RRCAT & NPCIL in the Pride of India (PoI) exhibition. exhibition was visited by thousands of representatives from R&D Institutions, PSUs, MNCs, Corporate, Policy makers, Researchers, Technocrats, Young innovators, Investors, Educationalists and Students of various schools and colleges. The exhibition provided an excellent opportunity to all to have a glimpse of the diverse activities of DAE under one roof. Various queries from students were attended to during the five day exhibition.

DAE organized the fourth series of Journalist's Workshop at RAPS, Rawatbhata during August 05-09, 2019. The aim of this workshop was to reach out to the general public, in the correct perspective about the objectives of DAE, using the media as a powerful interface. An exhibition on various technologies for better quality of life was set and a Scientist-Journalist meet was organized. The workshop ended with a Panel discussion and feedback from the journalists. The exercise proved to immensely fruitful.

DAE Pavilion at the 107th session of the Indian Science Congress

DAE-NUJ (I) Journalist Workshop at RAPS, Rawatbhata, Rajasthan

As a part of its Public Awareness Programme, DAE has been organizing, "DAE All India Essay Contest" for undergraduate students on topics relating to "Nuclear Science & Technology'' every year. The 31st DAE All India Essay Contest - 2019 on Nuclear Science and Technology was held on October 21-31, 2019. The topics for the essay contest were: Evolution of Nuclear Power in India; Radioisotope Production & Radiation Technology Applications and Lasers & their Impact on Mankind. The announcement was given wide publicity by contacting over 10,000 colleges within the country. A total of 36 students were selected for each of the three topics and they were invited in Mumbai to visit various facilities of DAE and to make

an oral presentation of their essays. In order to generate a competitive spirit, the selected students were awarded with cash prizes.

Winners of 31st DAE All India Essay Contest – 2019

During the year, DAE continued to participate in various Exhibitions, Events, Expos, National & International Conferences and Seminars organised across India. These events/exhibitions were well received by students and the general public.

As part of year-long Dr. Vikram Sarabhai Birth Centenary Year programme, BARC released commemorative coin of value Rs. 100/-. It is a constant endeavour in BARC to make the general public aware of the programs of BARC such as exhibitions, essay competitions, etc., in different parts of the country. BARC had set up an exhibitions in 105th and 106th Indian Science Congress held in Jalandhar and Bengaluru respectively; organised Parmanu Tech meet with Confederation of Indian Industry for exploring technology partnerships. National Science Day and National Technology Day were celebrated with several school and college students visiting the BARC facilities.

During the year, the public awareness activities of VECC included arrangement of visits of students and faculties to different laboratories and facilities of VECC, holding outreach programmes to create general awareness and attracting the fresh minds for career in the department and the members of the PAC cell also participated in scientific and technical fairs.

NPCIL has carried out series of Public Awareness (PA) campaigns on regular basis to convey factual and authentic information on nuclear power in a transparent manner with a structured approach. NPCIL has been reaching out to an average of around 5 lakh people per month as a result of various multi-pronged initiatives. Regular interaction with the population of the surroundings of the Indian Nuclear Power Plants (NPPs); organizing regular visits of villagers, students, officials from various organizations, opinion makers, members from the media and public to nuclear power plants; execution of various awareness campaigns on nuclear power for different target groups like media personnel, policy and decision makers, people's representatives, state officials, students and teachers, medical professionals and the public at large are some of the efforts, which is being continuously carried out across the country. NPCIL is also actively involved in setting up of number of permanent galleries on nuclear energy at the science centres across the country in phased manner to provide factual information in an interesting, innovative and interactive way on numerous applications of nuclear energy. Use of seminars, lectures, scientific meets, exhibitions, distribution of public awareness publications, screening of short films in vernacular languages, enhanced interaction with press and media, professional tie-ups with other professional agencies like Prasar Bharati, National Council of Science Museums (NCSM) and Department of Science and Technology at state and central level etc., use of social media and digital media for e-public awareness campaigns are also being adopted to enhance the public opinion at large, keeping in mind of new generation.

SOCIAL WELFARE

Corporate Social Responsibility

NPCIL is committed to economic and social development of the local communities around all its sites. CSR programme so far been implemented at the 14 sites of NPCIL, where either the operating stations or the projects under construction are located. These Sites are located mostly in rural and under developed areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme. The CSR projects have been taken up in line with Schedule VII of Companies Act, 2013 which falls in the areas of education, healthcare, infrastructure development, skill development, sustainable development.

Swachha Bharat Mission

The Department of Atomic Energy and its constituent units continued its activities for the "Swachha Bharat Mission". As per the directives Swachhta Pakhwada was observed in DAE headquarters from 16th February – 28th February, 2020 on the occasion of World Science Day.

Swachhta Pakhwada was observed in DAE from 16th February – 28th February, 2020

At IGCAR, construction of toilets (Ladies and gents) for contract workers in FBTR has been physically completed by 51%. At DPS, the Swatchta Abhiyan programme was conducted in all of its units, with special cleanliness drives and implementation of the aforesaid measures. DCSEM had engaged an agency namely Stree Mukti Sanghathana, expert in the field of domestic waste management and door to door campaign was started. Resident's Associations of the various buildings and volunteers of a group of residents are also involved in this campaign. At the General Services Organisation (GSO), a Swatch Machine was installed and commissioned at Anpuram Township for Disposal of Plastic Wastes in an environment friendly method. Swachh Bharat' activities were carried out at Headquarters and seven Regional Centers of AMD.

EMPLOYEES' WELFARE

The Contributory Health Service Scheme (CHSS) introduced in DAE in the year 1962 continued to provide the health services to its members. To provide best medical facilities to its employees and their dependent family members, NPCIL followed the Contributory Health Service Scheme (CHSS) of DAE.

RIGHT TO INFORMATION ACT (RTI) COMPLIANCE

The Right to Information Act of Government of India which came into force on 12th October 2005 has been implemented at DAE and all its constituent units. The provisions contained in RTI Act, 2005 were fully complied by DAE and its constituent units. The RTI applications and appeals received at DAE and its constituent units were promptly attended.

AWARDS & PRIZES

Several awards in areas of Safety and Performance, Vigilance, Public Awareness (PA) activities, Corporate Social Responsibility (CSR) and Official Language (OL) were bagged by various units of NPCIL and Headquarters. Various plants of HWB won many awards during the year. IREL received many awards these includes India's Most Trusted Company Award 2018 conferred by IBC Infomedia. IGCAR was awarded the Certificate of Excellence (second position among the DAE units) for the exemplary performance during the Swachhta Pakhwada activities. Scientists from TIFR won prestigious awards during this period. Dr. R.A, Badwe, Director, TMC was recognized by the ASCO (American Society of Clinical Oncology) as one of the top ten oncologists in the world.

CHAPTER 1

Rajasthan Atomic Power Project 8
Reactor Building

NUCLEAR POWER PROGRAMME STAGE-1

Overview of Unit-3 of KKNPP

PRESSURISED HEAVY WATER REACTORS (PHWRs) & LIGHT WATER REACTORS (LWRs)

Nuclear Power Corporation of India Limited (NPCIL), formed in 1987, is a Public Sector Enterprise under the administrative control of Department of Atomic Energy (DAE). NPCIL is a dividend paying company with highest credit rating of AAA by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. Safety is given overriding priority in all facets of nuclear power reactors. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. During the year, India created two world records, first, 962 days of continuous operation of Kaiga Generating Station Unit-1 and second, Tarapur Atomic Power Station unit-1&2 successfully completing 50 years of safe and reliable commercial operation on 28 October, 2019. TAPS-1&2 were the first nuclear power units in Asia and presently are the oldest operating nuclear power generating units of the world. First pair of 700 MW Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (KAPP-3&4) are indigenously designed, constructed and presently they are in the final stages of commissioning.These are followed by second pair at Rawatbhata in Rajasthan (RAPP-7&8) which are in the advanced stages of construction. Similarly, the second pair of Light Water Reactors (LWRs) at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Various preparatory/ pre-project activities are in progress for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP)-1&2 (2x700 MW PHWRs), KKNPP-5&6 (2x1000 MW LWRs) and for a fleet of 10 PHWRs (10x700 MW). In addition, various activities including Techno commercial discussions are in progress for setting up of large size LWRs with international cooperation as an additionality. NPCIL, in all its endeavours, is committed towards up-gradation and continuous improvements in Quality Management, Quality Assurance (QA), Quality Surveillance, Pre-Service Inspection/ In-Service Inspection, Software Quality Assurance (SQA) and interface with regulatory body.

Operating Performance

At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. Out of 22 operating reactors, fourteen reactors with total installed capacity of 4380 MW, are under IAEA safeguards.

Generation

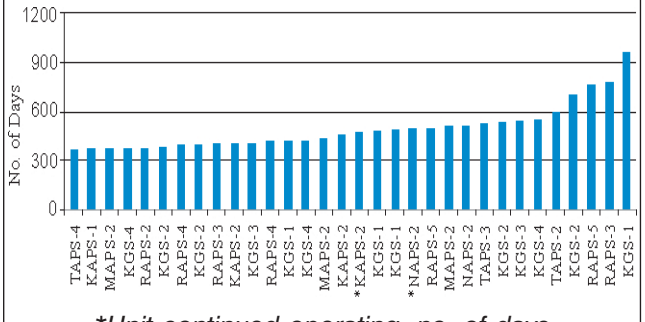
During the Calendar Year (CY) 2019, NPCIL registered highest ever nuclear power generation of 45163 Million Units (MUs). In the previous CY 2018, the nuclear power generation was 39051 MUs. NPCIL has registered power generation of 35808 MUs till December 31, 2019 in the current FY 2019-20. The expected generation for the current FY 2019-20 is about 45000 MUs. The actual generation during the previous FY 2018-19 was 37813 MUs.

During the Financial Year 2019-20, the overall Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2019 for all the reactors in operation were 91% and 85% respectively. These figures for last FY 2018-19 were 73% and 70% respectively.

Continuous Operation for more than a year

During the Financial Year 2019-20, four reactors i.e. NAPS-2, KAPS-2, KGS-4 and TAPS-4 achieved continuous operation of more than a year. NAPS-2 and KAPS-2 continued operating and registered continuous operation of 493 days and 465 days respectively till December 31, 2019. KGS-4 and TAPS-4 registered continuous operation of 370 days and 365 days respectively after which these units were shut down for carrying out planned maintenance activities.

Continuous operation for more than a year registered by NPCIL's Reactors



**Unit continued operating, no. of days shown is as on December 31, 2019*

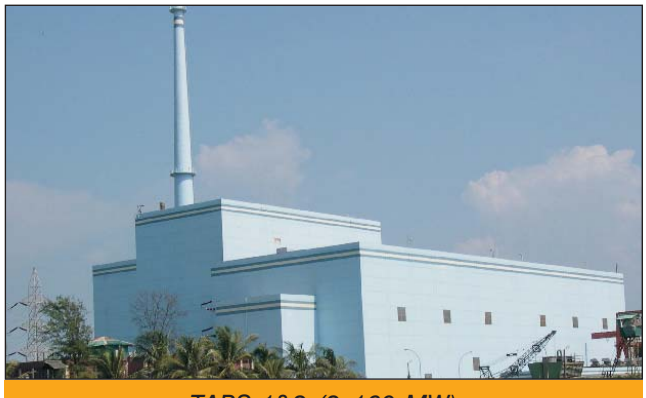
So far, the continuous operation of more than a year has been achieved 32 times by various reactors operated by NPCIL. Out of these, three reactors KGS-1(962 days), RAPS-3(777 days) and RAPS-5(765 days) have operated continuously for more than two years. The continuous operation of 962 days registered by KGS-1 is world record.

Commemorating the achievement of KGS-1 for establishing the world record of 962 days of continuous operation, Department of Posts, Govt. of India has released 'My Stamp' and 'Special Cover' on November 28, 2019.

Department of Posts released 'My Stamps' and 'Special Covers' on setting a World Record of 962 days of continuous operation of KGS-1

50 years of safe commercial operation of TAPS-1&2

Tarapur Atomic Power Station-1&2 completed 50 years of commercial operation and thus became the oldest nuclear power stations in the world in October 2019. Commemorating the achievement of TASP-1&2 on completion of 50 years of operation, Department of Posts, Govt. of India, has released 'My Stamp' and 'Special Cover' on December 28, 2019.



TAPS-1&2 (2x160 MW)

Release of 'My Stamps' and 'Special Covers' by Department of Posts on commemoration of 50 Years of TAPS-1&2 on December 28, 2019

Reactor Years of operation

Nuclear power reactors in operation registered 517 reactor years of safe operation by the end of CY 2019.

Renovation & modernization works

At Kakrapar Atomic Power Station (KAPS) Unit-1, the En-Masse Coolant Channels Replacement (EMCCR), En-Masse Feeders Replacement (EMFR) and other safety upgrades, which were undertaken in project mode since August 1, 2016, were completed successfully and the unit re-started and synchronized to Grid at 06:44 hrs. on 24th May 2019.

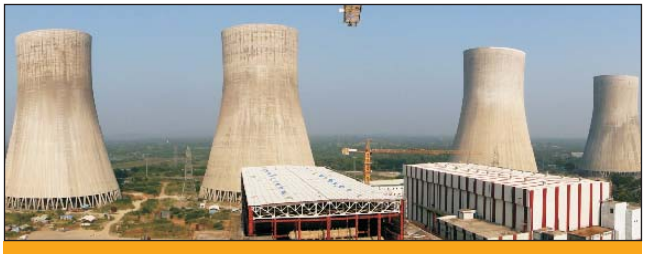
Projects under Construction

Kakrapar Atomic Power Project (KAPP)-3&4 (2x700 MW PHWRs)

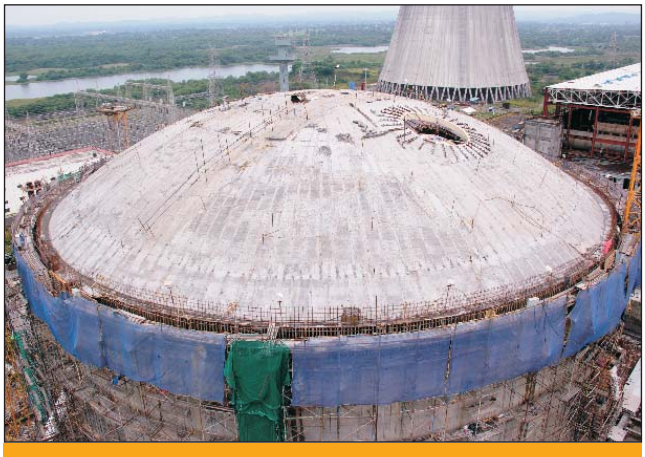
These units are the First pair of indigenously designed and constructed 700 MW Pressurized Heavy Water Reactors. Unit-3 is in commissioning phase and is moving towards initial fuel loading, approach to first criticality and synchronization. Many important activities such as Proof Test of Primary Containment, assembling and installation of first of its kind Mobile Transfer Machine (MTM) of 700 MWe PHWR, Primary Heat Transport (PHT) Hot Conditioning, installation, testing and qualification of Drive mechanism units of Adjuster rods, Control rods and Shutdown Systems (SDS)-1, etc. were completed.

View of Main Plant construction area – KAPP-3&4

In Plant water package Pump House, civil and mechanical works are completed and C&I work is under completion. Commissioning of one stream of Filtration & Demineralized (DM) Water Plant completed successfully to make DM water available for various Commissioning activities.



NDCTs-KAPP-3&4



KAPP-4 Reactor Building construction completed with OC

In Unit-4, Pre-stressing Inner Containment was completed. Outer Containment (OC) dome is completed, and with this Unit-4 Civil structural work is completed. In electrical system, Start Up Transformer (SUT-4A&4B) is charged. In reactor side coolant channel installation has been completed and feeders' fabrication work is in progress. Natural Draught Cooling Tower (NDCT)-4A and 4B structures have been completed and with this all 4 NDCTs outer shell structure completed.

Rajasthan Atomic Power Project (RAPP)-7&8 (2x700 MW PHWRs)

These units are the second pair of indigenously designed 700 MW Pressurized Heavy Water Reactors.

In Unit-7, construction of Inner Containment (IC) Dome and Outer Containment (OC) Dome has been completed including pre-stressing work. Civil works of Control Building, Reactor Auxiliary Building, Station Auxiliary Building-7A&7B are completed. Erection of all Steam Generators (SGs) is completed. Construction of Turbine Building is also completed. Commissioning of Plant Water Pump House is completed and Chlorination Plant & Demineralized (DM) Water Plant are under commissioning. Erection of feeders and PHT main loop piping is also completed in both vaults (i.e. north & south). The physical progress of the unit is about 86% as on end December 2019.

RAPP-7&8 Site View

RAPP-8 Reactor Building

In Unit-8, Construction of IC wall is completed along with ring beam. Construction of SG vaults is also completed and released for SGs erection. The physical progress of the unit is about 72% as on end December 2019.

Kudankulam Nuclear Power Project (KKNPP)-3&4 (2x1000 MW LWRs)

KKNPP Unit-3&4 located in Tirunelveli district of Tamilnadu, an expansion program of Unit-1&2, is under implementation in cooperation with Russian Organizations within the framework of the Inter-Governmental Agreement (IGA) signed between the Governments of Russian Federation (RF) & Republic of India in December 2008 and General Framework Agreement (GFA) signed between Joint Stock Company Atomstroyexport (ASE) and Nuclear Power Corporation of India Limited (NPCIL).

Overview of Unit-3 of KKNPP

Civil works like construction of Reactor Building, Reactor Auxiliary Buildings, Emergency Power Supply Buildings, Turbine Buildings, Common Services Buildings, Switchyard Buildings, Hydro-technical Structures etc. are in progress. Lowering and alignment of Catcher Vessel of Core Melt Localization Facility (CMLF) in Reactor Cavity, an important milestone on critical path of Unit-3, was successfully completed in November 2019. Work orders awarded for nuclear piping, secondary cycle piping and related equipment erection and mobilization by contractors is in progress. Development of Working Documentation (WD) is in progress.

View of Reactor Cavity- Membrane erected -KKNPP-3

Manufacturing and supply of equipment and components are in progress. Three shipments of project cargo (8,900 Freight Ton) carrying various equipment viz. Low Pressure Heaters, Second Stage Hydro Accumulators, Power Nut Driver, Control and Protection System drives, Turbine drives for Feed Water Pumps, etc. were delivered from Russian Federation and Third Countries to Tuticorin port / Kudankulam site during this year up to Dec-2019. Supply of first priority Stainless Steel tanks and Plate Type Heat Exchangers under Indian Scope of Supply (indigenous supply) is in progress.

The physical progress of Unit-3 and Unit-4 was about 38% and 36% respectively as on December 31, 2019.

Sanctioned Projects

Gorakhpur Harayana Anu Vidyut Pariyojana (GHAVP) Units-1&2 (2x700 MW PHWRs)

Excavation & ground improvement in Main plant area has been completed. Main Plant civil package has been awarded. Site is planning to take up First Pour of Concrete (FPC) after receiving consent from AERB. Purchase orders are placed for major equipment/ components like Primary Coolant Pump, Steam

GHAVP-1&2 –site activities in progress

Generators, Calandria, End-shields, Reactor Headers, Fueling Machine heads, Moderator and D2O (Heavy Water) Heat Exchangers, etc. Manufacturing of these equipment/ components are in progress. Process of tendering for other major packages like Primary Piping Package, Plant Water Package, Turbine Island Package, and Main Plant Electrical Package is in progress.

At site, 11KV/33KV network for construction power supply distribution has been commissioned & charged with 33KV power supply from Dakshin Haryana Bijli Vitran Nigam (DHBVN). Laying of construction water line from Fatehabad Branch Canal to site construction water tank has been completed. Water treatment Plant for Construction water, Domestic water and Fire water supply has been commissioned. Construction ware house has been constructed. Construction of other infrastructure buildings like Main guard house, public awareness building and project management building is in progress. MOU between NPCIL & Haryana Irrigation & Water Resource Department (I&WRD) is signed for construction of water tunnel from Tohana Head regulator to GHAVP site. Geotechnical investigation for the same has been completed. Erection & Commissioning for 300 KWp Solar Power Plant is in progress.

Kudankulam Nuclear Power Project (KKNPP) Unit-5&6 (2x1000 MW LWRs)

KKNPP Unit-5&6 are under implementation in pursuance of Inter-Governmental Agreement (IGA) of December 2008 signed between the Governments of Russian Federation (RF) & Republic of India for construction of two more Units at Kudankulam Site in the second stage.

Pit excavation for main plant buildings and structures completed. Confirmatory geo-technical investigation works at founding level has been completed. Ground improvement by consolidation grouting and concrete leveling course is in progress. Excavation and confirmatory geo-technical investigations for Main Pump House and Essential Load Pump House completed. Application for AERB consent for First Pour of Concrete (FPC) submitted. Notice Inviting Tender (NIT) for main plant civil works published in August 2019. NIT published for procurement of condenser cooling water pipelines under indigenous scope of supply.

Ten 700 MW PHWRs in Fleet Mode

Land is available for GHAVP-3&4 and Kaiga-5&6. Possession letter issued for all types of land for Chutka site Madhya Pradesh. Land acquisition is in advance stage at Mahi Banswara site in Rajasthan. Rehabilitation & Resettlement (R&R) colony for the Project Affected Persons (PAPs) is under construction as per approved architectural plan in respect of Chutka site. In respect of Mahi banswara site, land is identified for R&R colony and payment is made, demarcation work and topography survey for R&R colony land is completed.

Ministry of Environment, Forest and Climate Change (MoEFCC) clearance is available for GHAVP-1 to 4, Chutka site and Kaiga-5&6. Application for Environmental Clearance (EC) is under consideration of MoEFCC for Mahi Banswara site.

Geo-technical investigation works are completed for GHAVP-3&4 and tender for Main Plant Excavation & Ground Improvement is under evaluation process. All the scope of work of Geo-technical and Geo-physical investigation is completed for Kaiga-5&6 and excavation tender for main plant civil works is under evaluation process. At Chutka and Mahi Baswara sites, Geo-technical investigation works are at stand still due to public/ villagers agitations. AERB siting consent is available for GHAVP-3&4. Siting consent applications are submitted for Kaiga-5&6 and Chutka-1&2 and same are under review by AERB.

Purchase Orders are placed for Forgings for Steam Generators (6 units-24 Nos.), Lattice Tubes and Plates for End Shields (4 Units), Pressurisers forgings (4 units), Bleed Condensers forgings (4 units) and Incoloy-800 tubes for 40 Steam Generators (10 units). Tendering process for Steam Generators (7 units-28 Nos.), Reactor Headers (8 units-64 Nos.), Primary Coolant Pump (PCP) motor units, etc. is in progress.

New Projects / Sites

Future Light Water Reactor (LWR) Projects

The Government of India has also accorded In-principle approval for four sites namely Jaitapur in Maharashtra, Kovvada in Andhra Pradesh, Mithi Virdi in Gujarat and Haripur in West Bengal for setting up Nuclear Power Plants in the country with the mandate

for taking up land acquisition at new Sites and Pre-project activities at all the Sites.

For Jaitapur in Maharashtra, land has been acquired. Techno-commercial discussions with Électricité de France (EDF), France are in progress. For Kovvada in Andhra Pradesh, land acquisition process is in progress. Techno-commercial discussions with Westinghouse Electric Company (WEC) are in progress. In respect of Mithi Virdi in Gujarat, land is to be acquired as per the new Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013. In respect of Haripur in West Bengal, land acquisition is contingent to initiative by State Government.

Future Pressurized Heavy Water Reactor (PHWR) Projects

The Government of India has also accorded In-principle approval for one site namely Bhimpur in Madhya Pradesh for setting up Nuclear Power Plant. At this site, commitment for water supply is to be confirmed by State Government.

Quality Assurance

NPCIL, in all its endeavors, is committed towards up-gradation and continuous improvements in Quality Management, Quality Assurance (QA), Quality Surveillance, Pre-service Inspection/ In-service Inspection, Software Quality Assurance (SQA) and interface with regulatory body. Quality Assurance/ Surveillance (in India and overseas) activities have been carried out expeditiously for projects and stations. Pre-service Inspection/ In-service Inspection (PSI/ISI) activities of Projects/ Stations has been completed successfully. Corporate Peer reviews of operating stations have been conducted based on WANO guidelines. Audits of suppliers for major nuclear items are carried out in planned manner. Corporate QA audits of KKNPP-3&4, KAPP-3&4, RAPP-7&8, PSI audits of KAPP-3&4, RAPP-7&8, ISI audits of RAPS 3&4, KGS 1&2 and KGS-3&4 have been completed in a planned way. NPCIL continued to provide QA consultancy services to BARC and BHAVINI.

Preparation, review and approval of Generic In-service Inspection document for PHWR type of Nuclear Power Plants have been completed. Review was carried out in respect of TAPS-1&2 Reactor Pressure Vessel ultrasonic testing (UT) and Eddy Current Testing (ECT) results and BARCIS results of coolant channels of PHWRs during Biennial Shutdowns. Quality Surveillance activities were performed for various equipment and components manufactured for various projects and items required for EMCCR. Software QA (SQA) activities such as Independent Verification and Validation (IV&V) activities for 700 MW were performed.

FRONT-END FUEL CYCLE

Heavy Water Production

The Heavy Water Board (HWB), a constituent unit of DAE in its Industries Sector contributes to the first stage of Indian Nuclear Power Programme by producing Heavy Water for all Pressurized Heavy Water Reactors (PHWRs) in a cost effective manner, enabling the Department to provide nuclear power at an affordable cost to the common man. Presently, Heavy Water Board is not only self-sufficient in meeting the domestic demand of heavy water, but is also geared up to supply heavy water for the future PHWRs and AHWRs as per the envisioned nuclear power programme of DAE. The largest Heavy Water Plant in the world, HWP, Manuguru has completed 25 years of operation and surpassed 5 Million Kg production of nuclear grade heavy water during the period. Over a period of time, HWB has emerged as the largest global producer and a trusted supplier of this strategic material. Realizing the large potential for non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology areas, HWB is also nurturing R&D activities in this area. Many Indian companies and leading research institutions are now regularly sourcing heavy water from HWB instead of importing the same, for their research work and producing deuterated compounds as NMR solvents.

Heavy Water Board has achieved the production targets set for the year, for heavy water as well as for other products such as Boron, organo-phosphorus solvents and synthesis of d-labeled compounds. As

per the Annual Action Plan for the year 2019-20, HWP, Hazira carried out Major Turn Around in May – June 2019 and HWP, Thal took annual turnaround of both streams in November 2019. While HWP, Kota operated excellently during the period, operations at HWP, Manuguru was affected in second week of May 2019, due to very low water levels in river Godavari. Such unprecedented constraint of raw water supply was witnessed for the first time in last 25 years. Subsequently on 29.05.2019, main Cooling Tower of HWP, Manuguru was severely damaged due to wind storm forcing the plant to operate partially for prolonged period. At HWP, Tuticorin, revamping jobs for targeted restart up of the plant are in full swing. IOCL Natural Gas pipeline laying job from Ramanad - Tuticorin sector is in progress. Civil work related to Solvent Production Plant is in an advanced stage of completion. Work order has been placed for detailed EPC activities. At Solvent Extraction Plant, land development, boundary wall and peripheral road for securing newly acquired land was completed.

Heavy Water Plant, Manuguru

The plant operated normally till second week of May 2019 when both the streams of Exchange Units (XU) were shut down due to very low water levels in river Godavari at plant intake well. The main Cooling Tower of the plant suffered extensive damage on 29.05.2019 because of wind storm forcing the plant to operate partially till end October 2019. In spite of this, plant performance was satisfactory w.r.t. the performance indicators like feed processing rate, feed water chemistry, gas purity and recovery. Major improvement was initiated in security management at the site by setting up the Periphery Intrusion Detection System (PIDS).

Attempts are in hand to achieve maximum disposal/ utilization of fly ash generated at CPP. Disposal of 15,000 MT of pond ash is initiated for filling of low lying areas near oxidation pond at HWP, Manuguru colony. Contract has been lined up for lifting another 10,000 MT of Bottom ash for manufacturing red bricks. It is expected that in three years' time, M/s SCCL will be able to offer Manuguru mines for filling of fly ash generated at HWP, Manuguru.

At the Elemental Boron Plant (EBP), six nos. of cells were operated for production of enriched elemental Boron (B10 ≥50% IP) and targeted production was achieved. The target of conversion to Boron Carbide (B-10 ≥50% IP) has been achieved as targeted. Production of Boron Carbide (B-10 ≥67% IP) was achieved and pelletization is in progress. Hot Press was in operation and two batches of FBTR pellets with enriched Boron Carbide of B-10 ≥90% IP were produced. Sample pellets were sent to IGCAR for analysis and confirmation for use in FBTR. Micronization of Boron Carbide powder (B-10 IP ≥50%) is under progress.

Elemental Boron Plant, HWP, Manuguru

Hot Press at Boron Pelletization Plant, HWP, Manuguru

Heavy Water Plant, Kota

The plant operated excellently during the year achieving the production target with energy consumption within the targeted specific energy consumption for the year besides achieving the highest ever production for first six months of any financial year in the history of HWP, Kota.

Sodium Sulphate Crystallizer unit was operated surpassing the targeted operating hours and generated Na_2SO_4 crystals from the effluent Sodium sulphate solution. Sale of 40 MT of Sodium Sulphate Crystals was executed during the year.

With sustained supply of steam from the units at RAPS, it was decided to dispose off the Steam Generation Plant (SGP). The same was initiated during the year and successfully completed.

Heavy Water Plant, Hazira

The plant was in regular operation achieving the targeted production. Both the plant streams were taken under shutdown for Major Turn Around in May 2019. The major jobs carried out during the Major Turn Around included maintenance & ISI of exchange tower internals, maintenance of stage pumps, hydro testing of various loops, besides all the routine maintenance activities scheduled. Plant license has been re-validated up to 31.07.2023.

Stage removal of tower 12T2 during MTA at HWP, Hazira

Heavy Water Plant, Thal

Annual Turn Around (ATA) -2019 was taken up for both the streams in November 2019. Major ATA jobs included cracker catalyst and component replacement in stream A. Both streams were under strained operating conditions during the year because of repeated ingress of oxygenated impurities in feed synthesis gas from Ammonia Plants of RCF which affected internals of exchange towers 12T1A/B causing low load operation. Deuterium concentration in the feed synthesis gas remained low because of implementation of Gas Turbine Project in RCF Ammonia Plant. Plant license has been re-validated up to 31.12.2024.

Heavy Water Plant, Baroda

Tri-butyl Phosphate (TBP) plant and Potassium Metal plant were in regular operation meeting the set production targets.

Sodium test cell of 2KA capacity was put under operation for fine tuning the cell configuration and operating parameters. Actions have been initiated for fabrication of 24 kA cell along with its auxiliaries. Foundation stone of Sodium Metal Plant was laid on January 5, 2020 by Shri K. N. Vyas, Secretary DAE & Chairman, AEC.

The raw Sodium produced in the cell having impurities like Calcium, Iron, Zinc, Carbon, Magnesium, and Chloride needs to be purified to nuclear grade Sodium. A bench scale Sodium Purification Unit was installed and trial batches for purification of raw Sodium were carried out. The unit was inaugurated by Shri K. N. Vyas, Secretary DAE & Chairman, AEC on January 5, 2020.

Bench Scale Sodium Purification Unit

HWP, Baroda has been synthesizing several deuterated versions of Chloroform, Methanol, DMSO, Methyl Iodide, Acetone & Acetonitrile and Benzene using conventional and innovative methods as a part of developmental activities on alternate application of

heavy water. These are sent to BRIT (Mumbai) for marketing. The purity and deuterium content of 99.8% in organic deuterated solvents produced meets international standards and are well accepted by the users.

Heavy Water Plant, Tuticorin

After resumption of stable operation of M/s. SPIC with subsidy in supply of naphtha and assurance of M/s. SPIC on ensuring availability of synthesis and natural gas to the HWP at Tuticorin, revamping jobs for targeted restart up of the plant are in full swing. IOCL Natural Gas pipeline laying job from Ramanad - Tuticorin sector is in progress. Two other industrial scale projects are also being set up at HWP, Tuticorin viz Solvent Production Plant (SPP) and Solvent Extraction Plant (SXP).

Solvent Production Plant (SPP) is being set up for the production of organo-phosphorus solvents like TiAP, DHOA, D2EHPA-II, TBP & TOPO. The design of the plant is based on the operating experience of Versatile Solvent Synthesis Plant and TBP plant of HWP Baroda. HAZOP study for the various process loops of the plant has been completed. Civil works including roads and laying of external utility pipelines are completed. Work order has been placed for detailed engineering, procurement & commissioning and EPC Contractor site office has been established.

Solvent Extraction Plant is being set up at HWP, Tuticorin for recovery of rare material from Phosphoric acid to be sourced from M/s. Green Star Fertilizer Limited (GSFL), a nearby Fertilizer plant. Land development and erection of peripheral boundary wall is completed.

Heavy Water Plant, Talcher

At HWP, Talcher, the TBP production facility operated continuously to meet the targeted production. The plant produced the targeted (> 65% IP) enriched BF3 Di-ethyl Ether complex and produced 514 kg of enriched KBF_4 (> 65 % IP) in KBF_4 conversion Unit.

HWP, Talcher is engaged in conversion of RCl into ROH from the RCl+ROH mixture in the glassware setup. Aqueous effluent generated during above process contains mainly salt mixture composed of Sodium acetate and Sodium chloride which were successfully separated by suitable solvent.

The Integrated Effluent Treatment Plant is engaged in treatment of effluent generated at TBP production facility. Disposal of complete effluents generated in BEXD facility, KBF_4 & Boric Acid Plant has been carried out.

At the BF_3 Gas Generation and Bottling facility, five nos. of trial runs of BF_3 gas generation has been completed successfully and the data on trial runs are submitted to AERB. All documents have been submitted to SRC, HWB for obtaining consent for commissioning & operation from AERB.

Technology Demonstration Plant

It is proposed to utilize indigenous rock phosphate as secondary source for recovery of rare materials. For exploring indigenous source of rock phosphate actions have been initiated in coordination with AMD. Presently “Forest Clearance Application” for prospecting of identified one-hectare area has been cleared in principle by MoEF, New Delhi for approval of Central Forest Ministry. Further actions are in hand for prospecting work jointly by HWB and AMD. Rock phosphate samples from Madhya Pradesh were collected and development of beneficiation process with additional floatation trials and mineralization structure analysis are being carried out in coordination with Mineral Process Division, Hyderabad (BARC Facility).

HWB has set up a Cobalt recovery test facility at TDP, Mumbai for recovery of Cobalt from spent ammonia cracker catalyst used in HWPs. It is based on hydrometallurgical process developed by BARC involving leaching, solvent extraction, ion exchange, precipitation, thermal reduction for recovery of Cobalt. Three batches have been processed so far and confirmation of specifications of Cobalt Oxalate by BARC is awaited.

Based on the R&D technology developed by BARC for the recovery of Gallium from Bayer’s liquid of Aluminum plant, a facility has been set up and commissioned at TDP site. Experiments were carried out and Gallium rich sample was handed over to BARC

for electrolysis trials. Improved functionalized resin for further trials is awaited from BARC.

Gallium extraction facility at TDP, Mumbai

Hydrogen production via Iodine-Sulphur process of BARC coupled with Solar heating is one of the new projects which has been approved by PAC and the facility of 15 Nm3/day of Hydrogen generation is to be set up at TDP, Chembur.

HWB has also made head way in the new initiative of Helium extraction from Natural gas and Purge gas and skid mounted systems will be set up at TDP, Chembur.

Phase III revamping of Heavy Water Upgrading plant (UGP) has resulted in notable gains, including production of heavy water with enhanced isotopic purity of 99.97%, 20% increase in plant's total handling capacity and a good 10% reduction in total steam consumed during plant operations.

Mineral Exploration

Atomic Minerals Directorate for Exploration and Research (AMD) plays a vital role in front end fuel cycle of nuclear power programme and carries out survey, prospecting and exploration of atomic minerals required for the nuclear power programme of the country. The activities include assessment, analysis, evaluation, characterization and categorization of atomic minerals; design and fabrication of radiometric survey instruments and laboratory scale leaching studies. In addition, AMD also plays role in middle and back ends of the nuclear power programme by carrying out site selection for nuclear power reactors and waste disposals.

During the Annual Programme 2018-19 (November 2018 to October 2019), integrated multi-disciplinary approach has been adopted for uranium exploration with substantial inputs of radiometric, geological, ground & heliborne geophysical, geochemical surveys and drilling (Departmental and Contract), have resulted in augmentation of in-situ uranium resource.

Uranium investigations have been continued in the thrust areas for Proterozoic unconformity type, granite-related, carbonate, metamorphite, Palaeo-QPC and metasomatite types in Proterozoic basins; sandstone and surficial types in Phanerozoic basins.

In addition, pegmatite belts of Chhattisgarh, Odisha and Karnataka have been explored for augmentation of rare metals and rare earths resources. Besides, the Ambadongar Carbonatite Complex, Gujarat and Siwana Ring Complex, Rajasthan are being explored for REE and Nb resources. The coastal stretches of the country have been explored for augmentation of economic heavy minerals resources.

All the laboratories at AMD Headquarters and Regional Headquarters have been utilized to their full capacity and have contributed actively by providing speedy analytical support to the ongoing exploration programme.

Some of the significant achievements are summarised below:

Uranium Investigations

Geological and radiometric surveys

Reconnaissance (7,104sq km) and detailed (401sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

Chhotanagpur Granite Gneissic Complex (CGGC), Sonbhadra district, Uttar Pradesh, Singrauli district, Madhya Pradesh and Balrampur district, Chhattisgarh: Pegmatite Leucosome Mobilizate (PLM) hosted at Mejrout Kalan, Dighul and Chakcapki areas in Sonbhadra district, Uttar Pradesh; along Baran River in Singrauli district, Madhya Pradesh and at Gobara area, Balrampur district, Chhattisgarh.

Sendhpa Member, Malhera Chert Breccia Formation, Bijawar Group, Chhatarpur district, Madhya Pradesh: Chert, chert breccia and arenites hosted at Dai area.

Basement crystallines, Kadapa, Chitoor and Anantapur districts, Andhra Pradesh: Cataclasite Mylonite zones in Granite at Pedda Kantivaripalle – SontamVaripalle Kondakindapalle, and Varigapalle.

Khetabari Formation of Bomdila Group, in West Siang district, Arunachal Pradesh: Iron breccia hosted polymetallic U-Cu-REE & Au mineralisation was recorded at Laggi Gamlin and magnetite quartzite hosted uranium mineralisation at Laggi Gamlin and Siki areas.

Railo, Alwar and Ajabgarh Group of metasediments, Alwar district, Rajasthan: Contact of Quartz Muscovite schist (Railo Gr.) and quartzite (Alwar Gr.) at Sabraoli and in carbonaceous phyllite at Sehra areas.

Peninsular gneissic Complex, Kurnool district, Andhra Pradesh: Leucogranites at Pangal-Rajpet areas.

Geochemical Surveys

Geochemical surveys (4,695sq km) have delineated anomalous hydrogeochemical zones up to 1,013 ppb U in granitoid country at Kanamaipatti, Madurai district, Tamil Nadu; up to 1,413 ppb U in Pachpadra area, near confluence of Saraswati paleochannel and Luni river and upto 37 ppm lithium in salt pans of Pachpadra area, Barmer district, Rajasthan.

Ground Geophysical surveys

Ground geophysical surveys (Regional: 652sq km; detailed: 399sq km) have been carried out in potential geological domains of North Delhi Fold Belt, Rajasthan & Haryana; Bhima and Kaladgi Basin, Karnataka; Bijawar Basin, Madhya Pradesh; CGGC Chhattisgarh; Satpura-Gondwana Basin, Madhya Pradesh; Dongargarh-Kotri Belt, Chhattisgarh; Khairagarh Basin, Maharashtra; Rudravaram lineament and Nellore schist belt, Andhra Pradesh.

The geophysical surveys have delineated potential high chargeability- low magnetic zones south of Rohil Uranium deposit, Ladi ka bas and Geratiyon ki Dhani areas, Sikar district, Rajasthan. Trends and extensions of potential fracture zones were delineated in Kanchankayi, Yadgir district, Karnataka, Gujanal, Belgaun district, Karnataka and Rakshakhand, Balrampur, Chhattisgarh for guiding the drilling programmes in these exploratory blocks. Anomalous chargeability zones and deep seated faults have been delineated along Rudravaram lineament to guide the deep drilling programme.

Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 26,996 line km in parts of Alwar Basin (North Delhi Fold Belt).

Several uranium anomalous zones, EM data based trends of formational and discrete conductors and subsurface structural elements were delineated in parts of Alwar basin. Six potential exploratory drilling target blocks along Rudravaram lineament ranging from 450 - 750m were delineated for classical unconformity type model. Concealed fracture zones with conductive alteration zones were identified as potential drilling targets for unconformity type uranium mineralisation in Singhora Basin. In parts of Satpura Gondwana Basin, radioactivity is delineated at sandstone-mudstone interface and two paleo channels were interpreted in Motur sediments with potential of uranium mineralization over the confluence of streams associated mid-channel bars/braided bars.

Exploration by Drilling

A total of 2,56,033m (Departmental: 87,652m and Contract: 1,68,381m) drilling (reconnoitory, exploratory and evaluation) has been carried out to establish (a) additional uranium resource in the known deposits and (b) sub-surface continuity of mineralisation in the new promising areas.

Drilling has established significant correlatable uranium mineralised intercepts / bands in areas given below:

Naktu and Anjangira, Sonbhadra district, Uttar Pradesh: Associated with Pegmatiod Leucosome Mobilizate of Chottanagpur Granite Gneiss Complex (CGGC).

Rajpura and Loharkar, Una and Hamirpur district, Himachal Pradesh: Along Middle and Upper

Upper Siwalik Boulder bed Formation Conglomerate with few sandstone lenses around Gagret- Ambota area, Una district, Himachal Pradesh

Siwalik transition zone, sandstone/conglomerate hosted.

Tummalapalle sector, Kadapa district, Andhra Pradesh: Vempalle dolostone at Motunutalapalle, Tummalapalle-II, Kanampalle, Gidankivaripalle, Rachakuntapalle East and Bakkanagaripalle.

Kanchankayi, Yadgir district, Karnataka: Associated with brecciated limestone in the eastern extension of Gogi uranium deposit.

Suldhal-Gujanal, Belgaum district, Karnataka: Associated with conglomerate proximal to the unconformity contact.

Singhbhum Shear Zone, East Singhbhum and Seraikela-Kharswan districts, Jharkhand: Associated with sheared quartz-chlorite-sericite schist at Narwapahar Deep, Rajdah, Jaduguda (North), Baglasai-Mechua, Bangurdih, and Gura-Dugni blocks. Altered peridotite hosted uranium mineralisation was intercepted in boreholes in Kudada (Turamdih East extension).

Rohil and its extensions, Sikar & Jhunjhunu districts, Rajasthan: Associated with albitite zones in North Delhi Fold Belt (NDFB) along Rohil Central & west blocks, Narsinghpuri, Jahaz, Geratiyon ki Dhani and Ladi ka Bas.

Umra, Udaipur district, Rajasthan: Associated with Carbonaceous phyllite of Aravalli Supergroup in Umra NE extension and Umra grid area.

Dharangmau-Kachhar, Betul district, Madhya Pradesh: Associated with Motur Sandstone of Lower Gondwana Formations in Satpura Gondwana Basin.

Sarangapalli, Guntur district, Andhra Pradesh: Associated with Basement granite / Banaganapalle quartzite.

In addition to the above, potential/significant blocks have also been identified for sub-surface exploration at Dhoha-Dursendi, Gwalior district, Madhya Pradesh; Kanchankai East – Hulkal West, Yadgir district, Karnataka; Umra NE Extension, Udaipur district, Rajasthan and Rudravaram – Allagadda, Kurnool district, Andhra Pradesh.

Cross-bedding in Kaimur Sandstone near around Gurawal, Gwalior district, Madhya Pradesh

Rare metal and rare earths investigations

Reconnaissance (758sq km) and detailed (6 sq km) surveys have been carried out for identification and evaluation of Rare Metal and Rare Earth resources in Chhattisgarh, Odisha, Rajasthan and Karnataka.

Recovery of columbite-tantalite, beryl as by-product and polymetallic xenotime bearing concentrate was achieved at Pandikimal and

Beryl (greenish yellow) and ilmenite (black) crystals within quartz in pegmatites near Sapaha, Surajpur district, Chhattisgarh

Jangapara unit, Jharsuguda district, Odisha; Allapatna-Marlagalla sector, Mandya district, Karnataka and at Siri River, Jashpur district, Chhattisgarh.

A total of 7,079 m drilling has been carried out for RMRE in Siwana Ring Complex, Barmer district, Rajasthan and Ambadongar, ChhotaUdepur district, Gujarat. Strike continuity of REE mineralisation established over 2km strike length in Bhatikhera (in microgranite dykes) and 600m in Ramaniya (Granite), Siwana Ring Complex, Rajasthan.

Additional resource of 1,076kg of columbite-tantalite was estimated by detailed surveys and assessment of pegmatites of Chikka Yarahalli, Hosa Kannambadi and Alahalli areas, Mandya district, Karnataka (303 kg), Jangapara, Jharsuguda district, Odisha (472 kg) and Kuberpur- Hathichua areas, Surajpur district, Chhattisgarh (301 kg).

Beach Sand and Offshore Investigations

Survey (Reconnaissance:439sq km and detailed:13sq km) and prospecting (drilling, sampling and evaluation) were continued along the coastal tracts of Andhra Pradesh, Odisha and Tamil Nadu to establish additional beach sand mineral resources.

Exploration/Evaluation

Conrad bunka drilling has been carried out in 1,163 boreholes with a cumulative depth of 5,472.30m and 3,736 samples have been generated.

The following potential heavy mineral zones have been delineated:

Melamvaripalem- Vadlavaripalem (Narasapur deposit, Phase-III), West Godavari district, Andhra Pradeshwith upto 45% THM concentration.

Baipalli-Gunupalli coast, Srikakulam district, Andhra Pradesh with upto 36% THM concentration

Red sediments of Koyyam - Konada, Srikakulam district, Andhra Pradesh with upto 36% THM concentration.

Mining leasehold areas of IREL, OSCOM in Ganjam district, Odisha with up to 71% THM concentration.

Resources

The country's total heavy mineral resource was updated to 1,173mt which includes 648mt ilmenite, 34mt rutile, 12.47mt monazite, 36mt zircon, 187mt garnet and 255mt sillimanite.

Mining & Mineral Processing

Mining and processing of uranium ore in India is done by the Uranium Corporation of India Ltd. (UCIL). The corporation operates in Jharkhand state with seven mines at Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, Banduhurang, Mohuldih and two processing plants at Jaduguda and Turamdih. Mine and mill constructed at Tummalapalle, Andhra Pradesh has started delivering product. The Indian Rare Earth Limited (IREL) is a Mini Ratna (Category-I) Company and it is engaged in mining and production of beach sand minerals and rare earth compounds. The minerals produced by IREL find use in the Nuclear Power Programme and wide ranging industrial applications. The minerals separated by IREL from the beach sand at its three units located at Chavara, Kerala; Manavalakurichi, Tamilnadu and Chatrapur, Odisha are ilmenite, rutile, leucoxene, zircon, monazite, sillimanite and garnet. IREL also produces uranium, thorium and rare earth compounds.

Uranium Corporation of India Limited (UCIL) is mandated to engage in mining and processing of uranium ore in the country and has the sole responsibility to meet the nuclear fuel needs of the growing indigenous nuclear power programme.

UCIL continues to perform satisfactorily in all its operating units in Jharkhand and Andhra Pradesh with seven mines and two ore processing plants in the State of Jharkhand and one mine and one processing plant in Andhra Pradesh.

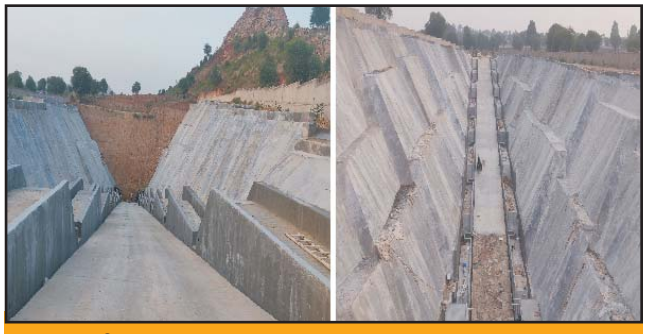
Tummalapalle plant has achieved highest ever production during 2018-19, despite severe socio political disturbances in the region.

In a major breakthrough in Industrial relations, for the first time in UCIL history, the Wage revision settlement in respect of workmen (due from 01.04.2018) has concluded for a period of 10 year

(earlier always 5 years). The same is under the process of approval at DAE.

The Project Appraisal Committee (PAC) of department has given its recommendation for approval of Musabani Uranium Recovery Plant Project, Jharkhand. Govt. land has been transferred to UCIL. Consent to Establish (CTE) from Jharkhand State Pollution Control board (JSPCB) has been received. Construction of boundary wall and other enabling work will be taken up soon.

Exploratory mining activities are in progress at Rohil uranium project. The development of 8^0 decline has progressed up to 105 meters (16.5meter vertical). UCIL has signed a MoU with 'Sikar Muncipal Council' for supply of water to the project. Technical design of water supply pipe line and pump has been submitted by Sikar municipality which is under review by consultant.



8^0 decline development at Rohil Project

The Atomic Energy Commission (AEC) has accorded in-principle approval of thirteen Projects of UCIL which consist of new mines and plants as well as expansion projects for existing units. The total estimated cost for the thirteen projects is Rs. 10571.21 Cr. Pre project activities such as laboratory and geo-technical studies, pilot plant studies, preparation of Feasibility Report, Detailed Project Reports, applications for clearances and approvals, land acquisition, etc. have been initiated for 10 projects.

UCIL continues to maintain the ISO 9001:2008 certifications for Quality Assurance, ISO 14001:2004 certification for Environmental Management System and IS-18001: 2007 certification for Occupational Health and Safety Management System. Risk assessment and Management are also covered under the IS-18001:2007 certification. Narwapahar township of UCIL in Jharkhand continues to hold its certification for ISO 14001:2004 (Environmental Management System) by TUV/NORD.

At IREL, production of Nuclear Grade Ammonium di-Uranate (NGADU), Mixed Rare Earths Chloride (MRECL) increased by 6.4% and 29% respectively compared to similar period during previous fiscal.

Production of minerals increased by 30% compared to similar period during previous fiscal.

IREL implemented flow sheet developed by BARC and has produced 50 kg Nuclear Grade Gadolinium Oxide (99.99%). Same can be converted into Gadolinium Nitrate which is used by NPCIL.

Gadolinium Nitrate

Established Brownfield Private Freight Terminal (PFT) on existing railway siding at OSCOM, Odisha as per Ministry of Railways' guidelines and an agreement with M/s Gopalpur Ports Limited is signed for commercial utilization.

Environment Clearance and Consent for Establishment received for the Rare Earth Permanent Magnet Plant in BARC Campus, Vizag. Detailed Engineering in progress and clearance from Design Safety Review Committee (DSRC) and Safety Committee (SC) of BARC are awaited for preparing the final drawings. Agency shortlisted for taking up procurement, construction, erection and commissioning of the plant on LSTK basis. Selection will be carried out after receipt of clearance from DSRC & SC, BARC.

At BARC, using Alkyl Phosphine Oxide solvent, 99% pure hafnium oxide was recovered from scrub

raffinate obtained from Zirconium Oxide Plant, NFC. 25% of the hafnium present in the scrub raffinate was recovered.

A real time ventilation system was developed for time monitoring, logging and trending of the major ventilation parameters (negative pressure, exhaust air velocity and fume hood duct velocity) in the Beryllium facility. Ventilation is an essential engineering safety control for Beryllium plant operation to control the exposure within safe limit.

Nuclear Fuel Fabrication

Nuclear Fuel Complex, a constituent unit of DAE in its Industries Sector is engaged in the production of natural uranium oxide fuel bundles for PHWRs, enriched uranium fuel assemblies for BWRs, Reactor Core Structurals, Reactivity Control Mechanisms and special materials like Tantalum, Niobium etc. In addition, NFC produces all the core sub-assemblies and other critical components like fuel cladding tubes, Hexagonal wrapper tubes etc., made out of special stainless steels/ D9 materials for Fast Breeder Reactors. NFC also caters to the demand of high quality Stainless Steel Tubes/ Pipes, Nimonic-75 tubes, MDN-250, MDN-350, MDN-59, SuperNi-42 tubes and Titanium alloy products for critical and strategic application in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

PHWR fuel

NFC has successfully manufactured PHWR fuel bundles from UO_2 powder to pellet route and met the requirement of fuel bundles for all the PHWRs in time. All the indigenous raw material in the form of MDU/ HTUP/SU received from M/s UCIL was converted into 19 element and 37 element fuel bundles for meeting the requirement of Out of Safeguard (OSG) reactors.

NFC has successfully established production facilities for production of 37 element fuel bundles in IAEA safeguarded facilities with modified bearing pads for upcoming 700 MWe PHWRs. NFC has achieved production of 557 MT of PHWR fuel bundles and 246 MT of pellet packing in addition to bundle production in the financial year till December, 2019. About 96 nos. of BWR fuel assemblies have been produced and another 8 nos. are under production. 80 nos. have been supplied & another 24 assemblies shall be dispatched by January, 2020 to meet the re-fuelling requirement of TAPS-3.

The Uranium Oxide Plant (UOP)

UOP at Nuclear Fuel Complex produces Uranium oxide powder by processing imported Uranium Ore Concentrates. Numerous innovative process development and modifications were carried out which resulted in increasing the plant capacity by many folds without any addition of major infrastructure.

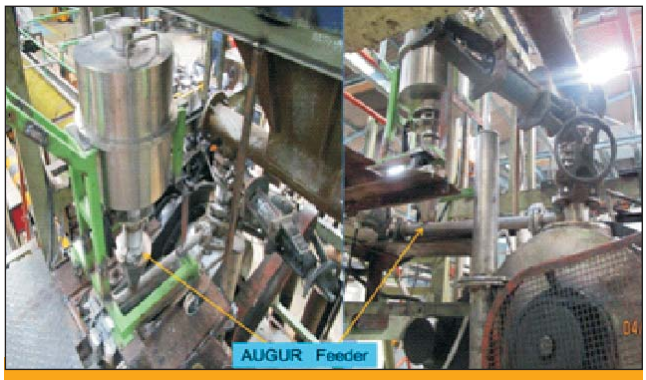
Developmental works at UOP Plant

Processing of Uranium Ore Concentrate (UOC)

Uranium Ore Concentrate received from Cameco, Canada contains high content of Molybdenum (Mo). Molybdenum is not separable from uranium by using the existing TBP solvent extraction process and resulted in impure product. Lab scale and pilot scale experiments were carried out to separate Molybdenum from uranium bearing solution. Ferric nitrate was found to be good complexing agent in presence of phosphoric acid for separation of Molybdenum with high decontamination factor. UOC containing 200 ppm of Molybdenum content was successfully processed in plant scale level to produce 7.3 MT of UO_2 powder meeting the quality requirements.

Installation of Augur Feeder in the dosing head of Stabilization Unit for addition of U_3O_8 in stabilized UO_2 powder

Addition of small fraction of U_3O_8 was found to eliminate the end capping defects developed during the final compaction process. An augur feeder for dosing of U_3O_8 powder into the Stabilization Unit was successfully installed. This system was equipped with a VFD for precise dosing of U_3O_8 powder into the stabilization unit, which helped in uniform blending of U_3O_8 powder along with the UO_2 powder during the stabilization process.



Augur Feeder

Water flushing provision in the exhaust line of Stabilization Unit

Water flushing provision in the exhaust line of Stabilization Unit

Stabilization is the final process in the manufacturing of nuclear grade sinterable UO_2 powder. In this process, the UO_2 powder which is inherently pyrophoric in nature, is stabilized for further downstream pelletizing operations. The off-gases of the stabilization unit containing entrained UO_2 particles after scrubbing was found to choke the exhaust line frequently which resulted in loss of negative pressure in the furnace. Frequent stoppage of the unit to eliminate the choke resulted in loss of production. A water flushing system was provided in the exhaust line of the stabilization unit for periodic flushing, which resulted in elimination of blockage.

Modification of Turbo Scrubber spray system for improved Air Activity in Turbo Exhaust

The exhaust gases from the Turbo Dryer pass through a Bag Filter and Scrubber System before being let out through the stack. Additionally, a water spray system was installed in the discharge line of the ID Fan for trapping the fine radioactive particles, resulting in controlling the air activity limits in the Turbo Exhaust. The water spray system was further modified for timely and effective sparging which resulted in further reduction in average air activity in Turbo Exhaust by 50%.

Processed Uranium Cake to M/s IREL, Alwaye

During the year 2019-20, NFC has processed the long stored Uranyl Nitrate Raffinate Cake (UNRC) and converted to Processed Uranium Cake (PUC) by thermal treatment. Around 30 MT of PUC was produced containing 1.3 MT of valuable uranium. The PUC, as produced, is free from moisture, nitrates and other volatile material. The entire PUC material was sent to M/s IREL in 9 batches for uranium recovery. A cumulative quantity of 113.5 MT PUC have been processed in the plant and sent to M/s IREL.

Automated Pellet boat transfer system

An automated guided vehicle, material handling conveyors and supervisory software modules were installed at the new uranium oxide fuel production plant in NFC, Hyderabad for fabrication of PHWR fuel pellets. The system is configured for picking up boats from a designated compacting press, delivering them to a selected sintering furnace, picking sintered boats from the furnace output, delivering them to the conveyor at the disassembly station and transporting the empty boat components back to the compacting press.

Ceramic Fuel Fabrication Plant – Pelletizing (CFFP – P)

CFFP (P) is involved in the production of natural UO_2 sintered pellets from the nuclear grade UO_2 powder received from UOP through conventional powder metallurgy route. The plant has achieved production of about 486 MT of finished UO_2 pellets during this period. Some of the achievements during the year includes set-up of new packing facility and development of new packing software meeting to international standards of nuclear material accounting for storage of UO_2 fuel pellets; Second rotary press was successfully commissioned and qualified for regular production of fuel pellets and New sludge handling system is developed for further control of air-borne activity in Center-less Grinding Operation.

Ceramic Fuel Fabrication Plant – Assembly (CFFP – A)

CFFP-A has produced 243 Te of fuel bundles till the end of December-2019. The major achievements includes successful completion of the erection, commissioning and qualification of Automatic End Plate Welding Unit comprising of 02 nos. of welding stations and a Robot arm for bundle handling. The unit has built-in features & interlocks for weld quality monitoring & control and operator's safety. The addition of the unit to the existing 37-e bundle production line has enhanced the production capacity with increased productivity, quality & safety.

Natural Uranium Oxide Fabrication Plant – Oxide (NUOFP – O)

NUOFP (O) successfully produced 33.291 MT of $DDUO_2$ powder in April-May 2019 as a part of special requirement by Atomic Fuel Fabrication Facility, Tarapur and Prototype Fast Breeder Reactor, Kalpakkam. The entire campaign was carried out safely without a single incident of higher air activity beyond the permissible Derived Air Concentration (DAC) limit of 1 Bq/m^3. From April'19 to December'19, NUOFP (O) has dispatched 3 consignments of 8 MT of Processed Uranyl Cake obtained through calcination of Uranyl nitrate raffinate cake to M/s IREL for Uranium recovery. About 25 kl of Acidic Raffinate Solution (A.R.S.) was produced by treating Uranyl Nitrate Raffinate (UNR), generated during solvent extraction process, using new processing methodology. This is being disposed through sale. In addition, 50 kl of low Uranium bearing aqueous solution was converted into solid cake, for easy handling and Uranium recovery. Provision of a dedicated DM water tank with temperature interlock was installed for automatic DM water addition in pellet dissolution tank, in the event of temperature shoot-up during acid addition for dissolution of recycle and rejected Uranium pellet/powder/cake, resulted in enhanced safety of dissolution operation.

Natural Uranium Oxide Fabrication Plant – Pelletizing (NUOFP – P)

Processing of Deeply Depleted UO_2

The plant has successfully processed $DDUO_2$ powder converting in to fuel pellets to fulfil the requirements of NPCIL for KAPS-3 & 4 initial core. Also $DDUO_2$ material was processed for making pellets for blanket fuel assemblies of forthcoming PFBR Reactor at Kalpakkam, Chennai. For processing of DDU material a HEPA bank was introduced at the flame exhaust of sintering furnace to ensure gaseous radioactivity discharge as minimum as possible following ALARA principle.

Development of Bowl feeder for centre-less grinding machine

Manual pellet charging system is replaced by automatic feeding system after introduction of Bowl feeder in centre-less grinding machine. This eliminated in manual pellet discharging operation with ergonomic advantages and reduction of dose to the operators in the plant.

Introduction of Auto pellet stacking machine

A vision based Robot aided automatic fuel pellet stacking machine was put into regular production for preparation of fuel stacks for subsequent fuel loading operation in to clad tubes, which reduced the fuel loading time and dose to the operators.

Mechanized UO_2 granule transfer for final compaction press

The plant has conducted satisfactory trial of mechanical alignment for UO_2 granule transfer system. On successful introduction of this system, drastic control of airborne radioactivity in the shop floor is expected.

Successful shop floor demonstration of Automatic Guided Vehicle (AGV) for movement of UO_2 pellets

An Automatic Guided Vehicle (AGV) developed by DRHR, BARC for automatic movement of UO_2 pellets between green pellet production station to

Successful shop floor demonstration of Automatic Guided Vehicle (AGV) for movement of UO2 pellets

sintered pellet discharge station. The AGV was commissioned at NFC and was put into shop floor trials successfully demonstrating the operation of AGV system.

Natural Uranium Fuel Assembly Plant (NUFAP)

The plant has achieved production of 313 MT of fuel bundles during this period. Some of the achievements includes iintroduction of modified bearing pad design in bundle manufacture of 37 Element PHWR Fuel assemblies for 540 MWe Reactors as per NPCIL requirement. Commissioned a Portable Exhaust System for manufacturing and supply of special fuel bundles (DDU bundles) for initial charge of 700 MWe PHWR, KAPS Reactors and supplied 564 Nos. (12MT) of these bundles well in advance. Installed an in-house developed automatic element weighing system for weighing of fuel elements for ensuring the element weight and Implemented a unique and new bundle numbering system for both 19 & 37 Element PHWR fuel bundles.

Equipment Development & Automation (ED&A)

Automatic Pellet Loading Unit – 1

Automatic pellet loading machine has been developed for automation of UO_2 pellet loading operation. This is a first of its kind machine that has been developed fully in-house in ED&A. The salient features are, all the 19 pellet stacks can be loaded simultaneously into 19 tubes using linear vibrators that are assisted by pushers. These pushers are driven by ball screw coupled with geared motor; automatic lifting & weighing of empty tubes and loaded tubes and automatic updating of empty tubes and loaded tubes' weight into MAPDS.

Integrated Spacer Pad & Bearing Pad Welding Units for NFC-Kota Project

As a part of the requirements of NFC-Kota, the first appendage welding unit has been made. The salient features are, the unit can weld spacer pads and bearing pads on empty tubes in fully automatic mode; Making of this unit consists of component fabrication, assembly, delivery, commissioning and qualification; All these activities have been completed successfully and one such unit is already made and this unit is currently deployed for production at NFC-Hyderabad till it gets shifted to NFC-Kota.

Special Valve design for Automatic Granule Transfer System

An Automatic Granule Transfer Unit required for transfer of UO_2 powder from SS container to the hopper of the rotary press has been earlier designed and supplied for carrying out production. In order to further improve the performance, a new design of the valve was introduced to enhance smooth transfer of granules from container to the hopper of rotary press. The specially designed valve ensured that leakage of powder during the transfer is nearly negligible.

Enriched Fuel Fabrication Plant (EFFP)

Received two (02) consignments of enriched fuel pellets from Russia, one in the month of June containing 28,279.139 kg (U) and the other in November containing 28,501.647 kg (U) towards meeting the fuel requirement for TAPS 1 & 2 Boiling Water Reactors for four (04) years from 2019-20 to 2022-2023.

Metallic Fuels

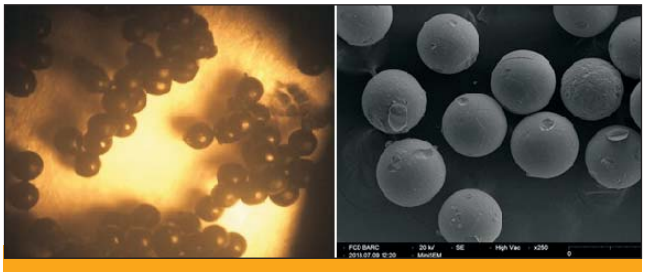
About 30 Tons of nuclear grade Uranium metal (450-850 kg/batch) was produced and supplied for research reactor fuel fabrication. By establishing a new reaction vessel, Uranium metal Ingot batch size has been increased to 1000 kg/batch. About 1 ton Uranium was recovered by processing 20 tonnes of MgF_2 Slag – a by-product of Magnesio- Thermic Reaction. A process involving selective leaching of calcium oxide, which results in Uranyl Nitrate Solution (UNS) with higher uranium concentration (10-12 gpl) was

1000 kg Uranium metal ingots

developed. Using the process, about 4.33 kg of uranium was recovered with 99.5% efficiency.

A real-time resistance spot welding monitoring system for improved weld operations was installed at IF3. The system is equipped with DSP-FPGA based data acquisition & processing system, weld monitoring algorithm and operator GUI to monitor electrode voltage and current during the weld process.

UO_2 microspheres of different sizes ranging from 300 to 500 micron with oxygen to metal ratios of 2.00, 2.08 and 2.15 were prepared and characterized using XRD and TG/DTA techniques. The isotopic composition of uranium was determined using thermal ionisation mass spectrometry. About 8 Kg of UO_2 microspheres were supplied as per the requirement.



Micrograph of chromium hydroxide microspheres, and SEM image of morphology of the sintered chromium oxide microspheres

Analytical methods using DC arc atomic emission spectroscopy were developed to determine trace metallic impurities for uranium silicide (U_3Si_2 dispersed in Al) matrix being used in Apsara-U reactor whereas major elements were determined using EDXRF technique. 130 Pu bearing nuclear material samples were analysed for their trace metallic content using DC-arc technique. More than 450 samples were analyzed for U, Pu, B, Mo, Li and Ga content and their isotopic composition to support the nuclear fuel development program.

Structural Materials & Components

Zirconium activities

Zirconium Oxide Plant (ZOP)

An improved process for production of high purity HfO_2 powder is developed. 5 Kgs of high pure Hafnium oxide (%Hf > 99%) produced in this route. This new process facilitates operation of HfO_2 plant in-tandem with Zirconium Oxide plant, use of established and easily available TBP for purification, generation of known and easily disposable liquid effluents and requires smaller size of process equipment.

Zirconium Sponge Plant (ZSP)

The Plant has produced 337MT of reactor grade Zirconium sponge. The major achievements during the year were zircaloy Scrap processing capacity enhancement from 15 MT/ month to 18 MT/ month through modification of the chlorine distributor of scrap chlorinator. Efficiency of Chlorine scrubbers has been improved through introduction of full cone nozzles and increase in Capacity and Head of Scrubber pumps. Modified bleeding scheme developed in Reduction Operation with the benefit of 20% reduction in cycle time for enhanced productivity and more than 2% in increase in recovery. A special exhaust system has been developed for chlorinators to improve working & surrounding environment during Zirconium tetra chloride discharge operation. Shredder for Size Reduction of Zirconium Sponge from 400 mm to 50 mm has been conceptualized. This Shredder will be helpful in elimination of safety hazard associated with size reduction operations on hydraulic presses; mechanization of Sponge size reduction operation and productivity enhancement. Provision of bypass arrangement for roots pump in all the vacuum distillation units for effective removal of gases in pre-distillation stages to enable smooth operation. Introduction of PID temperature control with thyrister in one of the Kroll's reduction units for precise control of temperature which is an important parameter for product quality & recovery.

Zircaloy fabrication

3780 MT horizontal extrusion press is a unique facility wherein the hot working of all the materials required for various applications of DAE, Space and Defence are carried out. In addition to regular hot working (extrusion) of zircaloy and stainless steel materials required for PHWR, BWR and FBR programs, development of hot working for several other strategic materials was carried out.

Manufacturing of Incoloy 800 alloy Steam generator tubes for 700 MWe PHWRs

Incoloy 800 alloy steam generator tubes are being manufactured for upcoming 700 MWe PHWRs.

These tubes are being produced for the first time from input billets sourced from India. About 1000 numbers of billets have been successfully extruded with excellent surface characteristics. These will be further processed to produce U bend tubes of size 19 mm outer diameter & 1.1 mm wall thickness.

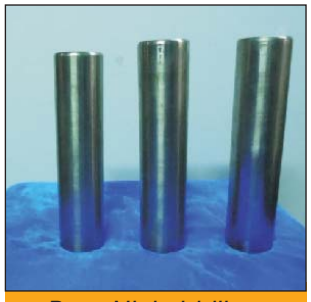
Compaction and extrusion of Oxide Dispersion Strengthened (ODS) Steel alloys for strategic applications

Oxide dispersion strengthened steels, potential materials for high temperature applications have very narrow hot working range. Six numbers of Powder filled billets have been successfully hot compacted and hot extruded to rods.

As extruded ODS rods

Extrusion of Pure Nickel tubes for Fast Breeder Reactor Programme

Pure Nickel billets were successfully hot extruded to tubes as per the requirements.



Pure Nickel billets before extrusion

As Extruded tubes of Pure Nickel

Augmentation plan for Hot Working Facilities

In order to cater the increased requirements of Fuel tube production for the upcoming 700MWe Pressurized Heavy Water Reactors, existing extrusion capacity is being enhanced from 13000 extrusions / year to 27000 extrusions/year. New Extrusion and Fuel Tube Facility has been proposed. Initiative for procurement of the major equipment have been initiated. The complete facility is scheduled to be in operation by the year 2024.

Fuel Tubes

Fuel Tube section manufactures tubes of different size & of different material for Indian nuclear reactors & other strategic application. In this financial year 2019-20, apart from zircaloy tubes required for fuel bundles for 220MW, 540MW and 700MW reactors, this plant produced and delivered bulk quantity of tubes of SuperNi 42 & Zr 1%Nb required by BARC for strategic purposes.

The plant has produced 4000 nos. of BWR fuel tubes equivalent to one BWR refuelling charge and record no. 11 lakh tubes for making 37 element PHWR fuel bundle to meet the requirement of upcoming 700 MWe PHWRs during this period.

Development & indigenization of bulk manufacturing of special material tubes for strategic application

- **Superi Ni Tubes:** These tubes are of various OD sizes approximately 1/3rd the size of PHWR fuel clad tubes and is a bulk requirement communicated by this year by BARC for strategic applications. After initial trial batch, bulk manufacturing of these tubes through 10 stages of thermo mechanical processing followed by final finishing operation, stringent quality checks of mechanical testing, ultrasonic testing, dimensional & visual inspection, the manufacturing route was established. Various process modifications were made during this campaign which significantly improved recovery and thus the productivity.

Super-Ni final tube of OD 13.5 mm x WT 1.2 mm

The Plant has manufactured & supplied different sizes of Super-Ni tubes in bulk to BARC including 400 nos. of 13.5 mm outer diameter X 1.2mm wall thickness X 1100 mm length and 1200 nos. of size 4.5 mm outer diameter X 0.3 mm wall thickness X 1100 mm length.

- **Zr-1%Nb tubes:** Zr-1% Nb tubes with flaring of 14 mm length on one end, 2 mm OD expansion and tapper machining in the other end is also an urgent requirement from BARC for strategic applications, which is taken up in this plant this year. Development was taken up and many challenges were encountered in establishing the end flaring process. These were resolved with split design fixture with 18 stages stepwise expansion to final size. The plant successfully manufactured & supplied 800 nos. of autoclaved Zr-1%Nb tubes to BARC.

Autoclaved Zr1%Nb tube

Structurals

Manufactured about 239 nos. of 220 MWe Pressure Tubes during this period. A total of 95 Zr-1%Nb TUBES (60mm OD X 0.8mm WT) tubes have been supplied to BARC in the financial year 2019-20, thus completing the first requirement of 500 tubes of 1350mm (L).

Manufacture and supply of 47.3 mm A/F x 0.7 mm WT Hexcans

CRTM R 60-160 pilger mill is designed for pilgering ingoing tubes of min OD 60mm. STP engineers have successfully modified the pilger mill to pilger ingoing SS316L tubes of 51mm OD which results in an outgoing hexcan of 47.3mm A/F X 0.3mm WT. These hexcans are required for FBTR. STP has successfully manufactured 65 Nos. of SS 316L hexcans of size 47.3mm A/F X 0.7mm WT.

Manufacture of control rod for Clad tubes for FBTR 45.1mm (OD) x 1.3mm WT

About 23 nos. of SS 316M control rod clad tubes of size 45.1mm (OD) x 1.3mm WT have been manufactured by STP. Lot of challenges were faced during manufacturing of the same. In order to meet the stringent NDT criteria in final stage, new honing rod with assembly was fabricated and utilized to carry out defect correction from ID of the tube in pre-final stage.

Development of process route for 29.5mm (A/F) x 0.4mm (WT) SS321 Hexcan for BARC

Fabrication of SS321 is one of the most challenging task. For the same, lot of care was taken during manufacturing of pre-final passes of the tubes. Further, the final required hexcan size was beyond the capacity of CRTM 60-160 pilger mill, it was decided to take up the same job on HPTR mill. HPTR pilger mill is designed for round to round pilgering process only. However, to manufacture hexcans, the entire tool design was modified, new set of tool were made and few hexcans of size 29.5mm (A/F) x 0.4mm (WT) were made and handed over to BARC for further trials and qualification.

Rolling Mill & Reactivity Mechanism Assemblies

One complete reactor charge of Reactivity Mechanism Assemblies for KAPP-3 is dispatched and reactor charges for KAPP-4 and RAPP-7 & 8 are in different stages of manufacturing and shall be completed by April 2020, July 2020 and December 2020 respectively. Manufactured and supplied: 16 nos. of Cobalt absorber assemblies for 220 MWe PHWR and another 8 nos. will be manufactured and supplied during the financial year 2019-20; 1 no. of Start Up Counter Guide Tube Assembly on urgent basis to KAPS-1 & 2 and 80 Nos. of assemblies consisting of 14 varieties of assemblies for CCTF to RPD, BARC.

A CNC lathe with programmable bar feeder was installed and commissioned for manufacturing of precision turned components up to 50 mm OD directly from bar stock. With bar feeder option, there is significant improvement in productivity and saving of raw material.

Tool Room Treatment Plant (TRTP)

Erection and commissioning of 3D-Coordinate measuring machine

A 3D-Coordinate measuring machine is procured, erected and commissioned in TRTP for inspection of tools. The equipment is highly accurate and enables precise measurement of tools improving the overall quality of tools dispatched from TRTP and reducing the reworks.

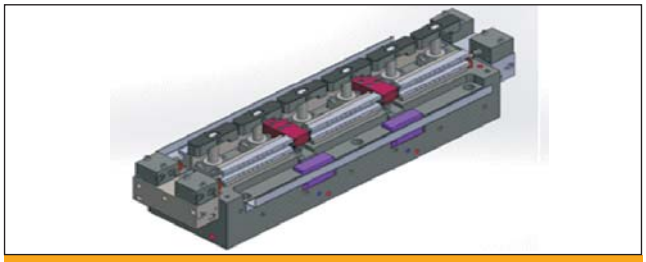
Erection and commissioning of 3D-Coordinate measuring machine

Design and manufacture of tooling for SS304L pipe pass size: 46x5.5-x2.87 on CPM-50 mill for pilgering at higher feed and speed

TRTP designed and manufactured tooling for SS304L pipe pass size: 46x5.5-x2.87 on CPM-50. The tools are designed with double eccentric side relief which allows for pilgering at higher feed and speed. Manufactured tooling are being used for SS 304L production.

Introduction of hard-part milling in manufacturing route for HPTR support plate

To reduce the cycle time without compromising on accuracy and surface finish of HPTR support plate a hydraulic fixture is introduced to clamp the support plate. Close G/D tolerances are ensured on butting faces and references surfaces on fixture to ensure self-aligning of job once it is mounted on fixture. The clamping action is fast as hydraulic clamps are used which operate at a press of button. A power bank of 300 bar capacity is given to provide adequate clamping pressure while machining. The tapers are pre-machine over the face in hardened condition leaving a uniform stock of 0.2 mm to 0.3 mm over the length of support plate for grinding. As such, reducing the total grinding time. It has brought down the total grinding time to 3-4 shifts against the present time of 12 shifts.



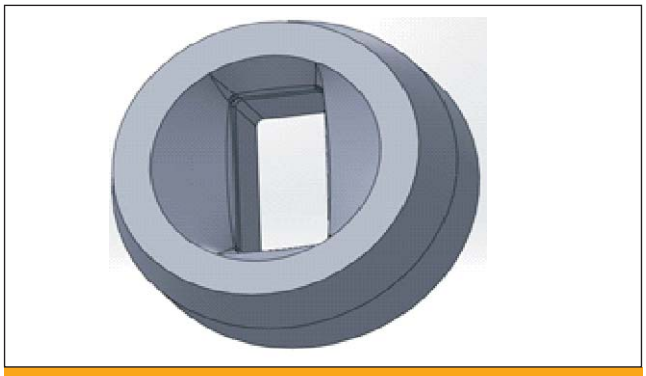
Hydraulic Fixture for support plate clamping

Modification of HPTR roller profile for pilgering of SuperNi-42 tubes

HPTR rollers have intricate profile for pilgering of smaller dia tubes. Flatness was observed on tube while pilgering of SuperNi tube of size 6.3mm (OD) x 0.25mm (WT). The roller profile was modified by increasing the relief section in the profile so to have larger relief portion. The quality of tubes got improved and tubes were pilgered successfully.

Manufacture of die for circular to rectangular extrusion of Zr slab

Cracks were observed on the surface of extruded Zr slabs. The extrusion die being used for extrusion was from rectangular to rectangular cross section extrusion, which was leading to cracks due to non-uniform/non-streamlined flow of material. A new die was designed with circular to rectangular cross section extrusion, CAD model was developed, CAM program was generated cutting parameters were optimized to prevent chattering/vibrations as due to long tool overhang. Bolster plate suiting to the die was also manufactured. The die is being used for the slab production and quality of slabs got improved.



Modified dies for slab extrusion

Special Materials

Development of a modified process for production of Zr2.5Nb alloy through electron beam melting route by using indigenously built 300 kW EBM furnace. This is expected to reduce number of VAR melting due to highly effective removal of harmful interstitials such as chlorine, hydrogen, carbon & phosphorous and also lead to increase in overall process recovery. Introduction of PLC controls in hydriding and dehydriding operations was adopted in production of niobium granules and micron size zirconium powder. This will lead to increased reliability, and safety of these critical operations. Development studies on modification of open Aluminothermic Reduction (ATR) used for niobium thermit by use of graphite liner. Results are highly successful. Development activities taken up in preparation of high RRR grade niobium sheets for applications in super conducting accelerator area. A MoU is being signed for collaborative studies between IITB, RRCAT & NFC. Taken up development of Zr30Ni powder, a product for strategic applications in defence field. Experiments and standardisation of parameters carried out by preparation of trial batches. Preparation of bulk production will be taken up after receipt of order from Ordnance factory. Preparation of high purity silver sheets by multi pass rolling with intermediate annealing of silver sheets to required thickness. These are required for special experimentation in physics division of BARC. Development activities for coating of niobium oxide on Inconel trays used in drying and calcinations of niobium hydroxide by electron beam and plasma technique. Continued preparation and supply of special quality sulphate free ZrO_2 to AFD, BARC for applications in strategic reactor applications. Supplied various high purity materials such as $POCl_3$, selenium, micron size zirconium metal powder, Ta_2O_5, Bi, Zn, Ta powder, low LOI ZrO_2 etc. to BARC, VSSC, industries, educational institutions as per the demand.

Commercial activities

Stainless Steel Tube Plant (SSTP)

SSTP has achieved production value of ₹67.75 Cr. against the target of ₹44 Cr. during this period. Plant has manufactured and supplied critical products which include 13578 nos. of SS-D9 grade Fuel clad tubes for Prototype Fast Breeder Reactor (PFBR), 178 MT of SS304L pipes in 10 different sizes ranging from 13.72 mm to 168.28 mm OD for FRFCF project, 912 m of SS321 pipes for RPD, BARC, 1821 m of Titan-24 (PT 7M) tubes for BARC and Ti-Half alloy tube for DoS-ISRO. It is expected to touch production value of ₹80 Cr. by March' 2020.

Development of manufacturing process of Pure Nickel Grade Tube for PFBR

These tubes are required for critical application of H_2 detection in liquid sodium used in PFBR under severe operating conditions in Liquid Sodium environment at temperatures above 500°C. Earlier these tubes were imported for this application by IGCAR. Though the tubes are highly soft in Annealed condition (Yield Strength - 85 Mpa), limited cold work can be imparted due to higher work hardening and material galling properties. Also, there are difficulties in handling these tubes as they get bent even while lifting.

Modification of Pickling Process for Production of Titan-24 Tubes

During initial development of Titan -24 Tubes, cracks were observed in flattening test and these were seen as surface imperfections in SEM on Pilgered tubes. Surface imperfections were studied and analysed at all stages and to avoid and eliminate these, deep pickling was introduced at intermediate as well as final stages. Process effectiveness was checked through SEM. To improve productivity & surface finish, new set up consisting of distribution manifold with multiple nozzles (13 nos.) was fabricated in house and ID jet picking trial was taken. Pickling solution was pumped through ID for removing surface layer having imperfections.

Modification of Pickling Process for Production of Titan-24 Tubes

Commissioning of new Pilger-mill EPCPM-50

Commissioning of new Pilger-mill EPCPM-50

A new imported Pilger-mill EPCPM-50 has been successfully commissioned to augment the production capacity of long tubes in the range of 10 to 35 mm finished OD. The mill has advanced features such as Tube feeding & turning through motion controller based Servo system; High-speed planetary gear transmission system for Roll-stand motion; Eddy-current based mandrel break detection system, etc. and ID lubrication system with pumping facility to circulate highly viscous TDN-86 oil.

Development & manufacturing of Inconel-617 tubes for Advance Ultra Super Critical (AUSC) Boiler application

Inconel-617 tubes for Advance Ultra Super Critical (AUSC) boiler application has been developed & manufactured. Heat treatment parameters were successfully optimized & 6 nos of these tubes were manufactured meeting the stringent specification requirements.

Development & manufacturing of Inconel-617 tubes for Advance Ultra Super Critical (AUSC) Boiler application

Projects

Green field Projects of NFC

NFC-Kota

NFC-Kota, Rawatbhata, Rajasthan, a green field project, is being established to produce 500 tpy of UO_2 Pellets and 65 tpy of Zircaloy Products to meet the fuel requirement of four 700 MWe PHWRs with scope for future expansion of 500 TPY fuel and 100 TPY Zircaloy products.

Major Events/Milestones

Basic site infrastructural activities are completed and construction of Plant and Non plant Buildings is in progress. Commitments worth ₹1000 crores are made and commitments to the tune of ₹700 crores are awaiting final approval for placement of order. Physical progress of the project as on December 2019 is 33.20%. Time and cost overrun proposal for NFC-K Project was cleared by AEC and was put up to PMO's approval. The proposal of manpower was sent to Dept. of Expenditure, Ministry of Finance. About 16 nos. of high value and long lead time Purchase orders were

Health Physics Unit

Transport Management Building

placed for procurement of Machinery & Equipment Viz. Vacuum arc Remelting furnace, Horizontal and vertical vacuum annealing furnaces, Sintering furnaces, Forge & Extrusion Presses and pilger mills. About 37 nos. of tenders are at various stages out of which 2 nos. are ready for placement and 8 nos. in advanced stage of processing. About 77% of civil works of Plant and Non-Plant buildings completed. Lease agreement for land for township has been executed.

Apart from this, 13 sanctioned projects with a total outlay of ₹1423 crores are being executed at NFC, Hyderabad. In principle approval for 8 projects with an outlay of ₹2378 crores was obtained. Out of which sanction was obtained for Augmentation of Township at Zirconium Complex, Pazhayakayal (ATZC) and the project Steam Generator Tube Manufacturing Facility (SGTMF) is awaiting financial sanction from I&M section, 1 project is being put-up to Project Appraisal Committee for approval and balance 5 projects are under DPR preparation stage.

Zirconium Complex

Zirconium Complex (ZC), Pazhayakayal, Tuticorin, Tamil Nadu is set up to produce 250 MT per annum of nuclear reactor grade Zirconium Sponge starting from washed and dried frit (crude zirconium hydroxide). Around 353 MT of nuclear pure zirconium oxide and 230 MT of Reactor grade zirconium sponge have been produced during this period.

Magnesium Recycling Technology Development & Demonstration Facility

Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF) is being set up under a MoU between NFC, HWB and DMRL. Civil works for construction of plant buildings have been completed. Procurement of various equipments are in various stages of the process.

Technology Demonstration Unit for 1.5 Ton Zirconium Sponge Batch

A Technology Demonstration Unit has been set up to scale up the zirconium sponge batch size from the present 750 kg to 1500 kg. Ten batches have been processed successfully.

Production Capacity expansion

The existing production capacity of the plant is 250 TPA of reactor grade zirconium sponge. Based on the projected future zirconium sponge requirement, it is planned to expand the capacity of the sponge production by 400 TPA with a capital outlay of Rs.1140 Crores. Detailed Project Report (DPR) preparation has been completed.

Augmentation of Amenities and Infrastructure (AAIS)

In order to improve the security infrastructure of the plant, fixation of Y angle with barbed wire fencing & concertina coil on the compound wall and peripheral road laying with black topping for a length of 10 kilometers have been completed at a cost of ₹3.93 Crore. A zirconium sponge storage shed of size (66m x 25m) has been constructed at a cost of ₹2.61 Crores to facilitate intermediate storage of zirconium sponge before supplying to NFC (H) for further processing.

Atomic Energy Central School

Atomic Energy Central School (Classes up to 5th standard) is functional. Construction work for permanent school building is in progress with a capital outlay of ₹7.17 crore and expected to be completed by May 2020. It is proposed to start classes up to 8th standard in the new school building from the next academic session.

Community Hall at ZC Township

In order to cater to the recreational requirements of the families of ZC employees and CISF, it is proposed to construct a Community Hall at an estimated capital outlay of ₹5.6 Crore and tendering is in progress.

Augmentation of ZC township infrastructure

In order to cope with the requirement of expansion of sponge production, augmentation of infrastructural facilities like construction of additional residential quarters, expansion of Guest House and laying of peripheral roads are planned with a capital outlay of ₹65 Crore. Financial sanction is obtained and tendering work is in progress.

BACK END FUEL CYCLE

Fuel Reprocessing

By employing Carbon reductant based thermochemical de-nitration technique, over 99% of sodium nitrate generated in Nuclear Fuel Cycle operations was de-nitrated in a fluidized bed reactor at 500^0C. X-ray diffraction spectrum confirmed the crystal structure of the product which matched with Na_2CO_3 data. The obtained sodium nitrate could be converted to Washing Soda - which is a non–hazardous form of waste, which can be safely disposed.

The process of recovery of pure ^{90}Sr (free from radio-chemical contaminants) from HLLW using multi-step separation processes was standardised. Bulk ^{90}Sr was separated from HLLW along with actinides and lanthanides using solvent extraction technique. Multi-step separation processes at laboratory scale were developed to recover 2 Ci ultra-pure ^{90}Sr solution. Carrier-free radiopharmaceutical grade ^{90}Y was successfully milked from ^{90}Sr-^{90}Y solution. Using Supported Liquid Membrane (SLM) generator, more than 15 batches of 150 mCi of ^{90}Y were produced for radiopharmaceutical applications.

Around 350 Kg of Uranium was recovered from 22,000 litres of acidified HLLW through a three-step separation process involving TBP. Calyx crown and TEHDGA solvents were used for separation of Cs, Sr and actinides. The innovative method based on partitioning of the radio-elements from inactive salt constituents, led to multi-fold reduction in volume of nuclear waste generated. 50000 Ci of Cs-137 was concentrated and vitrified to produce 41 Cs-137 pencils with 4.5 Ci/gm specific activity for use in blood irradiator. The Sr-An-Ln product stream was concentrated and vitrified using induction heated metallic melter to produce three vitrified canisters containing total glass of around 285 Kg.

Total 79,000 kg of protective wears were collected, decontaminated and recycled. Around 25 Te of aluminium cut end rods of Dhruva were safely handled and decontaminated for reuse in routine operations.

^{106}Ru was recovered from HLLW through a multi-step process starting with oxidation of the radioelement followed by its extraction in chlorinated carbon tetra chloride, stripping in acidic hydrazine solution. ^{106}Ru was then electrodeposited on a silver plaque which is used as a radiation source for brachytherapy. 15 such ^{106}Ru bearing brachytherapy sources were produced for treatment of eye cancer.

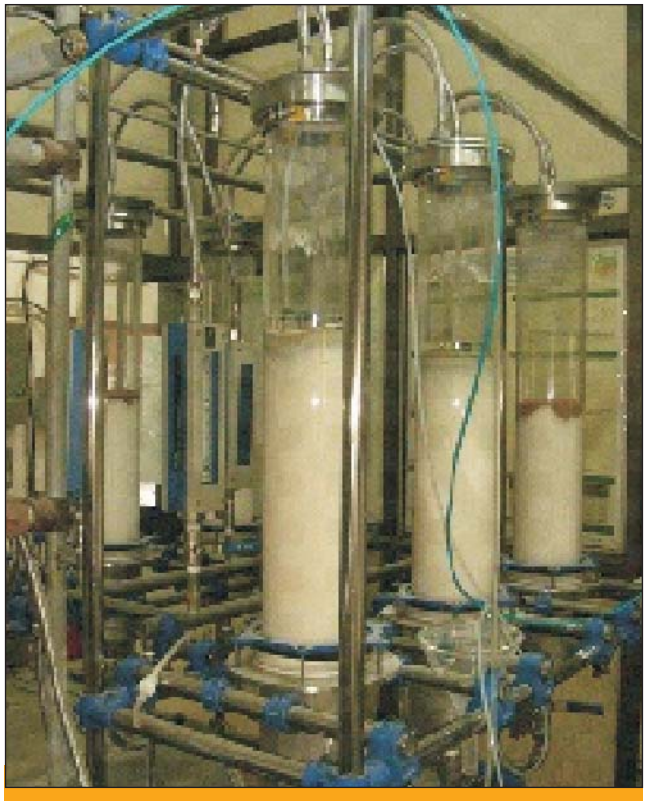
Minor Actinide Product Conversion Demonstration System (MAPCDS) was set up in Tarapur nuclear power plant for downstream processing of alpha product stream emanating from the plant's PHWR spent fuel reprocessing ASDF facility. MAPCDS was successfully hot commissioned by processing actinide stream of ASDF for recovery of minor actinides. Work is underway for improving the purity of alpha product (minor actinide).

The Induction skull melting facility was regularly operated to produce 200 kg of Aluminium-Silicon alloy taking the cumulative production of the alloy has exceeded 600 kg. The facility was also used for producing high purity Zr-Cu alloy, high purity specimens of high temperature alloys, including alloys of Nb. A high entropy alloy was also produced by melting and homogenizing Al, Zr, Nb, Ti and V. Melt densification studies were done using Zr-SS in order to obtain operating parameters and volume reduction factor.

Waste Management

A 60 m long waste transfer trench was built for transfer of High Level radioactive Liquid Waste (HLLW) from pump house in Waste Immobilisation Plant to AWTF and vice versa. The trench was hot-commissioned on 22nd Nov 2019 by transferring 1500 litres of HLLW from Plutonium Plant to AWTF via Pump House tank after obtaining necessary safety clearances. Constructed at an elevation of 3m above ground, the trench comprises of 15 Stainless Steel lines with pipe-in-pipe configuration in SS lined RCC/MS shield. Further, A 2.7 km long multiple-segmented seismic-qualified pipeline was also commissioned for transfer of low level nuclear waste between the Plutonium Plant and Effluent Treatment Plant at Trombay.

About 500g of Di-tertiarybutyl dicyclohexano 18 crown 6 ether (DTBDCH18C6) was synthesised in the bench scale plant by catalytic hydrogenation of the purified DTBDB18C6 with about 35% purity and 85% yield. It is used for separation of strontium from high level radioactive waste. Improvements carried out in columnar purification process resulted in 95% pure DTBDB18C6, the precursor for synthesis of DTBDCH18C6.



Apparatus for catalytic hydrogenation

550 m^3 of radioactive solid waste generated was disposed in Near Surface Disposal Facility (NSDF), Trombay after volume reduction. This waste is safely managed in disposal modules to isolate from the environment. Three spent resins of 50 Ci activity generated from Dhruva operations were immobilised at the resin fixation facility and safely disposed of in reinforced concrete trenches of NSDF.

Rubber and plastic waste contribute around 75% of total combustible radioactive solid waste. About 500 kg combustible radioactive rubber and plastic waste was incinerated in a plasma incineration demonstration facility at high temperature, without releasing toxic gases.

Safety Performance of Reactors

NPCIL is responsible for performing the safety analysis including deterministic and probabilistic safety assessment of nuclear power plants for design, siting, commissioning of new projects; and safe operation, periodic safety review, extension of operating license/ life management of operating plants, and also for obtaining regulatory clearance for the projects and operating stations.

Comprehensive Fire Hazard Analysis of KAPP-3&4 has been submitted as a part of hot-conditioning application to AERB. Level-2 Probabilistic Safety Assessment (Full Power Internal Events**)** of KAPP 3&4 have been completed.

The thermal hydraulic analysis is carried out for handling of Spent Fuel Bundle in Station Black Out scenario in 700 MW Indian PHWRs. The experiments for estimation of removal rate of Cesium Iodide (which is released in the form of aerosol) due to Containment Spray System **(**CSS) was carried out at R&D centre, Tarapur Maharashtra Site (TMS) successfully and it is assessed that CSS removes aerosol very effectively.

CSS Experimental Facility

Radiological Impact Assessment (RIA) using verified and validated codes have been completed for various projects.

NPCIL is participating in Organization for Economic Co-operation and Development (OECD)/ Nuclear Energy Agency (NEA) Thermal-hydraulics, Hydrogen, Aerosols and Iodine (THAI) - 3 project activities along with BARC and AERB.

HEALTH, SAFETY AND ENVIRONMENT

Probabilistic Safety Assessment (PSA) Level-3 for 220 MWe PHWR at Kakrapar were carried out to estimate risk, development of protection strategy and emergency planning in early phase of nuclear accident using site-specific meteorological and demographic data. Based on the analysis, Precautionary Action Zone (PAZ) and Urgent Protective Action Planning Zone (UPZ) have been delineated and protection strategy has been developed. Results of PSA Level-1 and 2 studies for 220 MWe PHWR carried out by NPCIL were used in PSA Level-3 for risk estimates.

A dedicated software for Fuel Handling System Dynamic Simulator (FHSDS) was developed for 220 MWe PHWRs. The software was implemented in FHS Training Simulator (FHSTS) of Kaiga Nuclear Power Station (KGS). Implemented in Visual C++, the software uses Proxy pattern in the simulator to allow for the interaction and synchronisation of North and South Fuelling machines during refuelling of a channel. New 3-D consoles have been developed to mimic the actual control panel functions associated with Fuelling Machine & Fuel Transfer operations in Kaiga Station control room. The software application in the consoles is based on Object Oriented Concepts, where various components, e.g. push button, lamp, digital panel meter etc. are developed as a separate class.

Post-Accident Monitoring of Electrical Systems (PAMES) was developed for examining the health of power supply cables in an operating power plant. The system was successfully validated at TAPS-1 & 2, and is extremely useful during post-accident Station Black Out (SBO) scenario in a Nuclear Power Plant.

Radiation Protection and Environmental Surveillance around Uranium Corporation of India Ltd (Jharkhand & Andhra Pradesh), Indian Rare Earths Ltd. (Kerala, Tamil Nadu, Odisha) and Nuclear Fuel Complex (Hyderabad) was carried out. Around 8260 occupational workers were monitored for external and internal radiation exposure in front-end operations of nuclear fuel cycle. Analysis of the data clearly indicated that the occupational radiation doses to workers in underground uranium mines and thorium handling facilities were well within the regulatory limit of 20 mSv/y. Information on the uranium mining and ore processing activities in Tummalapalle region was submitted to Andhra Pradesh Pollution Control Board to allay public misconceptions about uranium mining activities.

Environmental Surveillance at Trombay and Nuclear Power Plant Sites was conducted. The results from various Environmental Survey Laboratories (ESLs) indicate that the dose received by a member of the public at the fence post is a small fraction of the regulatory limit of 1000 μSv/year. Samples of various environmental matrices such as soil, sediment, air particulate matter, water, milk, food items, sea food, grass, etc., upto 30 km distance from the facilities are collected, processed and analyzed using radiometric techniques. A Geographical Information System (GIS) based database was developed covering areas around Nuclear Power Plants using open source data from Spatialite and PostGres to visualise spatial and temporal trends which will of help in emergency response during extreme conditions. Radiological surveillance and radiation protection for back-end fuel cycle facilities such as reprocessing plants, waste management facilities, MOX fuel fabrication plant, PRP, AUGF and RMP located at Tarapur, Kalpakkam and Mysuru were provided.

About 55,554 water samples were collected from various grids across 403 districts pan-India under a collaborative National Uranium Project to analyse presence of uranium and associated water quality parameters. A comprehensive study of distribution and variation of uranium revealed that the uranium concentration in water samples is in the range of 0.2 – 6873 ppb with a median at 1.68 ppb. 97.8% of the samples have been found to contain uranium well within the AERB stipulated limit of 60 ppb for drinking water.

Environmental Gamma Spectrometry System (EGSS) was developed for in-situ identification of radionuclides in atmosphere. The instrument provides isotopic composition in the environment and an estimate of the time varying source term (release rates) in case of an accident at nuclear power plant. EGSS is a battery operated (or solar powered) system with GSM communication.

A non-invasive, rapid and reproducible Urea Breath Test (UBT) for detection of Helicobacter pylori

(H. Pylori) infection was devised in place of painful endoscopy test. Testing is done using 1μCi urea capsules labelled with ^{14}C, provided by BRIT. H. Pylori bacteria in human stomach releases enzyme urease, which breaks urea capsule to release CO_2 tagged with ^{14}C in the exhaled breath.

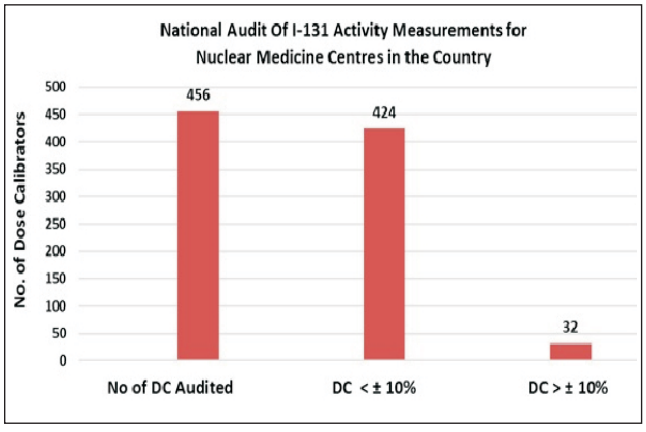
Hydroxyapatite (HAP) coated Activated Carbon (AC) nanocomposite was synthesized for sorption and removal of U, Pb and Cd ions from water. Studies indicated that HAP-AC is a better sorbent for removal of heavy metal ions from water compared to its precursors AC and HAP. The HAP-AC cartridge was effective without altering the physico-chemical properties of water.

A team of scientists from India and US jointly conducted five aerial surveys over land and water for estimation of terrestrial and cosmic background and effective air attenuation coefficient; ground deposition mapping survey of the Nevada Test Site's shallow underground nuclear tests and source search exercise by flying over point sources of Cs-137 and Eu-152 at varying altitudes. Two Aerial Gamma Spectrometry Systems developed by BARC were installed in a Helicopter along with a permanently installed AMS of US Department of Energy.

Radiation Monitoring Watch (RMW) powered by a 3V cell CR2450A was developed for gamma radiation monitoring. It is lightweight, very low power device in the form of a wristwatch and works on energy compensated Geiger Muller tube as the radiation detector. RMW displays persisting dose rate as well as the cumulative dose along with the date and time. The device caters to radiation measurement range from 0.04μSv/h to 4mSv/h. The user is alerted with an alarm whenever the dose rate exceeds the specified threshold.

4π Gamma Ion Chamber

Quality audit of I-131 activity measurements was carried out for 242 Nuclear Medicine Centres (NMCs). About 242 nos. of I-131 sources were procured from BRIT and standardized using 4ð Gamma Ion Chamber maintained as a secondary standard for radioactivity measurements. The standardised sources were dispatched to NMCs for measurements in their dose calibrators. The activity measurements carried out by NMCs were analysed and compared with BARC standardized activity. Certificates were issued to NMCs which are required during AERB regulatory inspection. A total of 456 dose calibrators were audited as many NMCs have more than one dose calibrator. About 424 (93%) were found in good working condition whereas 32 (7%) calibrators were found not working satisfactorily.



Mobile Radiological Assessment Lab (RAL), designed for monitoring of ambient Gamma dose rate, has started operating for Integrated Centre for Crisis Management (ICCM). RAL offers dependable radiation detection in applications such as real-time accident and post-accident scenarios at nuclear facilities, environmental surveys or in response to radiological terrorism.

Mobile Radiological Assessment Lab (RAL)

NPCIL has recorded about 517 reactor years of safe operation of reactors by the end December 2019. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by Atomic Energy Regulatory Board by following the principles of As Low as Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB. NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001:2015 and Occupational Health and Safety Management System (OHSMS) as per IS-18001:2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

Ministry of Environment, Forest and Climate Change (MoEFCC) accorded Environmental Clearance (EC) and National Board for Wildlife (NBWL) accorded Wildlife Clearance for Kaiga Atomic Power Project units 5 & 6 (2x 700 MWe, PHWRs). EIA report & subsequent NPCIL responses to the observations of Expert Appraisal Committee (EAC) for EC for Mahi Banswara Atomic Power Project (4x700 MWe, PHWR) are under appraisal with EAC, MoEFCC. For Nuclear Power Project (NPP) at Kovvada, three season environmental monitoring reports and draft EIA report based on three seasons data are under preparation. Process of obtaining Environmental & CRZ Clearances for Away from Reactor (AFR) for KKNPP-1&2 is in progress.

Industrial and Fire Safety aspects is being ensured through comprehensive Oversight and Support functions. NPCIL takes responsibility for maintaining a safe workplace by minimizing the risk of injury, fire and exposure to ill health for all employees and contractors. NPCIL is strongly committed to convey safety culture and safety values to the employees.

The Environment Stewardship Programme (ESP) is a voluntary activity of NPCIL for the conservation of nature in and around our sites. ESP focuses on the scientific study and conservation of the bio-diversity in and around the Exclusion Zones (EZs) of NPPs.

The association of NPCIL with Wildlife Institute of India (WII), Govt. of India, has enhanced our ESP activities. With WII, NPCIL have done public outreach activity on Clean Ganga Mission. Different activities like, educating fisher men, displaying posters, lectures on clean Ganga to villages, awareness to students on clean Ganga, rescue and rehabilitation of species for clean Ganga mission etc., are done in association with WII. The Turtle facility at NAPS is also enhanced by the expertise help of WII.

Bird marathons are being organized periodically at Kaiga Generating Station (KGS), KKNPP and NAPS to update database on the bird species found in the region with the active participation of professional environment conservation agencies. The artificial Mud-Flat is developed and mangroves are planted in and around township and plant areas at KKNPP with the expert help of Bombay Natural History Society (BNHS). In addition, NPCIL had published five coffee table books viz. “Our Flying Guests” on the birds found within and around all the Indian NPPs, “7 Edens and 70 Fairies” on the butterflies of Indian NPPs, “The Realms of Flowers” on the flowers of the Indian NPPs and “Fliers of Our Courtyards” again on some birds of Indian NPPs. Similarly, latest coffee table book is published with title “100 lives around us”.

Overall safety management was excellent at all Heavy water Plants and there was no unusual occurrence during the period. HWPs Manuguru, Kota, Baroda, Thal, Hazira and Tuticorin were felicitated through awards by reputed organizations like National Safety Council, ICC, FICCI and AERB, for their endeavours to excel in the fields of safety, energy conservation and environment management.

RESEARCH & DEVELOPMENT

NPCIL is engaged in setting up of R&D Facilities and carrying out experimentation, development & qualification of remote tools for inspection/ maintenance of reactor components/ equipment,

Indigenization and activities related to Construction Time Minimization. These activities are aimed towards achieving continual enhancement of nuclear & radiation safety, reliable operation, vendor base broadening, product development and cost reduction of Nuclear Power Plants.

For the year 2019-20, major achievements/ progress derived from the four verticals viz. R&D Facilities, Remote Tooling, Indigenization and Construction Time Minimization are as follows:

R&D Facilities

Primary Coolant Pump Test Facility (PCPTF)

Civil construction and fabrication & erection of structural steel columns are in progress.

Erection of PCP Test Facility Building

Hydrogen Recombiner Test Facility (HRTF)

HRTF continued to support performance evaluation of sample sets from production batches of Passive Catalytic hydrogen Recombiner Device (PCRD) being deployed at various PHWR units. Online Mass spectrometer system was re-commissioned. Operation trials and performance evaluation of Hydrogen and Steam Concentration Monitoring System (HSCMS) prototype were taken up at HRTF.

Fuelling Machine Test Facility (FMTF)

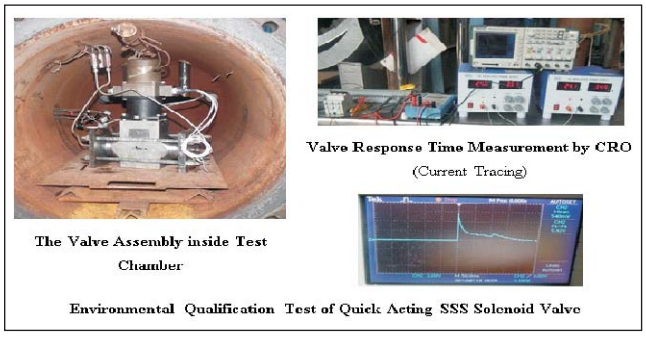
Testing, calibration and qualification of two Fuelling Machines of 700 MWe PHWR were carried out at FMTF. High pressure & high temperature filter along with balance field instruments installed for enhancement of the loop capability. Pressure pulsation related tests were taken up and stage-wise tests are in progress.

Environmental Qualification (EQ) Activities

During the year 2019-20, more than 220 items were subjected to environmental qualification testing for NPP application. Some of the notable activities completed are Validation of proposed design modification in control scheme of Calandria inlet Control Valves for operating PHWRs and Performance assessment of indigenously developed transmitters, etc.

Qualification of Quick Acting Secondary Shutdown System (SSS) Solenoid Valve

Radiation, thermal and accident profile testing of indigenously developed fast acting SSS Solenoid Valve Coils was carried out for KGS-1&2. Subsequently, the Solenoid Valve was qualified with main steam line break simulation profile testing.



Development & qualification of 19 element fuel bundle simulator

Fuel Bundle Simulator was fabricated and experiments were conducted for radiation heat transfer condition studies. The validation experiments were successfully conducted.

19 Element Fuel Bundle Simulator Test Setup

Remote Tooling

Coolant Channel Life Management Related Activities

Pressure Tube In-Service Inspection (ISI) campaigns using BARCIS for 220 & 540 MWe PHWRs (KGS-2, MAPS-1 & TAPS-3) were carried out successfully. These ISI campaigns included volumetric inspection of Pressure Tubes, Sag measurement and material sampling.

Laser Based Tools for Removal of 540 MWe Pressure Tube

Laser cutting technology was developed for the first time for removal of selected single Pressure Tube (PT) of TAPS-4 reactor. The design and development of system included remotely operable Laser Cutting Tools for Liner Tube, End Fitting, Bellow Lip Weld Joint & Bellow Ring and underwater laser cutting of PT Stubs. The system was successfully developed with RRCAT and deployed at TAPS-4.

540 MWe Liner Tube Laser Cutting Arrangement and the Tool

Pre-Service Inspection (PSI) of 700 MWe Pressure Tube

BARCIS Mock-up Facility with flow arrangements and a Control Room was made at KAPP Site for the PSI of Pressure Tubes. Arrangement of tools and gadgets were made. Finalized all the requirements, training imparted to site personnel and system is ready for deployment.

Moderator Heat Exchanger Inspection system

Considering the large requirement at multiple Stations, design and development of integrated delivery system for eddy current inspection of the 220 MWe Moderator Heat Exchanger (HX) Tubes using standard Industrial Robot has been taken up.

The system integrated with standard robot has undergone qualification, delivered and ready for deployment. Development of tooling system for remote operation of eddy current inspection head for 540 MW moderator Heat Exchangers has been taken up. The Remote Tooling being developed can be used for Shutdown Cooling HX and Bleed Condenser HX also.

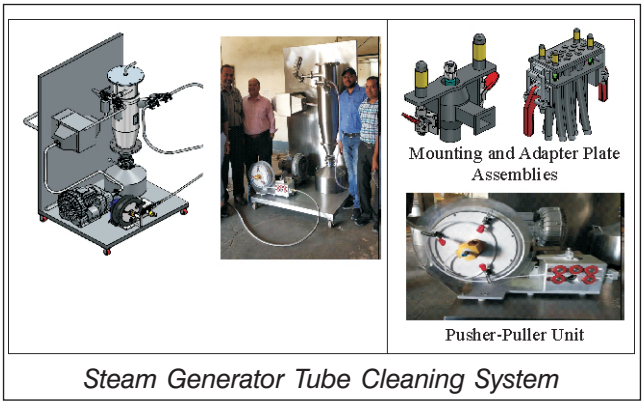
RAPS Positioning system Mock-up

Control Unit of Positioning System

Steam Generator Tube Cleaning System

To enable thorough cleaning of Steam Generator tubes, prior to taking up in service non-destructive examination, an integrated assembly of Steam Generator Tube Cleaning System has been developed

for 220 MWe Reactors and is ready at R&D Centre for Site application.



Steam Generator Tube Cleaning System

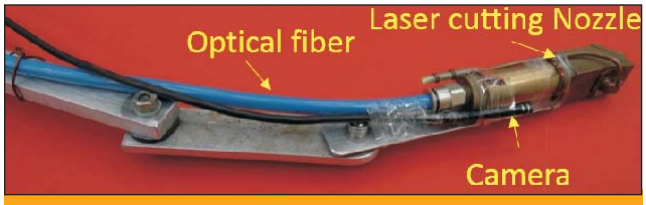
Automated Pipe Cutting and Beveling Machine (APCBM)

An automated remote HX Pipe cutting & weld edge Beveling Machine was developed to reduce radiation dose consumption and saving in human efforts and time during RAPS-2 Boiler Heat Exchanger replacement activity. Complete system is ready for deployment.

Automated Remote Cutting & Beveling Machine for RAPS-2 Hairpin HX 3D Model, Shop Trial and Site Operation Trial

Special Tool for SG Feed Water Box Distributor Plate related activities

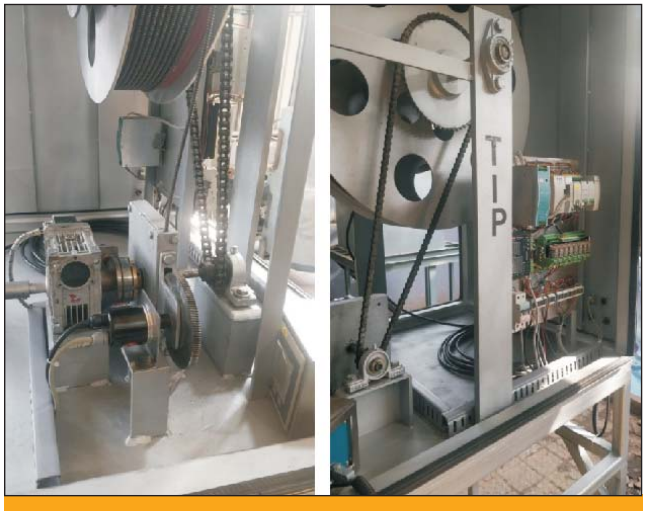
The system developed for Distributor Plate related activities of Kaiga Steam Generator Feed Water Box involves remote inspection, laser cutting of part segment of Distributor Plate and removal of cut section through limited access path. The technology & remote tooling development for removal of part segment from Distributor Plate has been qualified in mock up. Procedure qualification of the laser cutting system carried out at RRCAT.



Laser Cutting Manipulator for Feed Water Box Along With Camera

Travelling In-core Probe (TIP) Drive for 700 MWe

TIP Drive System to measure local neutron flux at various reactor in-core locations within identified Vertical Flux Units for initial phase of 700 MWe reactor start-up has been developed by NPCIL. The TIP Drive System with many innovative features has been delivered to KAPP Site for using in KAPP-3 for in-core data generation and calibration of neutron flux monitors.



Travelling In-Core Probe Drive

Indigenization

Commercialization of indigenous technologies developed in the recent past, has seen successful in bulk production during the period includes 700 MWe Steam Generator Heavy Forgings, large size low cobalt stainless steel plates for End Shields, Electrical Penetration Assemblies (EPA) for reactor containment building etc.

Electrical Penetration Assemblies of 700 MWe Projects

After successful installation & commissioning of 51 numbers of indigenously made factory-built EPAs for LV Power and C&I Cables in KAPP-3, fabrication for other projects is in advanced stage.

Steam Generator Forgings under Manufacture

High Flux Electric Heaters (Pressuriser Heater)

Indigenous development of High Flux Electric Heaters for Pressuriser of 540 MWe and present 700 MWe reactors have been completed.

Pressuriser Heater with Sheath Partly Removed

Thermal Dispersion type Spent Fuel Storage Bay (SFSB) water Level Sensing Unit

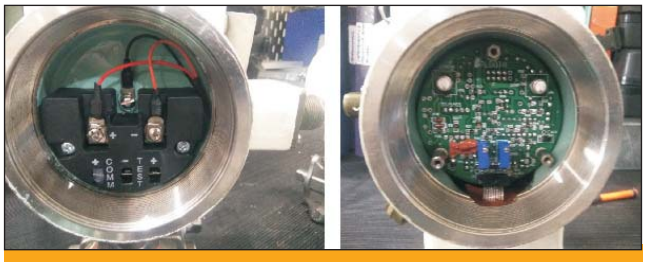
Design and seismic qualification by analysis completed. Prototype development, incorporating additional feature of bubbler method, is in advanced stage of manufacturing.

Proximity Switch

Development of Proximity Switch for radiation field application is in progress. Subsequent to successful environmental qualification of prototype covering radiation, temperature, steam and pressure conditions, manufacturing has been taken up.

Differential Pressure Transmitter

All tests including severe accidents profile tests & seismic tests completed successfully for the Differential Pressure (DP) Transmitter developed by one Vendor. Tests for other vendor are in progress.



Development of DP Transmitter for Severe Conditions

Boiler Feed Pumps for 700 MW reactors

Indigenous development of Boiler Feed Pumps (BFP) for 700 MWe reactors by two vendors are in progress. Hydro test of the first BFP Casing completed. Motor is under manufacturing. Balance activities including other fabrication/ manufacturing activities in progress.

Construction Time Minimization

Single Pass Laser Welding of Lattice Tubes to End Shield Tube Sheet

Subsequent to establishing single pass Laser Welding of Lattice Tube to Calandria Side Tube Sheet joint of End Shields, multiple weld operations were carried out to optimize operation parameters and prove consistency in weld product quality. The welding

Single Pass Laser Welding of Lattice Tubes to End Shield Tube Sheet

operations were carried out using fiber optic Laser with Adjustable Ring Mode Laser Technology.

Automatic Orbital TIG Welding Machine

Indigenous development of Automatic Orbital TIG Welding Machine (AOTWM) was taken up to aid the in-situ welding of new Hair Pin type Steam Boiler Heat Exchangers to primary loop inlet and outlet Headers at RAPS-2, meeting narrow gap space requirements. Based on large number of weld trials, repeatability of consistent quality welds has been established, operation parameters are optimized and the remote operation module qualified along with the AOTWM. It is proposed to adopt same in primary piping for en-masse replacement of Hairpin type Heat Exchangers of steam boilers.

Automatic Orbital TIG Welding Machine

R&D In Electronics, Control & Instrumentation

For Fleet projects, Engineering Workstation (EWS) is being developed. First version of "Engineering Workstation & Interpreter for Programmable Controller" is released, which will facilitate field programmability of control logic using application level "Functional Block Diagram" (FBD) language. It is built on existing control platform (Hardware and Common Software) to make a Safety Programmable Logic Controller. Hardware and software is upgraded for Programmable Digital Comparator System (Process Control) at KAPS-1. For KGS-1 and KGS-3 Emergency Core Cooling System (ECCS) Test Facility (ETF) software and Duel Computer Hot Standby Reactor Regulating System software have been modified to address specific events/ issues.

Engineering

Design, analysis and detailed engineering for various projects and design support for stations are continuing.

Design and engineering support activities were performed for Hot Conditioning of Primary Heat Transport (PHT) system, Emergency Core Cooling System integrated test, Light water commissioning of various systems, Site validation of Commissioned Computer Based Systems, Fuel Handling Control System (FHCS) software installation etc. in respect of KAPP-3.

As a part of demonstration of equipment qualification, completed experimental studies on seismic qualification of Coolant Channel Assembly (CCA) under latched & unlatched condition to Fueling machine for 700 MWe PHWRs.

Seismic Testing of Coolant Channel Assembly

Assessment of Structural Integrity of Calandria-End Shield Assembly by analysis for in-vessel corium retention for 700 MWe PHWRs was completed. Aerosol based fire protection for emergency diesel generator room was introduced for the first time and demonstrated efficacy of same. Full scope Training Simulator for RAPP-7&8 is in advanced stages of commissioning.

For GHAVP-1&2 project, design and engineering is progressing. AERB consent for First Pour of Concrete (FPC) for GHAVP-1&2 is in the advanced stage. Pile testing results were reviewed. Integrated engineering for various buildings up to 109/ 106 M El., Switchyard Control Building, Fuel Handling Mechanical Workshop and Tunnels & Trenches have been completed. Balance civil construction drawings, System and services drawings etc. are in progress. Piping stress analysis of about 100 models including for PHT system & Moderator systems were completed.

For Fleet Mode PHWRs project, plant layout drawings have been completed. Siting consent review for Kaiga-5&6 is in the advanced stage. Design Basis Ground Motion (DBGM) for Kaiga-5&6 was prepared. Excavation application for Kaiga-5&6 along with Preliminary Safety Analysis Reports (PSARs) and geo-technical data have been submitted to AERB. Technical sanction for engineering services contract for Kaiga-5&6 is approved. PSARs Section-2 & 3 for GHAVP-3&4 were prepared and submitted to AERB along with excavation application.

For Operating Stations, Engineering supports were provided for various activities/ analysis including Degradation of Components viz., Snubbers/ Flow Distribution Plates of Steam Generator, experimental studies on seismic qualification of Coolant Channel Assembly (CCA) under latched & unlatched condition to Fueling machine for 540 MWe PHWRs, assessment of Structural Integrity of Calandria-End Shield Assembly for in-vessel corium retention for standardized 220 MWe and 540 MWe PHWRs, etc. Generic ISI document for PHWRs was prepared by rationalizing various requirements based on operational feedback of Indian PHWRs and is under review by AERB.

R&D relating to PHWR

PREssure tube SAg Measurement (PRESAM) inspection system measures local curvature of pressure tubes using a radiation-resistant under-water serviceable Linear Variable Differential Transformer (LVDT). In the new versions PRESAM 220 Mark III and PRESAM 540 Mark II developed for 220 and 540MWe PHWRs respectively, improvements were made with respect to their performance, service life and ease of operation.

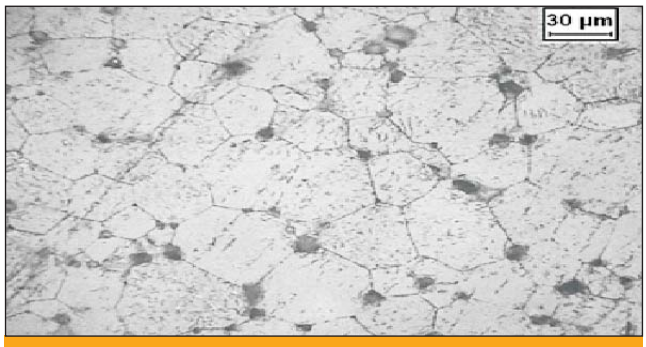
PRESAM 540 Mark II tool-head

During a severe accident in old design PHWRs like RAPS/MAPS, fuel channels may melt and collapse at the bottom of calandria onto the dump tank. With no cooling available, the dump port will eventually fail leading to relocation of molten/solid/semisolid corium debris mass into the dump tank at very high temperature. Fuel - coolant interaction may cause energetic steam explosions which may be a threat to the structural integrity of the dump tank. To assess the integrity of dump tank during such event, several experiments were conducted in scaled facilities with same melt to coolant ratios as that of actual reactor with prototypic melt consisting of CeO_2 (surrogate of PuO_2) + ZrO_2 + Al_2O_3 + Fe at temperature in excess of 2500 °C. During these tests, dynamic pressure pulses ranging from 12 to 55 bar were observed in the tank. However, there was no damage to the dump tank due to steam explosion in all the tests.

To increase the discharge burnup of PHWR fuels in future, few fuel bundles were intentionally irradiated to extended burnups. Detailed examination of a high burnup (22,000 MWd/tU) 19-element fuel bundle showed high fission gas release in outer fuel elements. Microscopic study of fission gas bubbles and noble metal fission products in the fuel using Scanning Electron Microscope (SEM) was carried out for the first time.

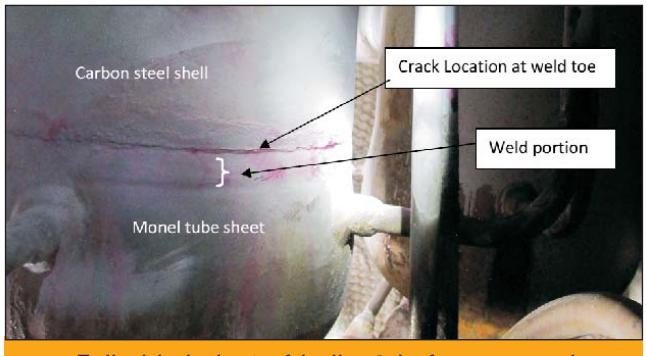
PIE of a high burnup, 37-element fuel bundle from TAPS-3 irradiated to a burn up 16,754 MWD/tU hasshown satisfactory performance. Planar defects, which are needle shaped features, were observed at the fuel centre. Planar defects are considered as the first step during High Burnup Structure (HBS) formation.

Fuel bundle as viewed through radiation shielding window



Needle shaped Planar defects observed in high burnup fuel

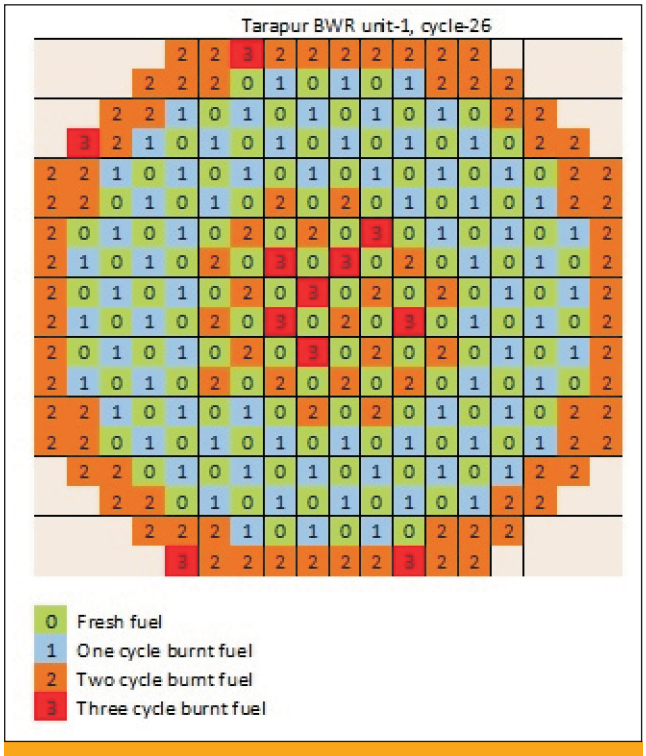
Failure analysis of out of core components is carried out at the low active labs of the hot cell facility. Failure occurred in weld of monel tube sheet and carbon steel shell side of boiler hairpin Heat Exchanger (HX) (boiler-8 hairpin4) of RAPS-2. Through wall radial crack propagated through weld joint along the circumference. Crack propagated along the fusion line and heat affected zone. High erosion corrosion and Flow Assisted Corrosion (FAC) led to reduction in shell thickness forming step with weld on monel side therefore more turbulence near weld & more thickness reduction. Reduction in thickness of shell led to high stress on weld line. Un-eroded insert forms a notch with carbon steel that acts as stress concentration point. This led to crack initiation at the notch between shell and insert. Stresses present along weld line cause crack to propagate.



Failed hairpin-4 of boiler-8 before removal from boiler

R&D relating to LWR

BARC has been providing off site fuel management services to TAPS-1&2 reactors. Tarapur Unit -1 was operated in Sequence-I till 27 December 2018 and the reactor was shut down for mid cycle sequence change. Unit-2, Cycle-26 operation was started on October 24, 2018 in control rod Sequence-I and the reactor was shut-down for its mid-cycle sequence change in the first week of July 2019. Evaluation of control rod patterns for mid cycle sequence change at various power levels were done for both the units. Core follow-up calculations for both the units were also done. The core optimization is generated using simulated annealing techniques. The tools used to design the reload pattern are 2D optimization code CORECOOK and 3D core neutronics code COMETG based on diffusion theory. Safety analysis has been done to obtain control rod withdrawal sequence.



Optimized core loading pattern for cycle 26

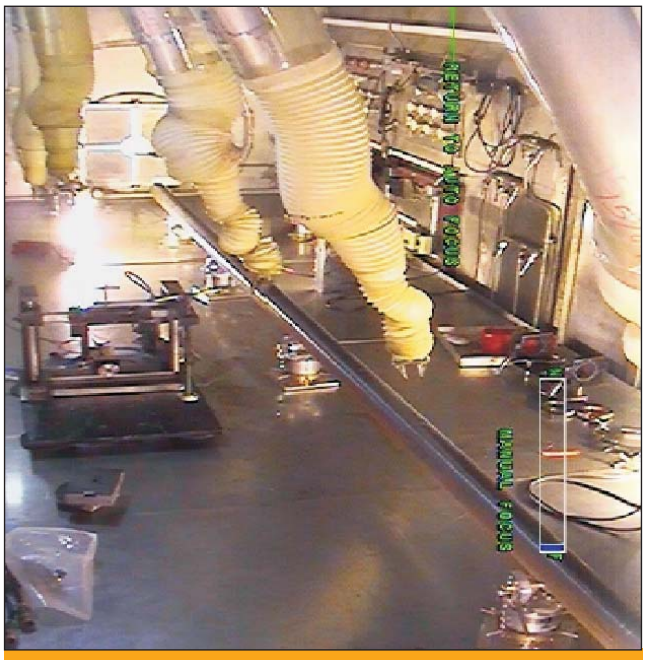
As a part of severe accident management guidelines, an experimental setup was designed, fabricated and operated to carry out tests to arrive at a correlation for evaporation rate from SFP. The study is done under different heat loads simulating postulated extended Station Black Out condition. The correlation obtained from the experiments is useful in assessing the evaporation rates from a typical LWR SFP. The obtained correlation will be used for analysing the verification of Fire Fighting Water injection flow rate adequacy.

High sensitivity Gamma Compensated Ionization Chamber (CIC) for IPWR was indigenously developed and tested: The neutron sensitivity of the detectors is 75fA/nv, about 5 times higher than the neutron detectors developed earlier. Pre-Start-up Equipment along with detectors was successfully deployed at the site.

The Radiation and Gas Monitoring System consisting of total 244 units were installed. After pre-installation checks, cabling and testing, first stage of commissioning was completed at the compact LWR plant.

An automated radiometry system, comprising of a tightly coupled and collimated low-energy high intensity gamma source, NaI(Tl) Scintillation detector and microcontroller based data acquisition and control system, for quality control of LWR fuel pin was indigenously developed and commissioned after rigorous trials. The system also consists of PLC based mechanical system controlled by PC Application software.

PIE capabilities have enhanced after commissioning of the New Hot Cell Facility (NHF) at BARC. Upgradation of microstructural examination and mechanical property evaluation set ups has boosted the examination of large number of pressure tubes, roll joint stubs, garter springs and fuel bundles. Until a few years back high dependence was there on the data available in literature on the properties of irradiated Zr-alloys. In recent years, capability of in-house mechanical testing of irradiated materials has been developed. As a result, recent PIE studies on irradiated pressure tubes have been useful in creating mechanical properties database of Indian Pressure Tube materials.



Irradiated full length pressure tube inside the hot cell

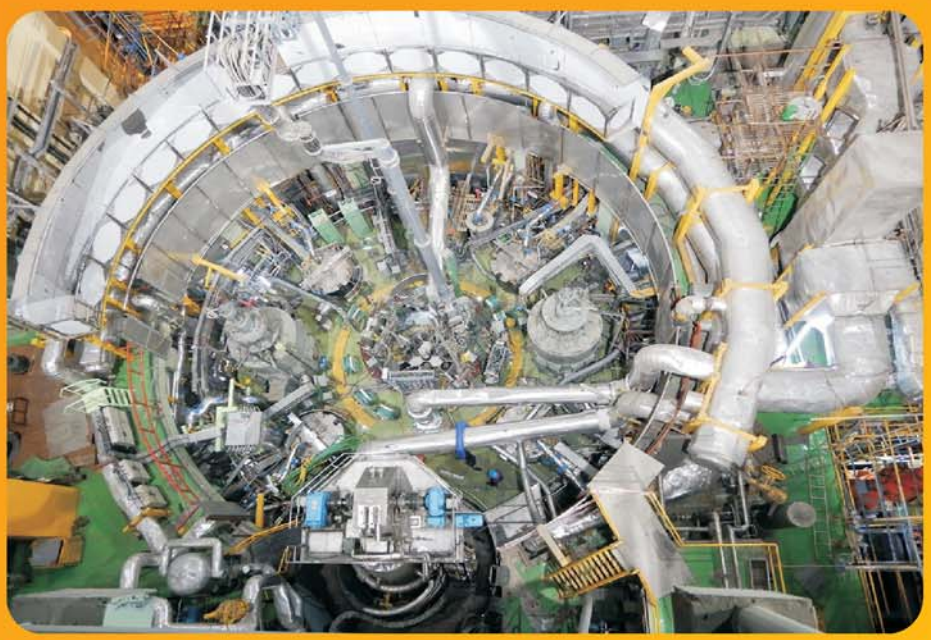
Reactor Pressure Vessel (RPV) Surveillance testing of archive and thermal sets from VVER 1000, Kudankulam PWR was carried out, for the first time, to evaluate the changes in mechanical properties and shift in transition temperature due to thermal ageing during initial years of reactor operation of around 5 years. The results obtained were as per expected behavior in this grade of steel. The following figure shows the surveillance specimens e.g. Charpy V-notch, compact tension and tensile.

Types of mechanical testing specimens from Thermal Ageing Surveillance Specimen from Kudankulam VVER reactor

CHAPTER 2

West Side view of PFBR

NUCLEAR POWER PROGRAMME STAGE-2



Top view of Reactor Assembly

FAST REACTORS

The second stage of the nuclear power generation programme is geared towards setting up of fast breeder reactors. These reactors produce more fuel than what they consume. The DAE organisations that are involved in the implementation of the Fast Reactor Programme are the Indira Gandhi Centre for Atomic Research (IGCAR), Bhartiya Nabhikiya Vidyut Nigam Ltd. (Bhavini) and Bhabha Atomic Research Centre (BARC).

IGCAR is engaged in the design and development of liquid sodium cooled fast breeder reactors, with associated fuel cycle technologies. This programme is supported by a strong research and development endeavour of IGCAR in disciplines such as reactor engineering chemistry, metallurgy, material science safety and instrumentation.

BHAVINI, a public sector company of DAE, was incorporated on 22 October, 2003 at Chennai, Tamil Nadu, as a Special Purpose Vehicle, for implementing India's first prototype 500 MW Fast Breeder Reactor project.

BARC contributes towards the research and development of fuels for fast reactors, technology for reprocessing of fuels, waste management and health and safety of the work force.

Prototype Fast Breeder Reactor

The major activities that have been completed during the report period and the plan ahead for the current financial year are as follows:

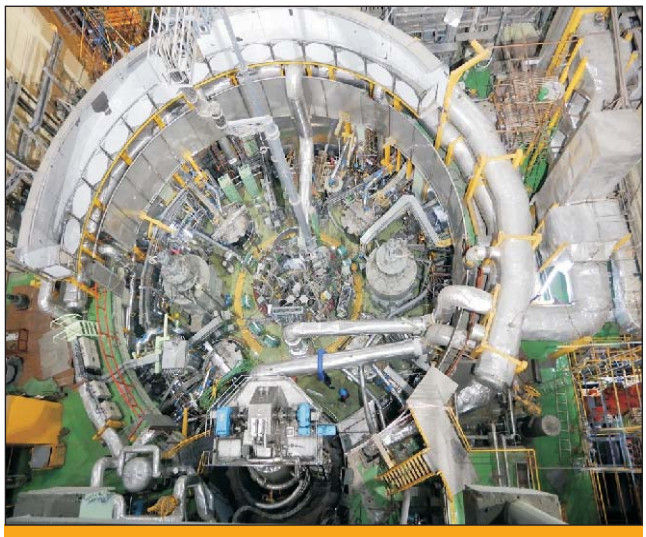
Secondary sodium pumps (SSP) in both the loops were started once again after replacement of Pump Internal Assembly of SSP-2 and the speed was raised in steps. Required data collection was done & both the pumps were run continuosly for about eight months and stable operation regime of secondary sodium loops was established. Subsequently, these pumps were shut down and the loops were completely drained as a preparatory step towards taking up the works on Large Rotatable Plug (LRP) bearing. During commissioning, LRP bearing which is used for positioning Transfer Arm (TA) over various fuel subassembly locations by its rotation, experienced slight deviation in its performance. It is planned to carry out minor remedial works on both LRP & Small Rotatable Plug (SRP) bearings.

Preheating system was shutdown to cool the main vessel and the main vessel is maintained in nitrogen atmosphere. Surface thermocouples and field instruments mounted over the rotatable plugs were disconnected and preserved. Thermal insulation and complementary shielding blocks provided over LRP, SRP, Control Plug and the associated cooling pipes have been removed. In parallel, preparations are underway for commissioning the primary sodium system.

With respect to fuel handling system, the modified gripper assembly of TA has undergone various tests at mock-up test station and was erected on pile and tested at preheated condition (150°C) of reactor assembly. All the systems for transporting Fuel Subassembly Cask from Interim Fuel Storage Building to Fuel Building was commissioned and elaborate mock up trials were conducted. Commissioning of the remaining fuel handling systems are in progress in parallel.

Commissioning of three Nos. of 230 kV / 21 kV 200 MVA Generator Transformer from 230 kV Switchyard was completed successfully. All the tests and preparatory works for energisation of three numbers of Generator Transformer along with 35 MVA 21 kV / 6.9 kV Unit Auxiliary Transformer (UAT 1 & 2) were completed.

After completion of works on LRP & SRP bearings, pre-heating of reactor assembly & secondary sodium loops once again, the secondary sodium pumps will be operated in the loops towards commencement of sodium filling in Main Vessel. This will be followed by isothermal testing, fuel loading and first approach towards criticality.



Top view of Reactor Assembly

During the year, for the supply of first and second core sub-assemblies and special sub-assemblies required for PFBR, many items were manufactured and supplied by NFC towards 2nd Core requirements.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

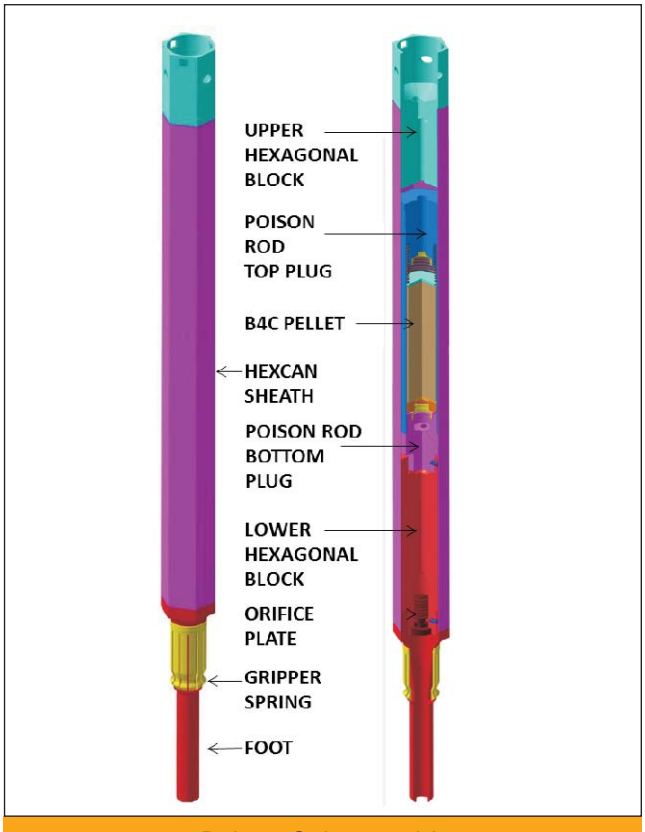
Fast Breeder Test Reactor (FBTR)

The 28th irradiation campaign was started on 2nd April 2019 with core of 58 fuel subassemblies (49 Mark I+ 1 Mark II + 8 MOX). Major missions of the campaign were continued irradiation of four types of metallic fuel pins; Tungsten carbide, a potential axial shield material; specimen for one more campaign and irradiation of actinide samples at Fast Flux Test Facility provided in the central canal plug of the reactor. On 6th April 2019, there was a forced outage in which reactor was shut down manually due to inoperability of one of the control rod drive mechanisms. After identification of the root cause and taking necessary remedial measures, reactor was restarted on 26th July 2019 to continue the 28th irradiation campaign. On 20th August, due to grid power supply disturbance, both the condenser cooling water pumps tripped and reactor underwent LOR. The campaign was completed on 25th September 2019.

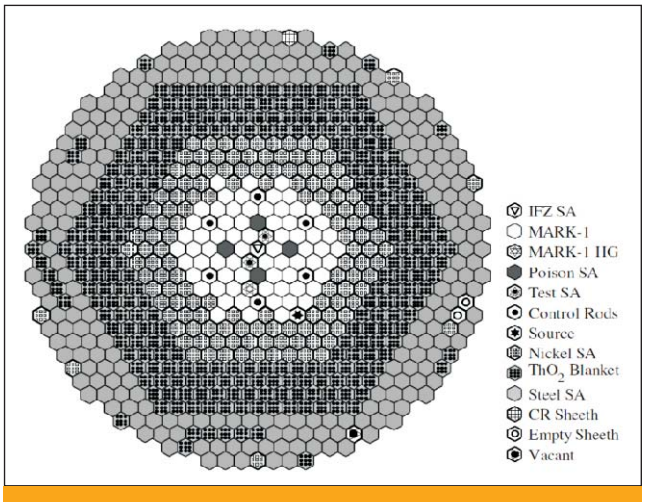
The intervening shut down period was utilized effectively to complete some of the recommendations from regulators such as: installation of two additional valves in the sodium flooding lines outside Reactor Containment Building (RCB) to facilitate flooding operation in case RCB becomes inaccessible in a post Design Basis Accident scenario; providing additional signals to the newly installed Safety Control Panel and installation; and commissioning of a global sodium leak detection circuit for the secondary sodium system. Installation of Mobile purification circuit to purify sodium in manual flooding tanks was carried out. The system was commissioned in all respects and the purification of 64 m^3 of sodium in the two flooding tanks was completed and the plugging temperature was brought down to less than 105°C. The Radiation & Air Activity Monitoring System (RAAMS) and Sodium Fume Activity Monitoring system was completely revamped by replacing its monitors and electronics. An automatic load control device and an Off-normal frequency monitoring system for Turbo-Generator were developed in-house and commissioned successfully. A Process Disturbance Analyzer was developed and commissioned successfully for monitoring the sodium outlet temperature of all fuel sub-assemblies. Major surveillance checks such as replacement of RCB exhaust filter banks and its efficiency testing, RCB biennial leak testing in as-is-where is condition and reactor vessel internal inspection were carried out. Regulatory clearance for starting the 29th irradiation campaign has been obtained and necessary core changes have been carried out. The 29th irradiation campaign has commenced in the 2nd week of December and reactor is under operation. Total duration of the campaign is 61 effective full power days.

It is planned to increase the power of FBTR to its full power level of 40MWt. The core consists of 70 numbers of Mark I sub-assemblies and 4 numbers of Poison sub-assemblies (Boron Carbide sub-assemblies enriched to 50% of B-10) in the second ring of the core to maintain the shutdown margin. The design of poison sub-assembly was finalised and the manufacturing drawings were released. The maximum power in poison sub-assembly is estimated as 35.73 kWt with a peak linear heat rating of 1140 W/cm. The design flow through poison sub-assembly is 0.409 kg/s while design safety limits are followed for nominal

power & 16% over power condition. The sodium temperature rise across the sub-assembly is 97.7°C and the required pressure drop across the sub-assembly is achieved through the use of comb type labyrinths in the foot of the sub-assembly. The maximum clad midwall/ pellet centre line hot spot temperatures are estimated as 537.6 / 2055.7°C respectively. The cavitation free and the lifting force criteria are met for 110% flow condition indicating that the design is safe.



Poison Subassembly



FBTR 40MWt Core

The details of the 40 MWt core is shown in the above photograph. Perturbation worth, fuel slumping worth and reactor kinetics parameters were computed using a 2D R-Z model, which were used for further detailed safety and plant dynamic analysis. The sodium void worth is -1035 pcm which is equivalent to -3.8$. The doppler constant is small (-47 pcm) and the maximum slumping worth estimated is 1.12$/cm. Neutron and gamma transport calculations were carried out using DORT code and IGC-S3 cross section set to estimate the neutron and gamma fluxes at various locations. The present shielding provided is verified to be adequate. There is a slight increase (11%) in the dpa of grid plate which limits the residual life of FBTR to 7.25 full power years. Safety analysis indicates that ULOFA event will not lead to a core disruptive accident. The conservative estimate of mechanical energy release under ULOFA is 12 MJ while the reactor vessel can take up to 9 TNT (39 MJ) of mechanical energy release without failure.

In order to demonstrate the safety of the plant, detailed analyses of various design basis events have been carried out using the plant dynamics code DYNAM. During all the events, except 'off-site power failure', 'station black out' and 'one control rod withdrawal', the clad hotspot and fuel hotspot temperatures are limited below the design safety limits even without safety actions. Moreover, safety of the plant is demonstrated under off-site power failure, station blackout, and one control rod withdrawal events with reactor trip credited based on the second appearing parameter. Thus, safety of the plant is demonstrated for operation at 40 MWt power.

R&D relating to PFBR

Technical Support to PFBR Commissioning

Thermal Hydraulic Assessment of Primary Sodium Filling in Main Vessel

Detailed thermal hydraulic analysis was made to estimate the evolution of primary sodium temperature in the main vessel during initial filling with heating through main vessel-safety vessel interspace, secondary sodium in circulation and after accounting for various heat losses through top shield cooling system, biological shield cooling system and safety

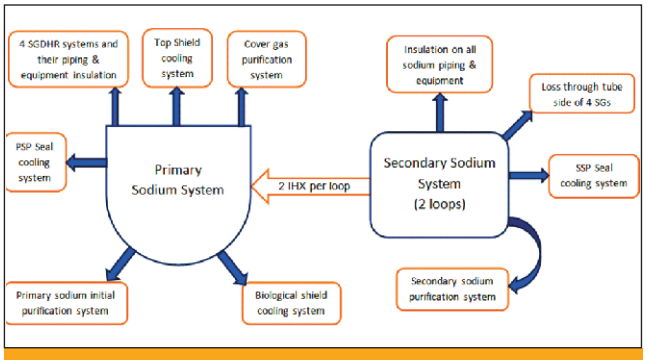
grade decay heat removal system. Analysis has been carried out for seven enveloping system configurations. For an initial sodium temperature of 150°C and with normal system configuration, at the end of complete filling, the sodium temperature reaches 213°C at the end of sodium filling. For the same case and with the most pessimistic assumption that all the heating systems are lost and all heat removing systems after sodium filling are available, the final temperature of primary sodium reaches 104°C. For an initial sodium temperature of 180°C and for the most pessimistic case of all heating sources not available and all heat sinks available, the corresponding sodium temperature reached is 125°C. From these studies, the temperature of sodium during main vessel filling was arrived at.

Determination of Heat Losses through SGDHR Circuit

A study was made to assess the effect of keeping the safety grade decay heat removal system filled with sodium or nitrogen during initial sodium filling of main vessel. The heat losses through Air heat exchanger and piping were considered. Analyses have been carried out for hot pool temperature in the range of 120°C to 250°C. It is seen that the heat losses are 10 times more in the sodium filled case as compared to nitrogen filling. Hence, it is recommended to keep the SGDHR circuits filled with nitrogen initially and fill the same with sodium after completion of primary sodium purification and after operation of the primary sodium pumps.

Scheme for Raising Temperature of Primary and Secondary Sodium Circuits upto Isothermal conditions with associated Sodium Purification

After filling primary sodium in main vessel, sodium temperature has to be raised to 200°C by running the Secondary Sodium Pumps (SSP) coupled with primary sodium purification. Operation of Primary Sodium Pumps (PSP) is envisaged only after achieving desired purity of the primary sodium to avoid the possibility of plugging in the hydrostatic bearing. The total heat input required to raise the temperature along with compensation of various heat losses (like biological shield cooling system, top shield cooling system, insulation losses of Safety Grade Decay Heat Removal (SGDHR) piping, losses through SGDHR Air heat exchanger, losses from secondary sodium piping, nitrogen blanketed side of steam generators, pump seal cooling, primary and secondary purification circuits (PSIPC & SSPC) are to be supplied by running the SSPs of both the secondary sodium loops at required speed. The heat transfer from secondary sodium to primary sodium is through 4 IHX immersed in primary sodium pool, mainly by conduction. The picture shows the heat input and heat losses from various paths.

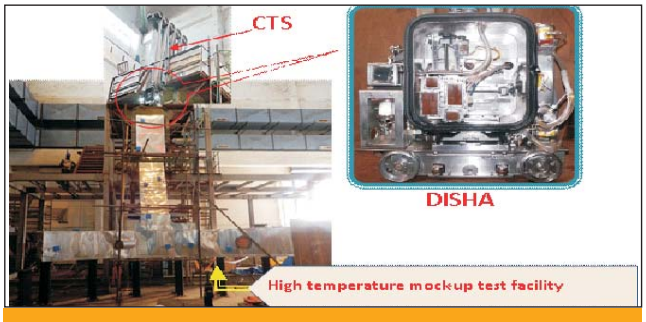


Various heat loss from primary, secondary and SGDHR systems

The scheme to raise the temperature of primary sodium from 150 to 200°C by running both SSPs at specific speeds, at each step of 25°C and maintain till completion of purification was worked out. The time required for each stage was estimated. After ensuring expected primary sodium purity, PSP would be started and SSP speed would be lowered to compensate the heat losses and maintain temperature at 200°C. The scheme for raising temperature further in steps of 25°C along with sodium purification at each step of temperature raise to ensure plugging temperature of <160°C, and finally to reach the plugging temperature of <120°C at sodium temperature of 450°C was also arrived at. The corresponding pump speeds required to raise and maintain the sodium temperature in both primary and secondary systems and the time period for each step of operation was estimated. From these studies, the time for reaching primary sodium temperature of 200°C along with desired sodium purity and the total time required to raise to 450°C isothermal conditions together with reaching plugging temperature of 120°C was arrived at.

High Temperature Testing of Dissimilar Metal Weld Inspection Device (DISHA)

A Dissimilar Metal Weld Inspection Device (DISHA) has been developed, for carrying out periodic In-Service Inspection (ISI) of dissimilar metal weld between the roof-slab and main vessel of PFBR. DISHA is designed to perform remote visual examination and Ultrasonic Testing (UT) at 120°C. DISHA is deployed using a Cable Take-Up/ Release System (CTS), and moves around the roof slab on the Anti-Convection Barrier (ACB) which acts as a guide rail. Navigation cameras on-board DISHA aid navigation of the device deployment, operation and retrieval. Following the successful room temperature qualification, DISHA was tested continuously for 24hrs. at 120°C in high temperature (HT) mock-up test facility and performance of the device was demonstrated at 120°C.



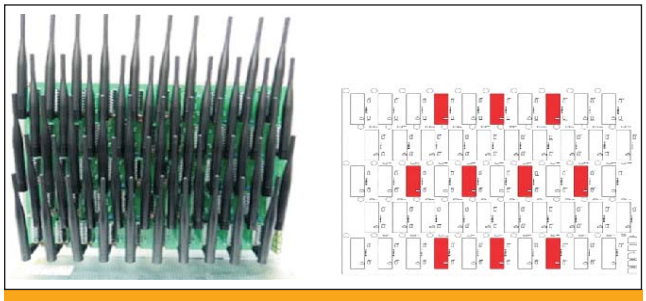
Testing of DISHA in High Temperature Mock-up Test Facility

Development of simulator based facility for reliability testing of control room HMI software

A simulator based test facility has been created for reliability testing of Control Room HMI software. Towards this, Safety Class -2 display station software of Primary Sodium System was installed in this test setup. Primary Sodium System VME simulator with simulated switch over logic was developed to simulate the communication functionalities of actual VME based system deployed in PFBR. The control room HMI software of Primary Sodium System was subjected to various test cases pertaining to its HMI functional requirements with inputs simulated through simulator such as network failure, data corruption during transit etc and the failure data recorded was used for reliability estimation.

Wireless Power Solution using In-house Developed Rectenna Panel

When Wireless Sensor Network (WSN) is deployed at hazardous zones, the prime challenge is powering the sensor nodes continuously. Life of battery powered WSN node is much limited; hence the wireless power solution is most sought. To design a sustainable far-field wireless power solution for battery-free WSN, in-house R&D activity has been initiated in the domain of RF power harvesting. With rectenna as basic element, an efficient rectenna panel has been designed to harvest power from directional RF source. A mathematical model has been developed to optimize panel parameters such as rectenna spacing, count, and arrangement pattern. It has been validated through experimental analysis. It is verified that the hexagonal rectenna panel with 10 number of rectenna is sufficient for battery-free WSN node to transmit data at 1 sec interval when placed at 70m from the directional RF source of 4W.



Rectenna panel array and optimum design

Design of Future FBR

Plant Dynamics Studies towards the Design of Plant Protection System

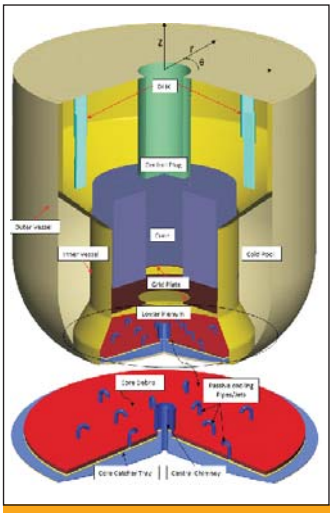
Enveloping design basis events of FBR 1&2 at nominal power and part load operation with 2 out of 3 primary sodium pumps in service have been analysed using the plant dynamics code DYANA-P V2.0 to estimate the maximum permissible delay time for the SCRAM instrumentation. It is seen that as compared to PFBR, there is scope for omission of two SCRAM parameters from the shutdown system logic without compromising safety. The required response time estimated for various instruments to ensure safety have been found to be much less than the response time achieved in PFBR during commissioning. Thus, design specification for SCRAM instruments have been developed through plant dynamic studies.

Transient pool hydraulic studies

Transient thermal loading on hot and cold pool components is one of the very important mechanical loading to be established for the thermo-mechanical design of reactor assembly components. Among the various design basis events that cause this loading, reactor SCRAM (giving rise to cold shock) and trip of one secondary sodium pump (due to asymmetric thermal loading) are the main events governing the design of hot and cold pool components respectively. Three dimensional CFD analysis of hot and cold pool has been carried out to predict transient evolution of flow and temperature in the pools during the above events. Temperatures in all important structural components, viz., main vessel, inner vessel, grid plate, core support structure, primary pipe and control plug have been computed. Movement of stratification front that sets up in hot and cold pools have also been captured through these simulations.

Investigation of Natural Convection Heat Transfer from relocated Core Debris on Two different types of Core Catcher through Analytical Studies

In-vessel core catcher is included in the pool type SFR primary sodium system for protecting the main vessel from the deleterious effects of relocated core debris that is formed after a core disruptive accident. Two different types of core catcher concepts namely; a) without multi jet / pipe and b) with multi jet / pipe were analysed with identical initial and final boundary conditions through 2D and 3D transient CFD models. 2D model is found to be conservative in the estimation of maximum temperatures. Core catcher with multi jet / pipe option reduces the core catcher maximum structural temperature by 40^{o}C. Safe limit of 650^{o}C for the core catcher maximum structural temperatures is satisfied for the case of 2/3 of core debris relocated on the core catcher.



Full scale computational model with multi jet / pipe in core catcher

Modelling of in-pin fuel motion in annular mixed oxide fuel during Unprotected Transient Overpower Accident (UTOPA)

A modelling tool, MITRA, based on the fundamental laws of mass, momentum and energy conservation has been developed to analyse UTOPA. It combines multiple modules to describe: Heat transfer and phase-change; molten fuel motion; fission gas release; gas escape to plenum; reactivity feedback and reactor point kinetics. The code has been verified against the 'CABRI-E9bis' test. In this test, an annular fuel pin was first subjected to UTOPA and then to under-cooling environment inside the CABRI reactor. MITRA is able to successfully simulate the molten fuel motion. A good level of conformance is achieved with the experimental data.

Analysis of postulated sodium pool fire's influence on a nearby PVC cable

Evaluation of impact of a credible leak sodium pool fire on parts of safety systems is essential in large sodium handling facilities. In all such facilities, especially in SFR based NPP, PVC cables carrying electric current and signals should be protected. Analysis has been carried out to evaluate the thermal influence of a postulated sodium pool fire (1 m^2 surface area) on a typical PVC cable. A CFD based 3-D numerical model has been developed using Fire Dynamics Simulator (FDS 6.7) software to simulate the sodium pool fire in conservative configuration with respect to the receptor components. Transient thermal conditions of the PVC cables at different elevations are evaluated and a Safe Separation Distance (SSD) required to avoid its ignition is predicted, which is seen to be 0.85 m directly above the pool fire.

Evaluation of possible mean droplet size formed under liquid sodium jet breakup process

The accidental leaks from reactor systems can create spray fire scenario due to sodium jet fragmentation. The spray fire involves burning of sodium in droplet form and assessment of spray droplet size distribution is required in the evaluation of spray fire scenarios. A numerical model has been developed based on linear stability analysis to evaluate the possible mean droplet size from the downward falling cylindrical liquid sodium jet fragmentation. The model predicted mean droplet sizes (0.1 mm to 2.5

mm) for different leak rates of sodium (up to 70 kg/h) through various sizes of nozzles (0.2 mm to 6.4 mm), which have been compared with the experimental results available in literature and found to be in good agreement (within ± 10 %). The estimated mean droplet size from the model is used to define the spray droplet size distribution in the numerical codes of sodium spray fire analysis.

R&D on FBRs

Recommendation to Implement Improvement in RCC-MRx Simplified Tubesheet Analysis Procedure

RCC_MR is the code widely used for structure design of fast breeder reactors. As per RCC-MRx RB 3944.42, for a simplified tube sheet analysis, primary membrane plus bending stress intensity is calculated based on radial and hoop stresses only. A comparison was made of the RCC-MRx simplified tube sheet analysis approach with a detailed 3D finite element simulation of tube sheet with perforations. The analysis results highlighted the importance of considering axial stress component in estimation of primary membrane plus bending stress intensity. Based on this, a modified proposal was made to AFCEN (French Association for Design, Construction and In-Service Inspection Rules for Nuclear Island Components) sub-committee to include the primary membrane plus bending stress intensity from all the normal component stresses. The proposal was accepted and will be included in the next version of the code.

Seismic Response Studies on Multi-Storey Concrete Building with and with-out base Isolators

Seismic response mitigation of safety related structures and systems using various response control techniques such as base isolators and dampers are among the actively studied areas in DAE. As a part of the ongoing collaborative research activity in BARC and IGCAR, shake table experiments were performed on 100 t multi axial shake table to study the seismic response of a full scale multi-storey reinforced concrete structure to demonstrate the effectiveness of base isolators in reducing the seismic response of concrete structures.

A three storey reinforced concrete building of dimension 4.5 m x 4.5 m x 9 m was constructed and instrumented with strain gauges accelerometers and laser sensors. Around 50 strain gauges were pasted on the steel reinforcement rods at critical locations before placing concrete and precautions were taken to protect the same during concreting. A lug supported tank was anchored at the second floor and a steel piping with one end anchored at the ground floor was connected to the tank nozzle by passing through the floor penetrations as shown in the picture. Various tests were performed to study the responses of building-equipment systems and response were captured using 10 tri-axial accelerometers, 50 strain gauges and 6 laser displacement sensors mounted at critical locations. Response of the building was measured for three cases, viz. structure mounted on laminated rubber bearing reinforced steel plates; structure mounted on fiber reinforced rubber bearing and structure rigidly fixed on shake table.

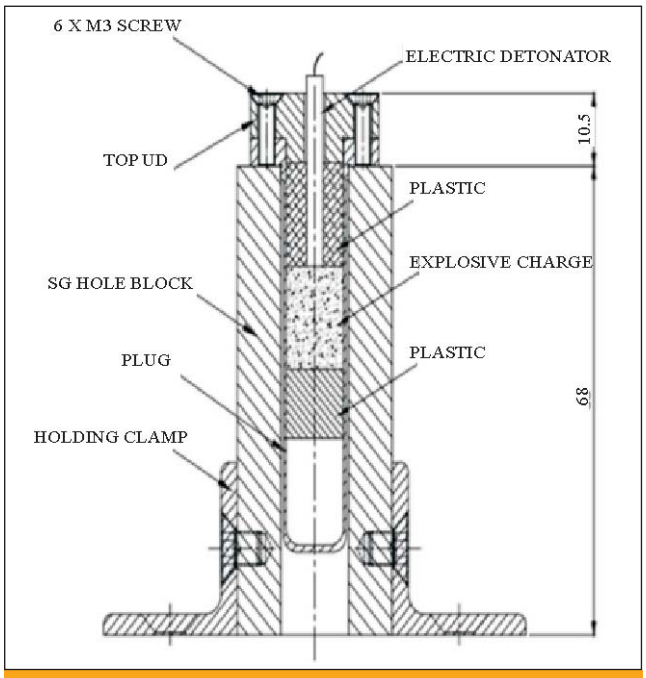
Multi-story concrete building mounted on shake table with base isolators

View of Base Isolator

For all the three cases, the dynamic characteristics of the system such as natural frequencies, damping etc. were assessed using sweep sine tests by varying the excitation frequencies from 0.5 Hz to 50 Hz for constant acceleration of 0.2 g and recording the responses using 128 channel data acquisition system. Experimental results indicated the reduction in fundamental natural frequency of the building from 1.8 Hz to as low as 0.7 Hz with the base isolators compared to fixed case. Subsequently, seismic tests were carried out for excitations corresponding to seismic zones II, III, IV and V as per Indian Standard (IS-1893) by increasing the amplitude of vibrations in steps. It is observed that the dynamic responses such as acceleration and strain values were reduced drastically (up to 40%) with base isolators and no failures were observed for the structure or equipment. As part of fragility assessment of concrete building, the earthquake excitations were increased beyond Zone-V level (more than 0.36 g) for fixed base case. Hinge formation on the base footing was observed around 0.6 g PGA which is almost 1.6 times of Zone-V earthquake level. These experiments helped in demonstrating the effectiveness of base isolators in mitigating the severe seismic loading on civil structures, piping and equipment. The experiments also generated data to serve as a benchmark for the future studies in this area.

Development of explosive welding technique for plugging of degraded Steam Generator tubes

Steam Generator (SG) tubes that show up indications during the ISI/ PSI inspections require to be isolated from service by means of plugging them at both ends to enhance safety of the plant. A collaborative study along with TBRL, DRDO, Chandigarh was mooted and mock tests were conducted on the Explosive Welding (ExW) of the designed SG tube plugs. The experiments conducted were successful and have produced sound bonding. After qualification, this will be deployed through a robotic system to remotely perform SG tube plugging on degraded SG tubes.



Mock test setup for PFBR SG Tubes

Experimental set up for SAD Performance Demonstration

Qualifying Sodium Aerosol Detector in Nitrogen environment for leak detection in electromagnetic sodium pump

Primary Sodium Purification Circuit of PFBR is provided with an Annular Linear Induction Pump (ALIP) to circulate sodium. Its sodium carrying pipe, which

is insulated with ceramic material, is surrounded by the pump winding. In order to maintain the ALIP winding temperature within its design limits, a closed loop nitrogen gas cooling system is provided. To detect any sodium leak in the pipe, a Sodium Aerosol Detector (SAD), is placed in the nitrogen circuit. SAD uses a heated ûlament to ionize sodium vapor or its aerosols and the ion current is measured by a collector electrode to provide an indication of sodium leak. The performance of SAD in the environment to which it is exposed in ALIP cooling circuit was required to be demonstrated before deployment in the reactor. Hence, in an experimental set up, sodium leak was simulated with PFBR ALIP conditions such as nitrogen sample flow rate, temperatures, materials and structural layout. SAD was found to respond to the leak adequately.

Qualification of Primary pump sensor (ECFM) along with its electronics in sodium up to 525°C

Integral testing of Eddy Current Flow Meter (ECFM) along with reactor electronics was carried out in a dedicated test station in Steam Generator Test Facility (SGTF). During the testing, the flow through the sensor was varied from static to 25 m^3/hr in steps of 5 m^3/hr and temperature was varied from 250 to 525°C in steps of 50°C. The satisfactory operation of the sensor along with the electronics was established. It was found that the system meets the design requirements for generating SCRAM in case of primary pipe rupture.

ECFM probe assembly

Output characteristics of ECFM for various flows

Performance Assessment of Large Diameter Bearing in a Qualification Rig

Towards qualification of an indigenously developed large diameter bearing measuring f4.6m, which is an import substitute, an experimental facility to test the bearing under simulated operating conditions such as load (230 tonnes), temperature (up to 100°C) and temperature difference (20°C) across the races as expected in the reactor was commissioned. Subsequent to functional testing, cyclic testing of bearing under the load was carried out both at room temperature as well as at operating temperatures of 90°C (top Race) & 80°C (Bottom Race). Further, cyclic tests were repeated for various axial and circumferential temperature gradients (10 - 40°C) as part of parametric study to assess the bearing performance. Based on the tests, it is observed that the bearing rotations were smooth and torque variations are within acceptable limits.

Large Diameter Bearing Test Rig with Lead Ingots Stacked to Simulate 230 t Load

ϕ2m Inflatable Seal

Indigenous Development of f2 m Inflatable Seals in Silicone

Inflatable seals are used in PFBR as primary seals to provide leak-tightness against leakage of radioactive argon cover gas from reactor vessel. As a part of indigenous development effort, an exercise was initiated with seals in Silicone. Since, the seals are to be proved reactor worthy before installing them in reactor, a plan was drawn to develop test inflatable seals of f2m and test them for their performance in a test facility under simulated operating conditions as expected in the reactor.

Two options were considered for seal development i.e., moulding and extrusion. Considering the symmetric geometry of the seal and lesser cost, decision was taken to follow extrusion route for the seal development. Subsequently, extrusion dies were developed, accounting for shrinkage allowance and seal extrusion trials were conducted. As a first step, a f2m sample seal was developed and fitment trial with the existing test rig was carried out. After establishing satisfactory fitment, 5 Nos. of f2m seals were successfully manufactured. Further, the end joining of extruded seals was demonstrated and the strength adequacy of the joint was verified by subjecting the spliced joint specimens to tensile tests. The tested seals will be qualified in the test rig before certifying them for reactor use.

Development of Permanent Magnet based Magnetic Particle Collector for DSRDM

Shutdown mechanisms of PFBR consist of three Diverse Safety Rod Drive mechanisms (DSRDM). The mechanisms consist of Diverse Safety Rod (DSR), which is held by Electro Magnet (EM). The lifting capacity of DSRDM electromagnet is very sensitive to the gap between EM and armature of DSR. Any foreign particle between EM & DSR interface increases the nonmagnetic gap, hence reduces the capacity of EM to lift the DSR. It is essential to remove the suspended ferromagnetic particles, if any, from the primary sodium during commissioning stage of the reactor.

Keeping the above mentioned requirement in mind, a Magnetic Particle Collector (MPC) has been designed and developed, shown in the picture, to collect suspended magnetic particles from primary sodium. The permanent magnet based MPC will produce magnetic field when inserted in the reactor in primary sodium region, which will attract any ferromagnetic particle floating in sodium. MPC devices will be introduced and taken out of the reactor at intervals. Sodium sticking at the outer surface of the magnetic particle collector and collected magnetic particles will be removed and again MPC will be reinserted in the reactor till primary sodium is free of suspended magnetic particles. DSRDMs will be installed in the reactor after complete removal of the floating magnetic particle from primary sodium.

Developed Magnetic Particle Collectors (MPC)

Development of Servo Manipulator for hot-cell applications

A 15 kg Servo Manipulator (SM) is developed for the hot cell applications. The dual SM has a master and slave interconnected by communication cables instead of mechanical links, which can widely separate the master and the slave. The operator has a feel of the slave environment and also the slave is capable of handling delicate objects without crushing them.

This helps the operators to carry out dexterous tasks within hot cells.

Servo manipulator for Hot cell Applications

Delicate operations using Servo manipulator

FBR - FRONT END FUEL CYCLE

An autonomous robotic solution for loading of PFBR fuel pins into transport magazines at Fuel Fabrication Facility (FFF), Tarapur has been commissioned. The system consists of a highly accurate position control system for the pins and an articulated robotic arm with a specially designed gripper. As a part of the automation work, deep learning-based algorithm and hardware have been developed for autonomous reading of fuel pin number and preparing a computerised data base. The robotic loading system increases the throughput besides providing active aid to human operators and protects them from radioactive hazards.

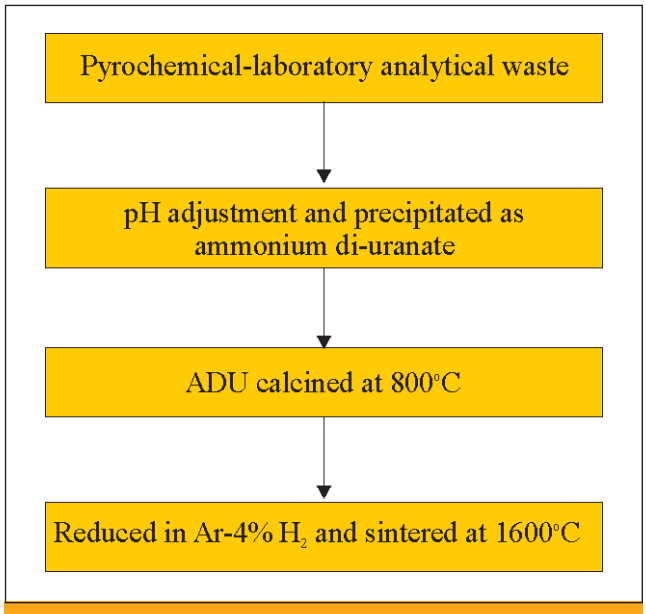
Autonomous robotic solution for loading of PFBR fuel pins

FBR- BACK END FUEL CYCLE

Feasibility of preparation of metallic U from pyro process laboratory waste solutions using direct oxide electro-deoxidation route

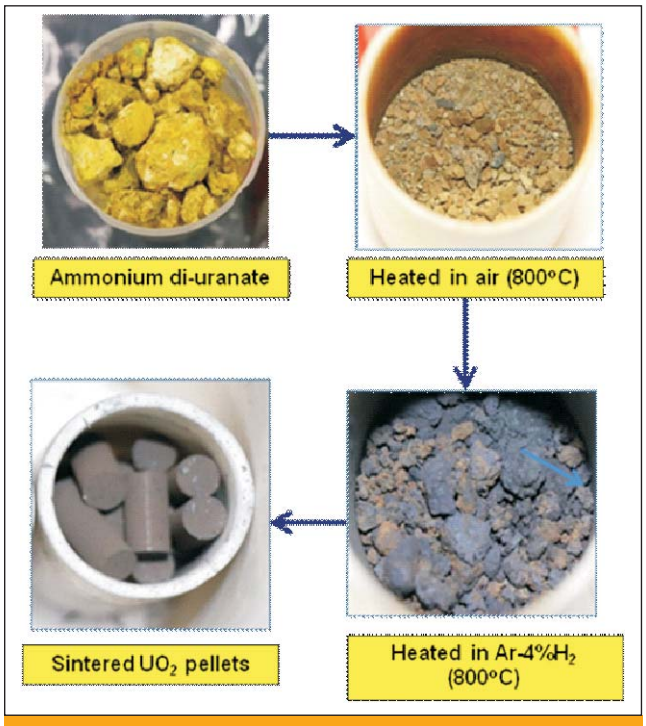
Pyrochemical reprocessing of spent metal fuels involves several batch operations pertaining to separation, consolidation, purification, spent salt treatment carried out at high temperatures. During laboratory scale pyro processing experiments carried out over the last five years on uranium and uranium based alloys, LiCl-KCl eutectic melt was usually

sampled from the melt for estimation of U by traditional Davies and Gray method. Several hundreds of such salt solutions containing U were collected and stored during this period in the pyro processing laboratory and it was therefore necessary to develop a flow sheet to recover uranium from the waste analytical solutions for converting it to metallic form for further use in electro refining experiments. It was felt that aqueous laboratory waste could be treated in the conventional way for precipitating uranium as Ammonium Di-Uranate (ADU) and electro reduce it to metallic uranium by molten salt based Direct Oxide Electrochemical Reduction (DOER) route. This process in laboratory scale was demonstrated by initially precipitating uranium as ADU from about 10 L of nitrate form of laboratory analytical waste. ADU was then analyzed for various impurities such as Fe, Cr, Ni, Cu, Zn, Ag and Cd using AAS. Total U in ADU was also estimated using Davies and Gray method. The precipitated product was then taken in 70 g batches and calcined at 800°C and pelletized. Finally the uranium oxide pellets were reduced under Ar-4 wt.% H_2 atmosphere at 1600°C to prepare sintered UO_2. Flow-sheet for preparing sintered UO_2 pellets from ADU is shown in the above picture.



Flow-sheet for recovery of U from laboratory salt waste recovered as ADU

These pellets were subsequently loaded in 30 g batches in cathode basket in a high temperature electrolyser vessel containing 450 g of LiCl-1wt.%Li_2O melt operated at 650°C with Pt as anode. The following picture shows various products obtained at various stages during the preparation of sintered UO_2 pellets.



Pictures of various products obtained at various stages during the preparation of sintered UO_2 pellets

Electro-reduced U metal after distillation of salt and arc- melting

Prior to the electro-reduction experiments, cyclic voltammetry was carried out to determine the $Li^+|Li$ cathodic onset potential and onset potential of chlorine evolution at 650°C thereby establishing the purity of the melt. Ni|NiO was used as reference electrode. Electroreduction was carried out at constant current

(5 A) mode for 8 h. The reduced product after electrolysis was distilled under vacuum at 900°C for removing the adhered LiCl salt (about 20 - 30 wt%). Few pellets after distillation were further arc-melted and from the metallic luster of the consolidated product, near complete reduction with extent of reduction of >95% was confirmed. Thus, the proposed method for the recovery of uranium as U metal from pyrochemical laboratory analytical waste is confirmed.

Reprocessing of mixed carbide spent fuel of FBTR

Campaigns for Reprocessing the spent fuel discharged from FBTR, (with 155 Giga Watt days / tonne burnup) have been carried out in the CORAL facility with excellent recovery and lowest ever dose expenditure. At the "first of its kind" DFRP (Demonstration Fast Reactor Fuel Reprocessing Plant), the second stage of commissioning viz. acid solvent runs are in progress. The major tasks accomplished so far include installation, testing and calibration of many customized equipment that were housed inside special enclosures suitable for handling highly radioactive solutions. A novel laser based equipment had also been designed, procured and tested for disassembly of the fuel bundle. This would be housed in a separate facility called the Head End Facility (HEF) at DFRP. High level liquid waste tanks with large capacity (Over Dimensional Components) were designed and fabricated for installation at the waste tank farm of the Fuel Reprocessing Plant. The latter is a new plant that is being built as part of the mega project, viz., the Fast Reactor Fuel Cycle Facility.

R&D on Fast Reactor Fuel Reprocessing

Dissolution studies of PFBR MOX fuel pellets in nitric acid

In order to understand the reaction ensuing during the dissolution of the Mixed Oxide (MOX) fuel pellets that would be discharged from Prototype Fast Breeder Reactor (PFBR), mock experiments were carried out. The data generated through these studies would serve as fundamental inputs for the design of a continuous dissolution system for reprocessing the irradiated fuel discharged from PFBR. One of the major findings of these studies is the differential dissolution rates of the constituents of the MOX fuel pellet and the composition of the off-gas streams evolved during the dissolution process.

Studies of the solubility of alternate solvent in nitric acid medium

Solvent extraction is used in the aqueous reprocessing of the irradiated fuel discharged from the Fast Breeder Reactors (FBR). This involves dissolution of the fuel in nitric acid and extraction of U and Pu with the help of a suitable organic solvent, viz., Tibutyl Phosphate (TBP). The aqueous stream containing the undesirable rad-waste is subsequently concentrated by evaporation before further treatment. During the solvent extraction, some amount of the organic solvent could be carried over on to the aqueous stream. During the concentration of the latter by evaporation, the residual organics that are potentially hydrolysable could turn into non-volatile intermediates (called the "red oil") that pose the risk of a highly exothermic reaction during evaporation. This could subsequently lead to explosion which is undesirable. Thus the removal of the solvent residue from the aqueous phase is of considerable importance in nuclear fuel reprocessing, for the safe disposal of the aqueous waste. In order to mitigate the formation of the red oil; an alternate solvent, namely Tri–isoAmyl Phosphate (TiAP) is being considered. Tests were conducted in order to understand the solubility of the latter in nitric acid under different conditions, and the solubility of this solvent in nitric acid was investigated. The solubility data generated would be useful in design of appropriate equipment for the removal of dissolved organics from the aqueous stream.

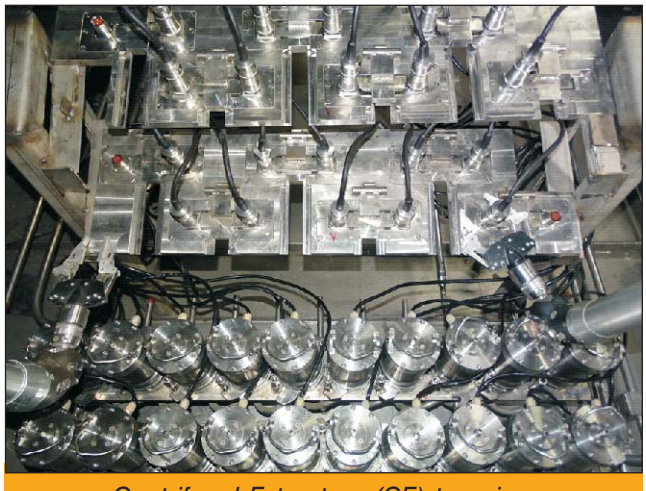
Application of activity coefficient model for the modelling of Uranyl nitrate extraction in different solvents

In designing the flow sheet for nuclear fuel reprocessing, developing a theoretical model for the solvent extraction process is important since it helps to optimize the unit processes. Often experimental results related to the chemistry of the solvent extraction process need to be extrapolated to the actual conditions prevailing in a plant. Models based on the activity coefficients of the constituent moieties are necessary in order to obtain a closer approximation

of the actual process. However, choosing an appropriate model is often rendered difficult due to the complex interactions between multiple electrolytes at high ionic strength, especially in the aqueous medium. An appropriate model having minimum adjustable variables to describe a multicomponent system that best suits our requirement was chosen. By using this model, the activity coefficients for the ionic species in the aqueous phase were determined. From this data the equilibrium organic phase concentrations were determined. The concentrations estimated by using this model were found to be in good agreement with the experimental results.

Catalytic generation of reducing agent in Nitric Acid Medium

In the aqueous reprocessing of spent nuclear fuel, the oxidation state of uranium ions needs to be adjusted by reducing it from a higher oxidation state. This is usually accomplished with the help of an electrochemical technique. In order to overcome the limitations of this method an alternate method needs to be developed. As an alternative, a catalyst assisted electrochemical reduction method was developed. The kinetics of this reduction over a platinum/silica catalyst in nitric acid medium was investigated. Experiments were carried out to understand the dependence of the kinetics of the reaction as a function of all the experimental parameters. The suitability of different kinetic models was examined in order to describe the process. These analyses indicated that the reduction proceeds through a surface reaction between the adsorbed molecules and is a chemical reaction-controlled process.

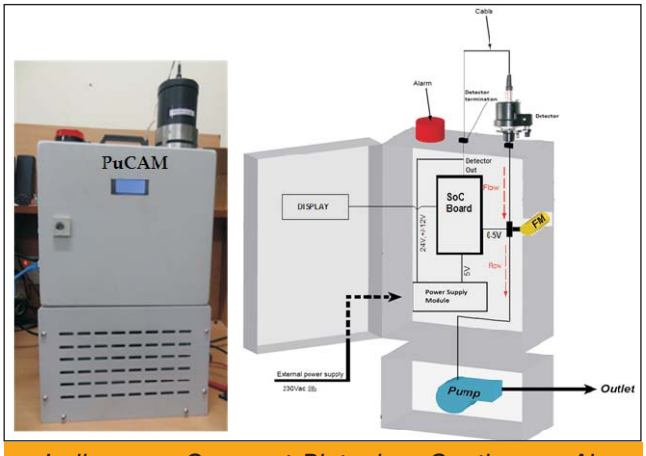


Centrifugal Extractors (CE) top view

Centrifugal Extractors with remote handling

Indigenous Compact Plutonium Continuous Air Monitor

Plutonium Continuous Air Monitor (PuCAM) is a very critical instrument of the air monitoring program in all labs dealing with Plutonium in powder form. At present, in DAE, this requirement is met with imported systems. Lack of configuration to suit site-specific requirements and the limited details with respect to analytical techniques used in the instrument lead to frequent false alarms from the imported units. Due to these reasons, an indigenous design and development of PuCAM was taken up. A first version of spectroscopy based PuCAM in collaboration with BARC, has been designed and developed using off-the-shelf modules. Gaining confidence from the successful field experience of first version, the design of a compact PuCAM using system on chip (SoC) based programmable logic devices was initiated. A



Indigenous Compact Plutonium Continuous Air Monitor (PuCAM)

motherboard is designed and developed which performs the functionalities of off-the-shelf modules such as: multi-channel analyzer; single channel analyzer; panel PC and input/output module used in first version, thus making this version more compact, reliable and maintainable. The motherboard, detector head, power supplies and vacuum pump were integrated into a portable cabinet and have been tested successfully.

Fast Reactor Fuel Cycle Facility

FRFCF is being built with the objective of closing the fuel cycle, and ensuring sustained fuel supply for fast breeder reactors at Kalpakkam. FRFCF is a multi-unit mega project of DAE, co-ordinated by BARC, IGCAR & NFC and being executed by IGCAR. FRFCF is co-located along with PFBR and has five major plants in the nuclear island. After obtaining all clearances, construction was commenced in 2014. In the infrastructure area, civil construction of infrastructure, utilities & service buildings completed and Gold rated Green Building Certificate was obtained for training centre, the first green building in DAE, from Indian Green Building Council (IGBC).

In the nuclear island, civil construction of the Core Sub-assembly Plant (CSP) building reached (+) 13.0 m elevation and Waste Management Plant (WMP) building reached (+) 6.0 m elevation while Fuel Fabrication Plant (FFP) & Reprocessed Uranium Oxide Plant (RUP) reached FFL. One block of Fuel Reprocessing Plant (FRP) also reached Finished Floor Level (FFL). Purchase orders have been placed for all long-delivery equipments and components needed for commissioning of various plants of FRFCF. Portions of optical slabs and lead ingots for radiation shielding have been procured and received at site. Procurement of stainless steel plates, pipes & rounds required for fabrication of process vessels and tanks has been completed and received at site. Manufacture of glove boxes and fume hoods required for setting up of analytical certification laboratory has been completed and glove box integration of equipments is underway. Manufacture of master slave manipulators, over dimensional consignment tanks, annular tanks, ventilation system dampers, differential pressure transmitters, radiation monitors and criticality alarm systems are in progress.

First IGBC Gold rated Green Building in DAE (FRFCF Training Centre);

Core Sub-assembly Plant

NFC is also setting up two plants i.e., Reprocessed Uranium Oxide Plant (RUP) & Core Sub assembly Plant (CSP) under the project “Fast Reactor Fuel Cycle Facility” (FRFCF) at Kalpakkam.

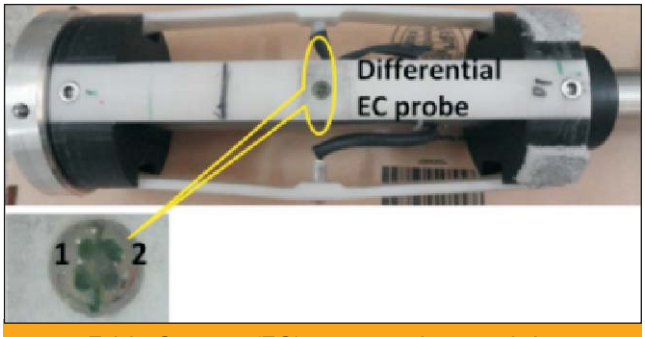
REPAIR & INSPECTION TECHNOLOGIES

Non-destructive Evaluation of PHWR coolant channels

In-service inspection of coolant channels of PHWRs are performed using BARC Channel Inspection System (BARCIS). Backlash in scanning

system in the reverse direction poses specific challenges in analysis of ultrasonic signals and characterization of indications using the commercial software (with restricted hardware dongles) used by NPCIL. A complete software named IGcar Ultrasonic ANalysis & Imaging - BARCIS (IGUANI-BARCIS) has been developed with suitable algorithms to correct the backlash during analysis of the signal. Further, all necessary features are included in the software for comprehensive analysis of the ultrasonic data acquired using BARCIS and reporting the indications. The software has been provided to NPCIL after imparting training to colleagues from NPCIL head office and site, at IGCAR.

Focussed surface differential eddy current array probes, a head assembly and inspection procedure have been indigenously developed at IGCAR for testing of calandria tubes during En-Masse Coolant Channel Replacement (EMCCR) campaign at KAPS-1&2. Calandria tubes of 20 selected channels were successfully inspected with detection sensitivity of 50 micron deep notches using the developed probe head assembly.



Eddy Current (EC) array probes and the head assembly

HEALTH, SAFETY & ENVIRONMENT

Radiological Safety

Effective Health Physics surveillance and radiological protection has been provided to all the active facilities of IGCAR. As part of radiation dosimetry services around 3462 occupational workers of IGCAR and BARC facilities have been monitored for external exposure using TLD badges, a total of about 841 occupational workers engaged in active facilities have been monitored under in-vivo monitoring and around 155 radiation workers have been monitored under bioassay (in-vitro) services. The finger print and personnel data of new radiation workers and the Thermo Luminescence Dosimeters (TLD) dose data of all radiation workers are being uploaded in National Occupational Dose Registry System (NODRS) periodically. A Fluorescence in-situ Hybridisation (FISH) translocation dose response curve for Cs-137 ã-rays (0.1Gy/min dose rate) was established in biodosimetry facility by irradiating peripheral blood samples obtained from a consented male volunteer. The quality of the dosimetry services has been ensured to international standards by participation in the international intercomparison exercises conducted by European Radiation Dosimetry Group (EURADOS) for both physical dosimeters and computational modelling of in-vivo dose estimation to ICRP/ICRU voxel phantoms exposed under different conditions. In the year 2019, a total of around 189 in-situ/in-house testing of HEPA filter banks, 6 iodine filter banks of FBTR, filter banks of clean room and 21 HEPA filter banks at NFC, Hyderabad were tested in the accredited HFTL facility.

Around 450 radiation survey instruments from various nuclear facilities at Kalpakkam; KGS, Kaiga; VSSC, Trivandrum; BEL, Chennai; MECL, Nagpur; Apollo Hospitals, Chennai and other industries were calibrated at the AERB accredited Regional Calibration Facility. Lead bricks used in hot cells of FRFCF have been tested for their shield integrity by radiometry technique.

The online Decision Support System for radiological and nuclear emergencies developed by IGCAR called ONERS-DSS has been operationalized for other NPP sites, enabling site specific plume dispersion forecasts and radiological impact assessment at any instant. Weather and Dispersion modelling has been completed for the Chemical Emergency Response System which is being developed for managing and mitigating inadvertent accidental chemical releases from storage tanks of Fertilizers and Petrochemical industries in association with Factories and Boilers (FAB), Govt. of Kerala.

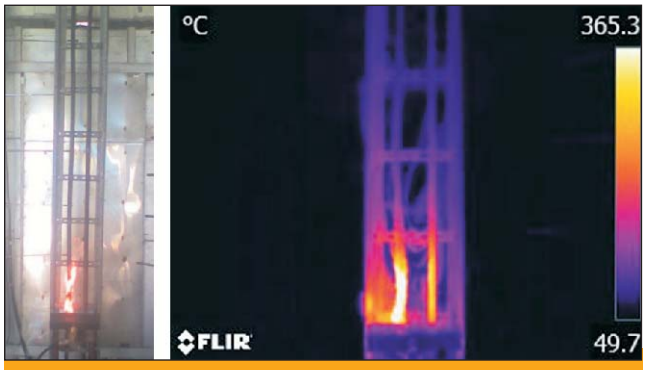
Industrial Safety, Fire Safety and First Aid training programmes were organized periodically in addition to safety promotional activities to promote safety culture among the IGCAR employees on various occasions such as National Road Safety Week, National Safety Day, World Environmental Day, etc. Periodical Illumination and noise level monitoring was scheduled and carried out at various IGCAR facilities. In addition, well equipped Occupational Health Centre (OHC) is made available to provide medical assistance for occupational injury / illness for IGCAR and BARC employees and Periodic Annual Medical Examination for about 1500 employees has been carried out.

Soil and water samples from different radiation facilities and from other institutions involved in collaborative projects were analysed for NORM estimation. Environmental radioactivity measurements comprising of soil, water and air (Radon, Thoron, Tritium and C-14) measurements was continued for Kalpakkam Complex and demonstrated the continued compliance of levels in comparison to world average values.

Qualification tests such as thermal shock resistance and sodium compatibility were carried out with commercially available MgO. Experiment on thermal shock test with molten tin at 900^{o}C revealed that sintered MgO can safely withstand thermal shocks caused by fragmented corium. Sodium compatibility testing of MgO bricks for a period of 1500 h at 400^{o}C revealed that there is no significant interaction of sodium with MgO bricks.

Detection and quantification of defects and cracks in 550 NB pipe elbow fatigue crack growth study has been carried out using active thermography technique. The thermal imaging technique has also been utilized for the characterization of vertical cable fire in collaboration with SRI, AERB.

Crack Detection in 550NB pipe Elbow model using Lock in Thermography



Characterisation of vertical Cable Fire.
a) Experimental setup;
b) Thermal imaging of vertical cable fire

As part of radiation awareness programme, about 600 students and 35 teachers from nearby schools were taken to various facilities at IGCAR. Awareness lectures were delivered at a few institutions with in the state.

Students Visit during Radiation Awareness Programme

CHAPTER 3

AHWR Thermal-Hydraulic
Test Facility (ATTF)
at NPCIL R&D centre in Tarapur

NUCLEAR POWER PROGRAMME STAGE-3

State-of-art material testing facility for R&D in Molten Salt Breeder Reactor

THORIUM BASED REACTORS

Nuclear power employing closed fuel cycle is the credible and sustainable option for meeting a major part of the world energy demand. World resources of thorium are larger than those of uranium. Thorium, therefore is, widely viewed as the 'fuel of the future'. The Indian Nuclear Power Programme Stage-3 aims at using thorium as fuel for power generation on a commercial scale. In the thorium fuel cycle, thorium-232 is transmuted into the fissile isotope uranium-233 which is a nuclear fuel. As a part of this programme, BARC has been developing a 300 MWe Advanced Heavy Water Reactor (AHWR). Fuelled by thorium and using light water as coolant and heavy water as moderator, this reactor will have several advanced passive safety features.

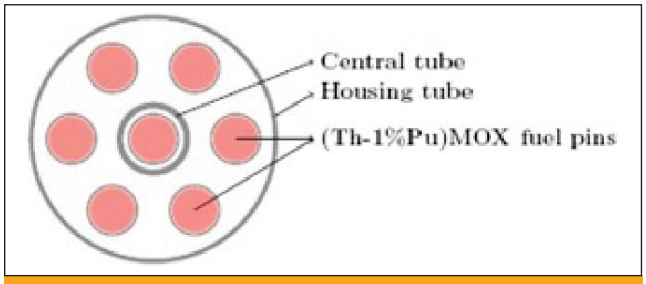
ADVANCED HEAVY WATER REACTOR

Tests conducted at AHWR Thermal-Hydraulic Test Facility (ATTF) in Tarapur demonstrated stable channel flow during power manoeuvring from cold start-up from 2% full power to 80% full power. The fuel clad surface temperatures were found to be well within safe limits during the power raising operation. Flow instabilities are now eliminated by design in AHWR.

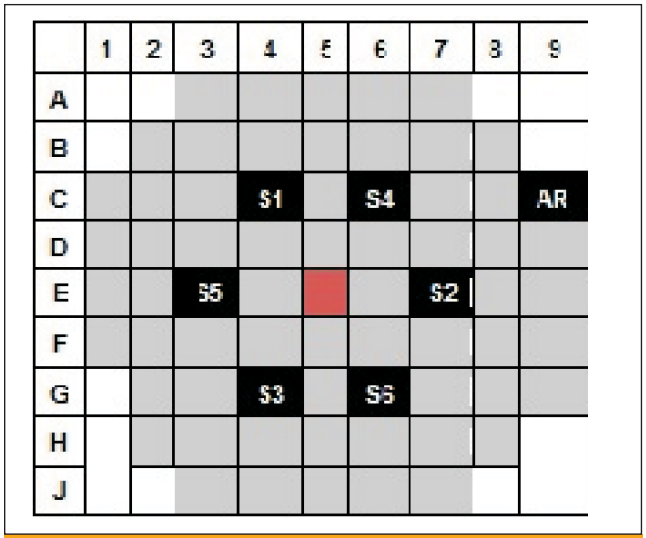
Critical Facility for Advanced Heavy Water Reactor (AHWR) was operated on 80 occasions. Measurement of neutron flux near experimental AHWR type [(Th-1% Pu) MOX & (NU-Th-NU) sandwich] fuel cluster was carried out. The facility was utilised for testing of nuclear detectors and for activation of large volume samples for Neutron Activation Analysis (NAA). A total of 42 nuclear detectors were tested and 165 large volume samples & 72 gold foils were activated in the facility.

Coolant void reactivity experiments in AHWR fuel was taken up for validation of the safety parameters in line with the physics design. A special experimental cluster was designed with AHWR fuel consisting of 7 pins of (Th, 1%Pu) MOX to carry out void reactivity measurement with this cluster placed at E5 lattice location in the Extended Core of AHWR-Critical Facility. Safety analysis was also performed for these core configurations and all kinetic and safety parameters were found to be within the prescribed limits.

AHWR Thermal-Hydraulic Test Facility (ATTF) at NPCIL R&D centre in Tarapur



Cross-section of AHWR experimental cluster



Extended Core of AHWR-Critical Facility

THORIUM FUEL CYCLE

A facility for electrochemical purification of cationic impurities in FLiNaK coolant salt of $5MW_{th}$ IMSBR was set up. FLiNaK (an eutectic mixture of LiF, NaF and KF) has been selected for the secondary side of IMSBR. Due to extreme sensitivity of fluoride salts to moisture and oxides, the facility has been located inside an inert gas glove box, with oxygen and moisture impurities kept below 1 ppm each. A three electrode system has been used with the voltage being controlled through a potentiostat-galvanostat. Demonstration of salt purification by electrolysis was been successfully demonstrated.

Electrochmical salt purification demostration facility located inside an inert gas glovebox

As melted (left) and purified (right) samples of coolant salt of 5 MWth IMSBR (FLiNaK)

Electrochemical salt purification demonstration facility located inside an inert gas glovebox with oxygen and moisture content kept below 1 ppm each

A voltammetry based technique was demonstrated for online determination of cationic and oxide impurities associated with Fluoride salts for the $5MW_{th}$ Indian Molten Salt Breeder Reactor (IMSBR). Online determination of impurities in fluoride salts is crucial to operation of IMSBR, as they cause potential precipitation of uranium as oxyfluorides leading to hot spot formation.

Facility for demonstration of online measurement of impurities in molten fluoride salts

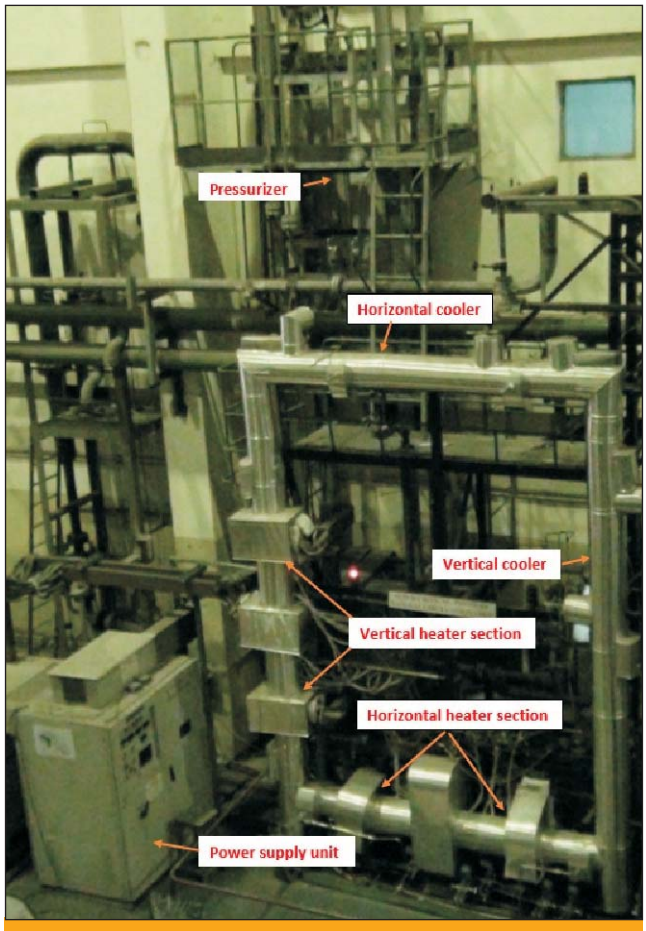
Kalpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) continued to operate successfully at a maximum power level of 30 kWt. It is serving its unique

role as a facility for neutron activation studies and testing indigenously developed neutron detectors.

OTHER THORIUM REACTOR SYSTEMS

Thermal-hydraulic investigations were performed to evaluate heat transfer behaviour of Supercritical CO_2 under natural circulation in Supercritical Pressure Natural Circulation Loop (SPNCL). These experiments were performed for different combinations of heater and cooler orientations. Experimental studies were carried out for pressures ranging between 8.0–13.0 MPa i.e. 108 – 177 % of the critical pressure (7.38 MPa) of CO_2. Also, critical heat flux experiments using sub-critical CO_2 near its critical pressure were conducted for horizontal and vertical flows at 5.8 – 7.3 MPa pressure. Supercritical (SC) fluids are potential candidates for employment in future generation nuclear reactors owing to several advantages.



Supercritical Pressure Natural Circulation Loop (SPNCL) at Hall-7, BARC

A state-of-the-art material testing facility was commissioned for conducting various types of mechanical, fatigue and combined creep-fatigue tests up to 1200°C in a high vacuum environment. The facility's 50 kN loading frame capacity is equipped with both contact-type and advanced non-contact type sensors (laser and video extensometer) for in-situ recording of test data. Special fixtures were designed for conducting high temperature tests on graphite, ceramics and refractory alloys for Molten Salt Breeder Reactor (MSBR) and Indian High Temperature Reactor (IHTR), which are currently being designed at BARC.

State-of-art material testing facility for R&D in Molten Salt Breeder Reactor and Indian High Temperature Reactor

CHAPTER 4

IR-FEL setup installed inside
a 60 m long radiation shielded area
at RRCAT

ADVANCED TECHNOLOGIES AND RADIATION TECHOLOGIES AND THEIR APPLICATIONS

Advanced Effluent Water Treatment Plant (AEWTP) pilot plant

Advanced technologies and radiation technologies development and their applications, is one of the major programmes of the DAE's research organizations such as BARC, Mumbai, IGCAR, Kalpakkam, RRCAT, Indore, VECC, Kolkata and the industrial organization BRIT, Mumbai.

These organisations have developed a number of advanced technologies, hi-tech facilities and various sophisticated equipments over a period of time under this programme. This includes Research Reactors, Accelerators, Lasers and laser based equipment, Synchrotrons.

Applications of radiation technologies are immensely beneficial in the areas of healthcare, nuclear agriculture, food preservation and industry.

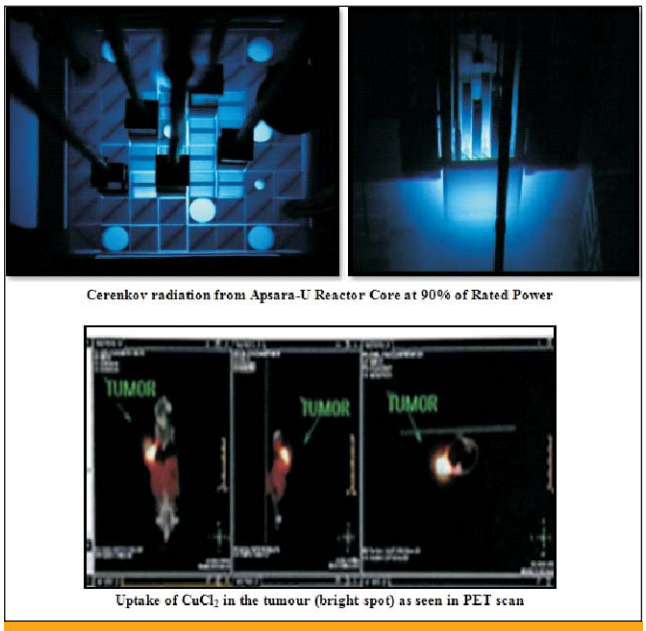
DAE has been working in close cooperation with other organizations of the Government of India to widen the reach of the technologies for the benefit of common man.

The Tata Memorial Centre which functions through its three units viz., Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) and Centre for Cancer Epidemiology (CCE) and provides the Cancer Diagnostic and Treatment Services to the masses. It also engages in the programmes aimed towards Cancer awareness and it's prevention.

RESEARCH REACTORS

APSARA - Upgraded

The newly commissioned Apsara-U reactor was operated at up to 90% of its full rated capacity of 2 MW after achieving the first approach to criticality on September 10, 2018. Trial production of radioisotopes has commenced. High specific activity ^{64}Cu (Copper-64) in a No-Carrier-Added (NCA) form was produced by irradiating natural Zn target and was radio-chemically processed using separation methods. Biological efficacy of $^{64}CuCl_2$ was demonstrated by PET imaging in nude mice with human prostate cancer Xenograft, wherein the tumour could be visualized.



Activities carried out in APSARA-U

DHRUVA

Research reactor Dhruva operated at its full rated capacity of 100 MW with high availability factor. Radioisotope production was on full stream with more than 700 samples irradiated during the year. An additional isotope tray rod was installed to augment production of radioisotopes. Two new high capacity Class III Diesel Generator sets were commissioned in tune with the safety recommendations prescribed in the revised Design Basis Flood Level for BARC complex.

Class III Diesel Generator of Dhruva

Research reactor Dhruva continued to serve as the National Facility for Neutron Beam Research. Research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

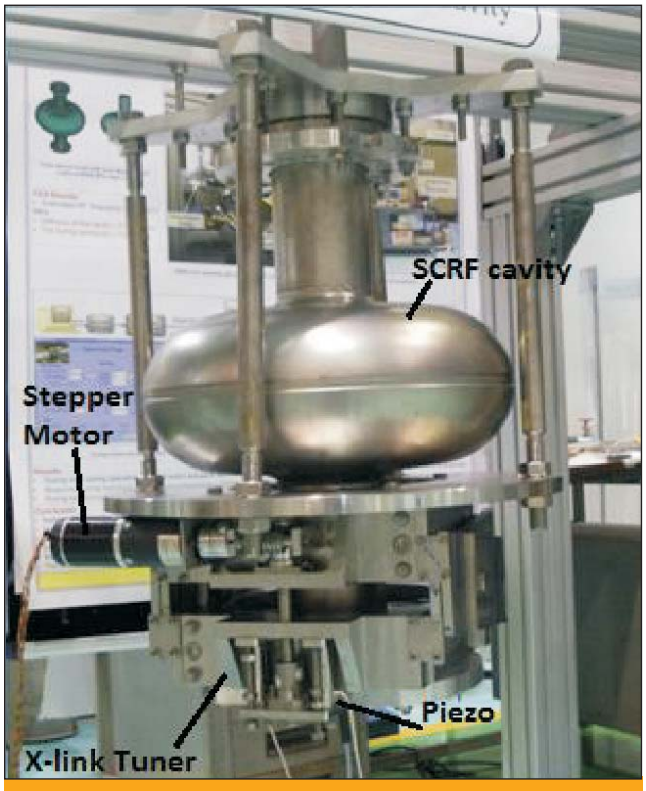
CIRUS

Safe decommissioning of various facilities in Cirus reactor is in progress by minimizing various radiological and industrial hazards. To make use of the vacant space in the reactor complex, a 100 Ci/batch I-131 processing facility is being installed to meet the growing requirement for radioactive iodine for healthcare applications. Construction of experimental shed for CLOE loop of JHR has been completed in the complex.

ACCELERATORS

RRCAT is developing Superconducting RF (SRF) cavities and its sub-systems for future accelerator projects of superconducting proton linacs. Tuner for SRF cavity plays an important role for resonance control during accelerator operation. X-link tuning mechanism developed based has received three international patents from Japan, Europe and USA. This tuner is able to perform slow and fast tuning operations as per the requirement of SRF cavity and tested with 650 MHz single-cell SRF cavity. The qualification of tuner controls was done by driving the motor and piezo at room temperature, as well as at cryogenic environment up to LN_2 temperature. Piezo was operated with half sinusoidal pulse width up to 1 ms at 100 V and repetition rate of 50 Hz. Pulse width, repetition rate and the amplitude of piezo excitation are varied to study the system for fast tuning. The phase response of cavity for piezo excitation of 10 ms pulse width at 62 V and repetition rate of 4 Hz was plotted. Further, this tuner will be assembled with dressed high beta 650MHz 5-cell SRF cavity for its qualification at 2 K temperature in Horizontal Test Stand (HTS).

Development of 650 MHz (β=0.92) five-cell Superconducting RF (SRF) dressed cavities is ongoing at RRCAT under Indian Institutions Fermilab Collaboration (IIFC). Large numbers of multi-cell dressed cavities shall be required for the future high energy superconducting proton accelerator proposed at RRCAT. Cavity dressing requires an important



X-link tuner with single-cell SRF cavity

Environment-controlled glove box for dressing of the cavity and its control panel

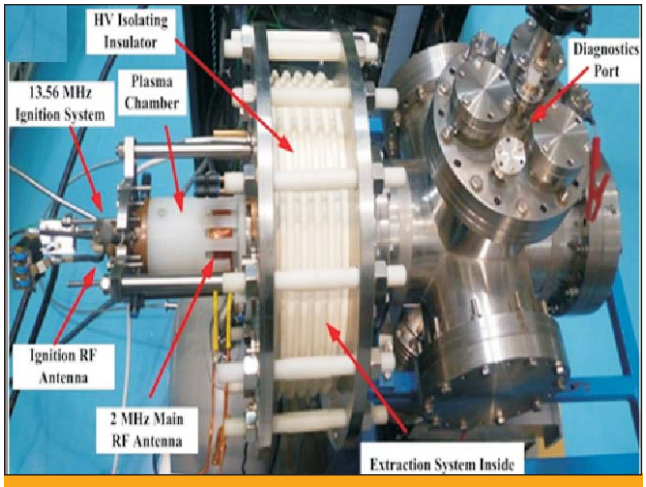
infrastructure, known as controlled-controlled welding glove box. The glove box environment produces the best quality TIG welds that meet ASME boiler and pressure vessel code. The dedicated large volume welding glove box has been installed, tested and commissioned with achieved oxygen level < 10 PPM and relative humidity (RH) level < 2%, which are better than the required level of 20 PPM for Oxygen and 15% of RH. This is an important milestone towards the development of dressed SRF cavity. The dressing of a five cell HB 650 cavity will be performed first time in India using this facility.

A Horizontal Test Stand (HTS) facility for testing of dressed Superconducting RF (SCRF) cavities at 2 K is being set up at RRCAT under the Indian Institution and Fermilab Collaboration (IIFC). The HTS facility mainly consists of indigenously developed: HTS cryostat, cryogenic transfer lines, 2 K helium pumping lines, 40 kW solid state RF amplifier (SSA), Low Level RF (LLRF), RF Protection Interlock (RFPI) system and control systems. HTS cryostat is housed inside a concrete shielded cave/vault of size 15 × 9.5 m^2. The cryogenic transfer line has been installed and liquid helium has been successfully transferred to the dummy cavity vessel from a 10,000 liter liquid helium dewar. The 40 kW solid state amplifier, low level RF systems and safety interlocks have been installed and tested. This is a first of its kind facility in the world for testing two 650 MHz SCRF cavities at 2 K in a single cool down. Efforts are underway to test the HTS at 2 K and initial powering of a five cell dressed cavity.

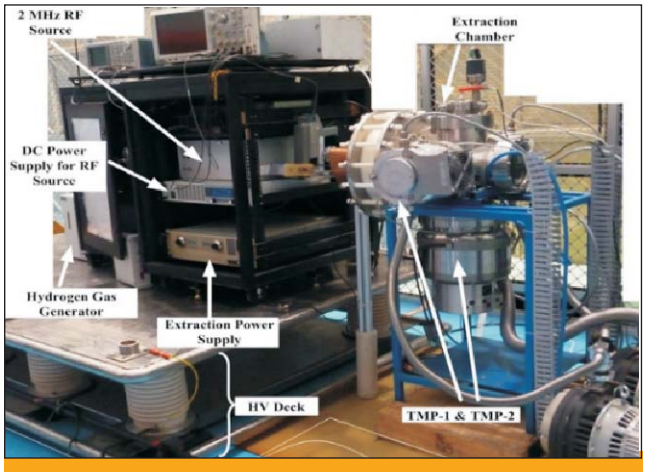
HTS Vault with 40kW SSA. HTS Cryostat and LLRF & Control System

For operation of HTS, the sub-systems like Radio Frequency (RF) high power stage, Low Level RF (LLRF) system, RF Protection Interlocks (RFPI), cryogenics, vacuum, radiation monitoring, personnel and machine safety interlock etc are integrated in centralised data acquisition and control system for machine operation and carrying out cavity characterization. An overall data acquisition and control system was designed and testing is in progress.

An external RF antenna based multi-cusp H negative ion source has been indigenously designed, developed and operated in pulsed mode with up to 50 keV beam energy, 16 mA ion current in 0.5 - 2 ms pulse duration at 2 Hz repetition rate. The main challenge was the in house development of 100 kW power source at 2 MHz, and its coupling through the external RF antenna to the hydrogen plasma in the plasma density during its evolution (100 μs). A good differential vacuum condition is maintained in the extraction chamber to extract 16 mA ion beam current at 50 keV. The successful operation of ion source validated the required RF power, gas purging rate, cooling system, various power supplies, plasma and extraction chamber and vacuum pumping system. This ion source is developed for capacity building for proton linac. In future, this ion source will be tested and operated at high duty factor 10 %.



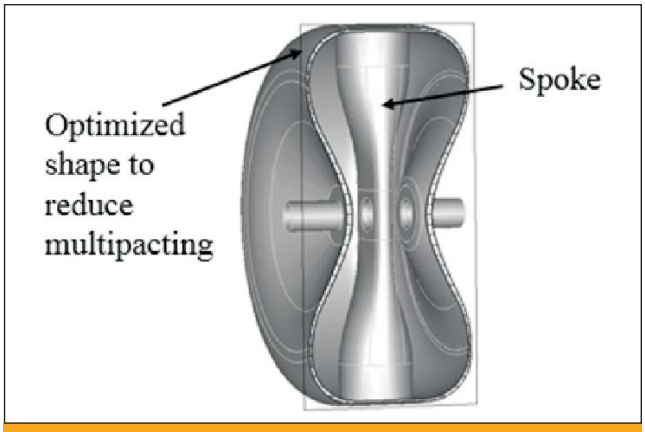
Prototype pulsed RF based H negative ion source components



RF antenna based multi-cusp H negative ion source

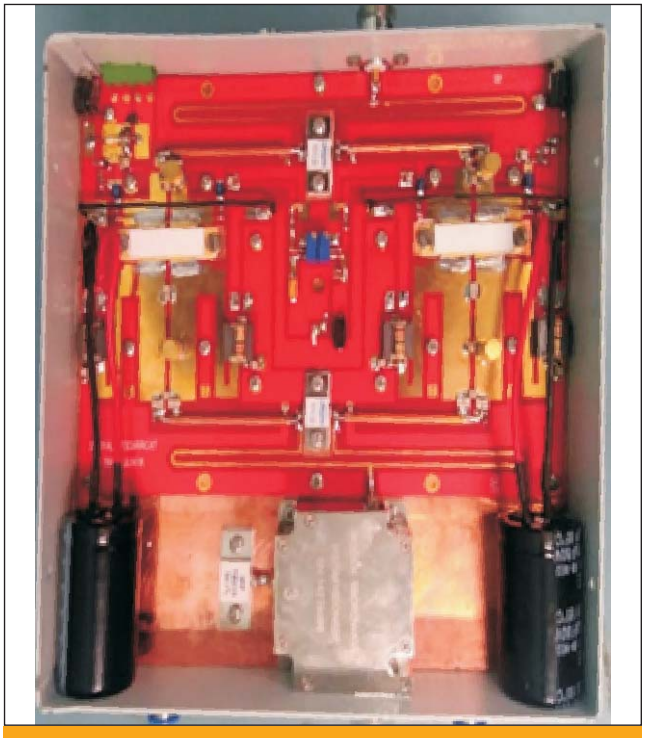
A methodology has been developed to re-tune the lattice of the linac to compensate for the failure of solenoid or quadrupole magnets of the 1 GeV, H negative (H^-) accelerator proposed for Indian Facility for Spallation Research (IFSR). This makes the design of the accelerator robust. Also, a new design of β_g = 0.11 Superconducting Spoke Resonator (SSR) has been worked out by carefully optimizing the end-wall

shape to make it completely free from multi-pacting at operating gradient. The work on physics design is in progress.



The CST-MWS model of optimized design of β_g = 0.11 SSR cavity

A 100 kW pulse power 325 MHz solid state RF amplifier was designed and developed with all RF sub systems and components. The radio frequency amplifier was designed based on solid state technology, using transistors. It consists of two 50 kW cabinets, which are power combined, using in-house developed high power, 2-port combiner. It was rigorously tested up to 100 kW from 1ms to 5 ms pulse width and 50 Hz pulse repeating frequency.



1.5 kW x 2 power module

325 MHz pulsed solid-state RF amplifier for RFQ

A compact, 13 kV, 5 A, prototype Capacitor Charging Power Supply (CCPS) has been indigenously designed, developed and tested successfully for partial discharge capacitor charging applications. It is an import substitute with an aim to transfer the technology to Indian industries. The power supply comprises of ferrite based high frequency high

13 kV/5A power supply

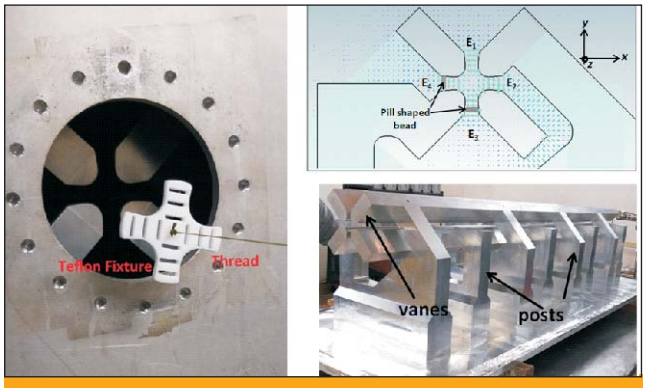
voltage transformers, IGBT based high current full bridge inverter modules with optically isolated gate drivers, fast high voltage rectifiers and control scheme. Regulation and efficiency better than ± 1 % and 94 %, respectively, have been achieved at full load. The power supply was tested at a Pulse Repetition Rate (PRR) of 300 Hz along with the actual pulse modulator. The measured value of output variation was less than 1 % (pk-pk) at full load.

Test set up of high voltage solid state switch with the klystron

A prototype 10 kV, 1 kA water cooled IGBT based switch has been developed to evaluate the possibility for using it as a main pulsing switch in hard switch type pulse modulator of 6 MW peak power microwave system. The solid switch is an import substitute for the costly life limited thyratron switch. The switch has been tested at 10 kV, 1 kA, 200 Hz in a pulsed modulator system which generates 130 kV pulsed voltage of 12 μs pulse width for the klystron.

Cold model tests and RF design validation of proton RFQ linac

A full scale prototype RFQ LINAC having unmodulated vanes has been fabricated at VECC. Low power RF measurements have been performed to find out dipole component and quadrupolar asymmetry in the fabricated structure and were compared with simulation results. The measured quadrupolar asymmetry and dipole component at radial distance of 7 mm from the beam axis are within ± 1% validating the RF design. Particle tracking of 5 mA proton beam in full scale RFQ with modulated vanes shows that vertical and horizontal shift for the accelerated beam can be reduced to 0.1 mm and 0.03 mm respectively. The study establishes that an extended vane type four-rod RFQ can potentially be used for accelerating high current proton beam.



(Left) Bead-pull fixture used for quadrupolar asymmetry measurements,
(Right top) Prototype RFQ schematic showing position of the beads oriented parallel to the field direction
(Right bottom) A photograph of prototype RFQ

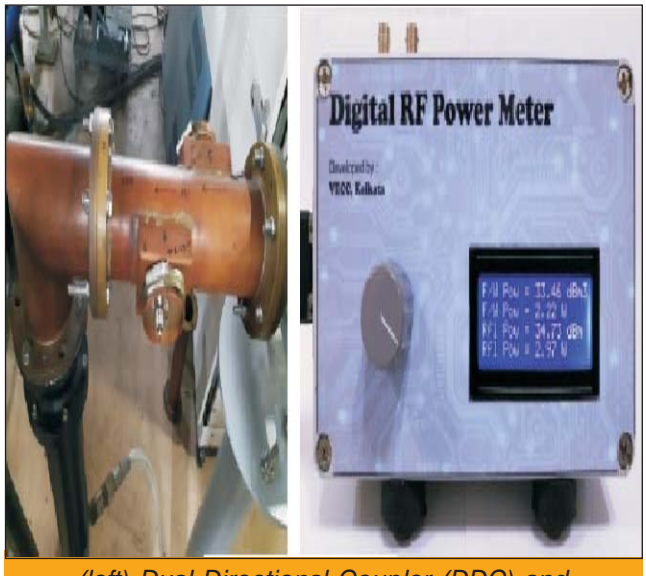
Design and development of Niobium Quarter Wave Resonator (QWR) cavities in collaboration with TRIUMF Canada

Traditionally Superconducting Heavy-ion Linacs built so far have common vacuum for the cryomodule and beam-line. This creates a number of difficulties due to increased chance of contamination of Niobium surface and expensive logistics of cryomodule assembly inside a Clean-room. Recently, a few groups e.g. at Michigan State University, USA have built hermetically sealed cryomodules in which the Niobium QWR (quarter-wave resonator) superconducting cavities and solenoid magnet are interconnected via bellows and beam tubes with the beam-line to achieve isolation w.r.t. cryomodule vacuum. For the VECC RIB project one such superconducting Heavy-ion Linac Cryomodule is being built jointly with TRIUMF Canada under a MoU. This cryomodule will be used for accelerating heavy ions with a high acceleration gradient of around 5 MV/m. Physics, RF, beam dynamics and engineering design of Niobium Quarter Wave Resonator (QWR) cavities has been frozen and two cavities have been fabricated at TRIUMF. In recently conducted preliminary tests acceleration gradient has been measured and matches with the design value.

Photograph showing Niobium Quarter Wave Resonator (QWR) cavities being prepared for tests at TRIUMF

Indigenous development of RF power monitor for amplifiers in the RIB facility

An indigenous RF power meter along with Dual Directional Coupler (DDC) with monitoring electronics is designed, developed and tested successfully jointly by RIB and C&I Group at VECC. It offers low cost import substitution for the indigenous linear accelerators at the centre. The DDC can be used over a frequency range of 30-115MHz. The dual channel RF Power Meter can measure forward and reflected power simultaneously. The combination of power meter and DDC is tested at 37.8MHz with amplifier at the RIB facility up to 5kW. The result is compared with commercial Keysite power meter and found satisfactory.

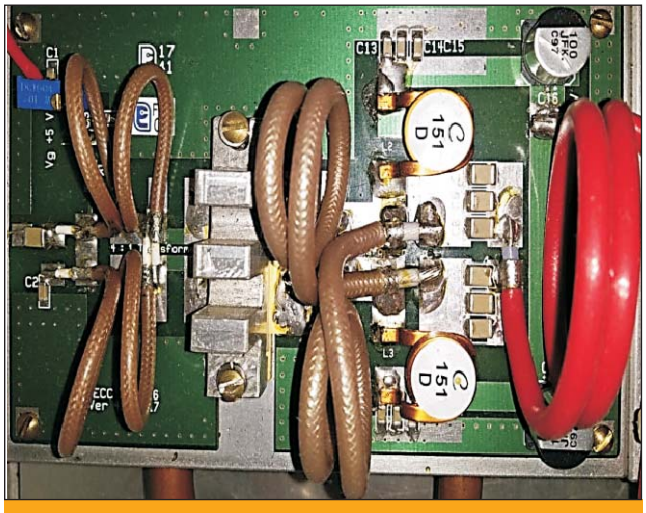


(left) Dual Directional Coupler (DDC) and (right) RF power meter designed and developed indigenously at VECC

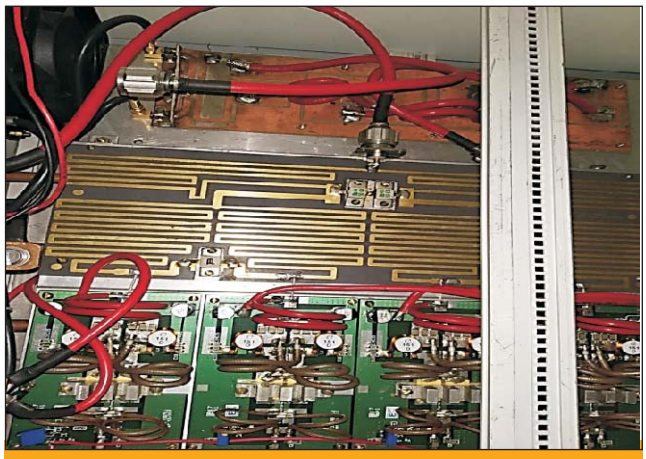
Indigenous design and development of 10kW, 75.6 MHz, Solid-state RF power amplifier for RIB facility

Design and Development of high power solid state amplifiers for Radioactive Ion Beam facility has been done in VECC. The advent of high power LDMOS technology has opened new avenues in the fields of solid state RF amplifier development in scientific and industrial applications. High power RF amplifiers in accelerator laboratories were traditionally built using Vacuum tube electron devices. In VECC solid state amplifier development at 75.6 MHz and RF power combiners was started as a part of research and development.

The basic building block of this amplifier is a 325 Watt amplifier module having 50 ohm input/output impedance. Generally, the output impedance and input impedance of RF LDMOS is very low (<6Ù). The amplifier is equipped with impedance matching network along with rf transformers both at the input stage and output stage. The impedance matching transformers has been realized using transmission line sections of specific characteristic impedances. LDMOST FET is connected in Push pull configuration but both of them is N type Fet. The transformers serve the purpose of both impedance matching and 180 hybrid splitter/combiner. The amplifier is mounted on a water cooled aluminium heat sink. Four such amplifier modules are combined using a microstrip line planar combiner fabricated on a low loss PCB laminate to make a medium power amplifier unit. This medium power amplifier unit is characterized and tested at 1300W. Eight such medium power amplifier units are further combined to make the final 10kW high amplifier.



325 W RF Amplifier Module



Medium Power (1300W) Amplifier unit

The RF combiner for the final stage is a Gysel type combiner. A novel method of inverted transmission lines was used to reduce the size/length of the combiner. The design simulation of the combiner was done in 3D FEM code. The combiner of is made of ETP copper and has reasonably low insertion loss. The combiner was characterized using Vector Network Analyzer. It is very important to keep the phase and amplitude same of the individual amplifiers for efficient power combing at high power. Special care was taken for making RF cable assemblies to have equal phase/ amplitude relationship. Forward and reflected power is monitored in each medium power amplifier using a dual directional coupler.

The installation of amplifier cabinet, power supplies, RF load and water cooling lines has been completed during this period at RIB Annex building. Test and measurement of all the amplifier modules and medium power units has been done at rated power levels. Temperature distribution in the amplifier was measured using a IR thermal imager. All RF amplifier modules for 10kW system are installed and tested individually.

(a) Final RF Amplifier (b) Medium Power Units (c) Combiner/ Divider

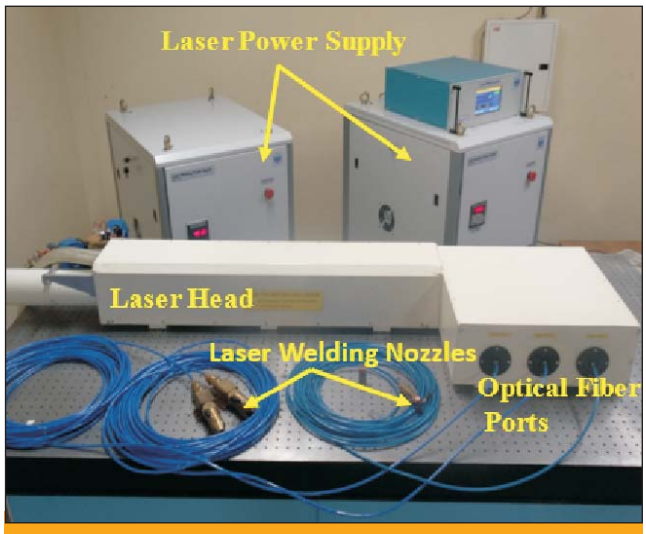
Commissioning of hexapod-based mirror alignment system

At BARC, a telescopic mirror system was developed for exhaustive recording of EXAFS (Extended X-ray Absorption Fine Structure) spectrum of Indus-2 beamline. Mounted on a hexapod, the motorized mirrors equipped with six degrees of freedom and advanced software help carry out high precision focusing of beam on the targeted sample at a resolution of 1 μm in translation and 1 arc-second in rotation independently about all three perpendicular directions.

Hexapod based mirror alignment system for Indus-2 beamline

LASER TECHNOLOGY

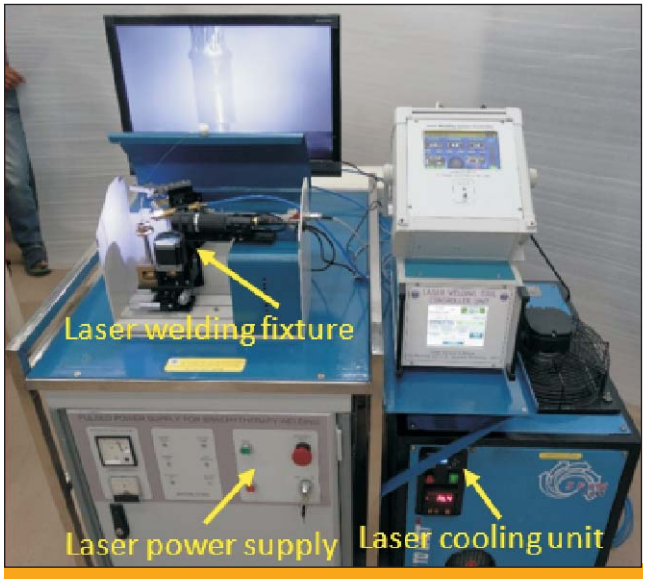
At RRCAT, a fiber coupled pulsed Nd:YAG laser system providing maximum average output power of 500 W and 10 kW peak power with variable pulse duration in the range of 2-40 ms and variable pulse frequency in the range of 1-100 Hz has been developed for welding of D9 fuel tubes of PFBR and zircaloy-2 fuel tubes of BWR. Welding of fuel pins for PFBR and BWR has been qualified. An electrical to laser conversion efficiency of 5% has been achieved. Laser output has been delivered through an optical fiber of 400 mm core diameter with 90% transmission efficiency. This system have been packed and dispatched at the Advanced Fuel Fabrication Facility (AFFF), Tarapur.



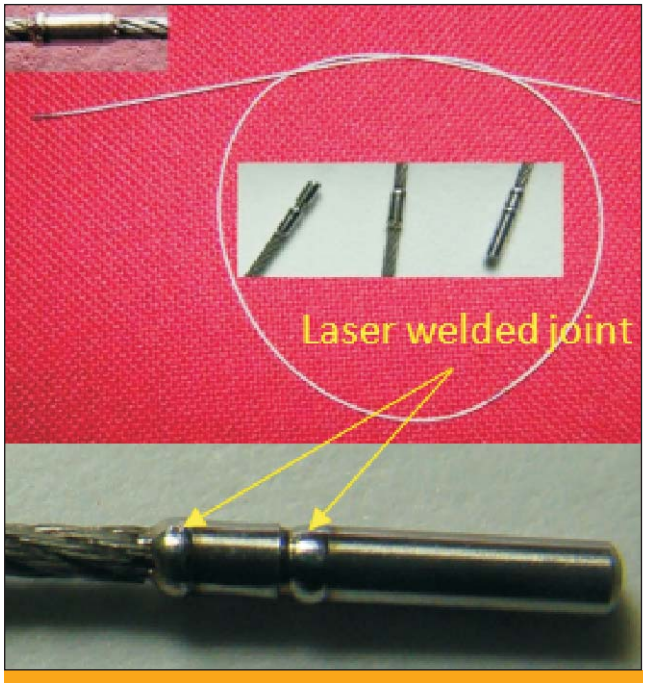
In-house developed ceramic reflector based 500 W average power and 10 kW peak power Nd:YAG laser

Laser welded samples of PFBR and BWR fuel pins

A compact Nd:YAG laser system providing a maximum of 12.5 J pulse energy at 12 ms pulse duration was given to RPHD, BARC in the previous year for welding of Iodine brachytherapy capsule. A similar system for BRIT has been developed for welding of ~ 1 mm diameter and 150 micron wall thickness Iridium-192 brachytherapy assembly. The welding fixture and tooling are different in this welding system. The system has been equipped with two time shared fiber ports of 200 mm diameter, one for welding outside hot cell and another for welding inside hot cell. A welding fixture with rotary arrangement and motion controller for welding has also been developed. Welding fixture has a CCD camera based online viewing set up for monitoring of laser welding process. This laser system has been installed at BRIT, Mumbai. The system is yet to be installed in the hot cell by BRIT.



In-house developed 12.5 J pulse energy Nd:YAG laser system for welding of Ir-192 brachytherapy assembly



Laser welded sample of brachytherapy assembly

Development of 20 W of average output power all-fiber Yb-doped Q-switched fiber laser at 1064 nm has been carried out using Master Oscillator Power Amplifier (MOPA) configuration. From all - fiber Q-switched Yb -doped fiber laser oscillator, an average

output power of 1 W with a pulse duration of 220 ns at 20 kHz of repetition rate was achieved, which was further amplified using a single amplifier stage to generate an average output power of 20 W with a pulse duration is 220 ns at 20 kHz of repetition rate. Laser output is nearly diffraction limited with a measured value of M^2 1.6. This fiber laser will be utilized for laser marking and micromachining applications.

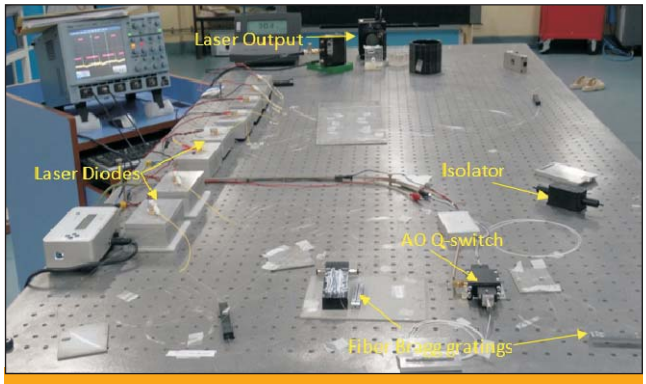
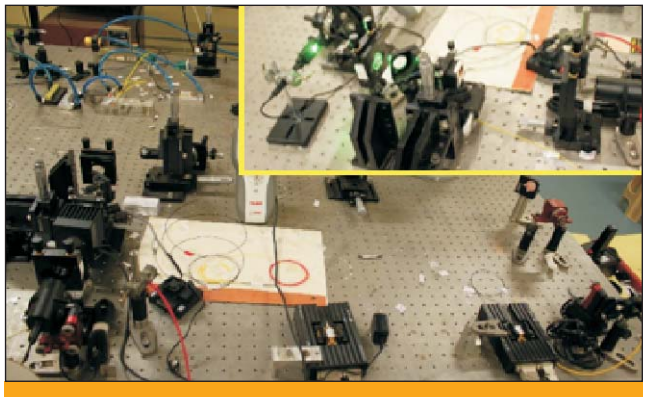


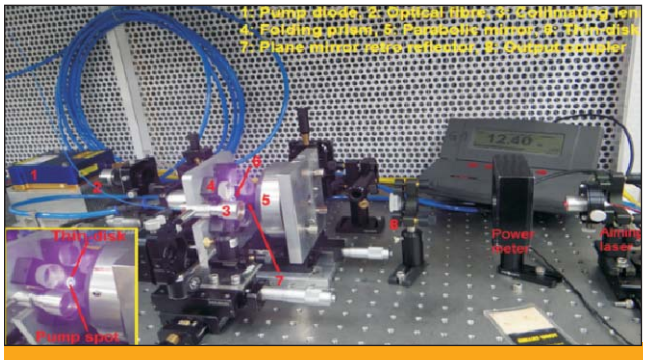
Table-top set up of 20 W Yb-doped Q-switched fiber laser



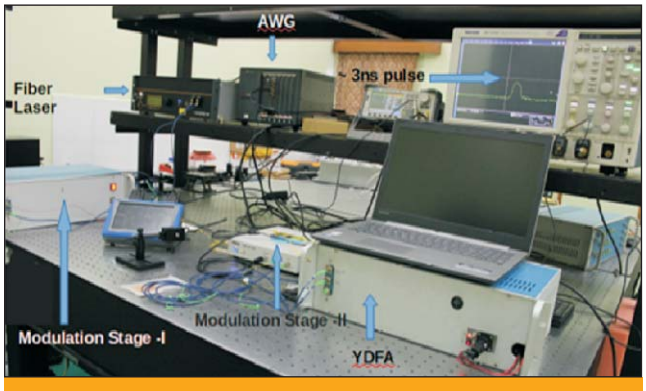
Photograph of the narrow linewidth amplifier setup, inset photograph is second harmonic generation part

A multi stage Ytterbium doped all-fiber amplifier setup is developed for amplification of narrow linewidth seed source delivering 20 mW output power at wavelength of 1064 nm, with linewidth < 2 MHz to scale the power to 10 W level. Second harmonic generation of the amplifier output is carried out in periodically polled crystal to generate narrow line width at 532 nm with output of 350 mW. This laser is being developed to serve BARC requirement.

Thin-disk laser is an advanced variant solid state laser for high power/energy with excellent beam-quality. Design and development of an Yb:YAG thin-disk laser (1030 nm), based on diode pump with 24-pass pump-head, has been carried out. This CW laser provides output of more than 12 W with about 27 % slope efficiency. The developed laser system will help in scaling up of output power of solid state lasers without compromise on their beam quality and will enhance their applicability in various materials processing applications.



Developed CW Yb:YAG thin-disk laser in operation



A view of in-house developed all-fiber fiber optic front end system

A Fiber Optic Front End System (FOFES) is developed for a high energy Nd:Glass laser. The FOFES is a seed laser system based on all-fiber architecture for alignment. It consists of a narrow line width Ytterbium doped fiber laser operating at 1053 nm and emitting about 100 mW of CW power. The laser is externally modulated in two stages. The first stage of modulation is based on acousto-optic modulator that reduces the average power of the system without effecting peak power. It provides a pulsed signal at 100 kHz with a pulse width of 300 ns and average power of 500 μW. The second stage of modulation is based on electro-optic modulator driven by an arbitrary waveform generator. This stage is operated to provide square shaped pulses with a pulse width of 3 ns at 100 kHz and a pulse energy of 20 pJ. The laser pulse energy is amplified with a gain of 30 dB from fibre amplifier to 20 nJ. The output pulse energy of current system is limited to 50 nJ by the fiber amplifier.

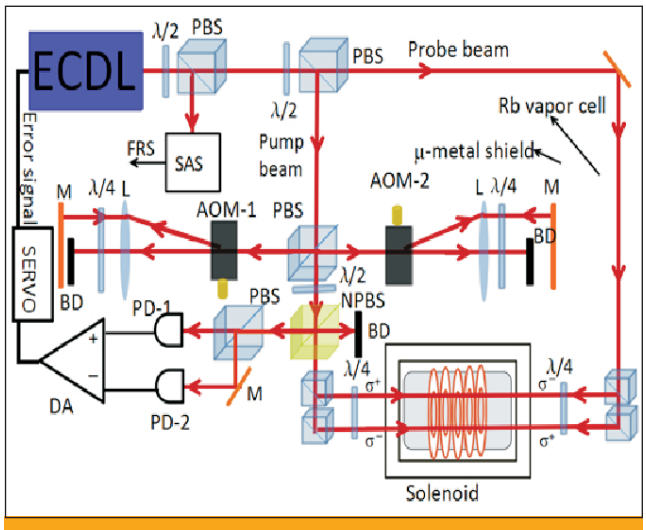
The system named LASMART (Laser based sag measurement application for reactor tubes), consisting of He-Ne laser, collimator-beam expander, mirrors (stainless steel), motorized steering mirrors mounts, thin film coated beam splitter, CCD camera for imaging and software for remote operations of the steering mirrors, image grabbing and analysis were indigenously developed at RRCAT for the sag measurement of the calandria tube of the nuclear reactor. The measurements are usually performed using inclinometers or LVDT probes but due to high radiation in the tubes, the life of the probes is limited and measurements are less precise due to deterioration of the probe. Shadowgraphy using laser beam is a remotely operated, non-contact measurement technique which is suitable for use in radiation zone. The LASMART system is capable of measuring the maximum sag with an accuracy of 0.5 mm and typically, the sag is of the order of 10 - 20 mm. The system was qualified on mock-up tests at KAPS and finally used for measurement of sag in three calandria tubes at KAPS-1.

Laser based sag measurement setup in the vault of KAPS-1

Capillary discharge x-ray laser system emitting at 46.9 nm

Significant enhancement was obtained in the energy of soft x-ray laser operating at 46.9 nm generated from high voltage capillary discharge system. In order to increase the energy, the length of this gain medium (Ne-like Ar ions-) was increased from 15 cm to 45 cm inside an alumina capillary of 3.2 mm inner diameter. This was subjected to a discharge current ranging from 25 to 35 kA with 90 ns quarter period. The argon gas pressure and the pre-pulse conditions were tuned in order to maximize the laser amplitude measured using a calibrated vacuum photo-diode. As a result, the maximum energy per pulse achieved from this soft X-ray laser was found to be 70 μJ. The further enhancement in energy is possible while optimizing the parameters with capillary of different inner diameters and it will be carried out in future.

RRCAT has developed a new frequency stabilization technique for External Cavity Diode Laser (ECDL) at 780 nm, where an enhanced symmetric dispersion like reference locking signal with large slope is generated for frequency stabilization. In this technique, a pair of pump and probe beams having mutually opposite circular polarizations in presence of an external magnetic field is used to generate a Saturated Absorption Spectroscopy (SAS) signal for F=2 '! F´=3 transition of ^{87}Rb atom, which is much higher signal than conventional SAS signal having linearly polarized pump and probes. Using another pair of pump and probe beams, but with reversed polarizations, another enhanced SAS signal is generated. Then, a symmetric dispersion like locking signal is generated by subtracting the above two probe signals. This signal is called as polarization enhanced Doppler free Dichroic Lock (PE-DFDL) signal. The schematic of setup is described below where Rb-vapor cell at room temperature is used for setting-up spectroscopy in the presence of external magnetic field. This PE-DFDL signal for F=2 '! F´=3 transition of 87Rb atom gets nearly two times enhanced as compared to usual DFDL signal obtained from Lin-II-Lin configuration of SAS. The higher slope obtained in the dispersion like signal is useful for tight frequency locking of lasers.



Schematic of polarization enhanced Doppler-free Dichroic Lock (PE-DFDL) set-up

An Infra-Red Free Electron Laser (IR-FEL) designed to lase in the 12.5 - 50 mm wavelength band is presently in an advanced stage of development at RRCAT. The injector system of the IR-FEL has recently been upgraded to deliver up to 50 W average electron beam power, which is planned to be achieved in stages. In first stage of commissioning of the IR-FEL, the electron beam qualification experiments have been performed in the low energy (6 W) section of the machine and the RF conditioning of all accelerating structures are in progress to operate at electron rated beam power. Electron beam trials and lasing experiments will continue over the next quarter leading to lasing with laser peak power 1.5 MW and laser average power 10 mW at a wavelength of 30 μm.

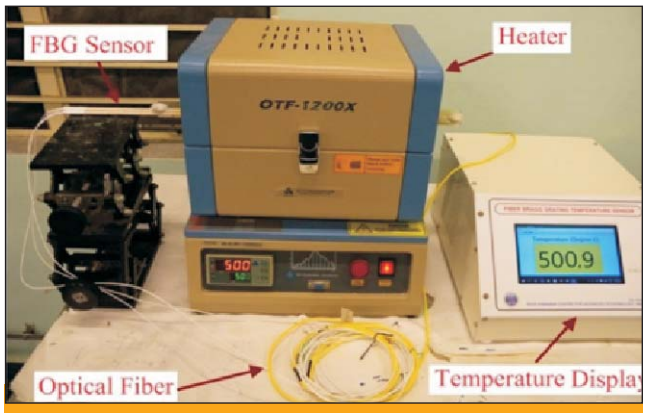
IR-FEL setup installed inside a 60 m long radiation shielded area

Laser Applications

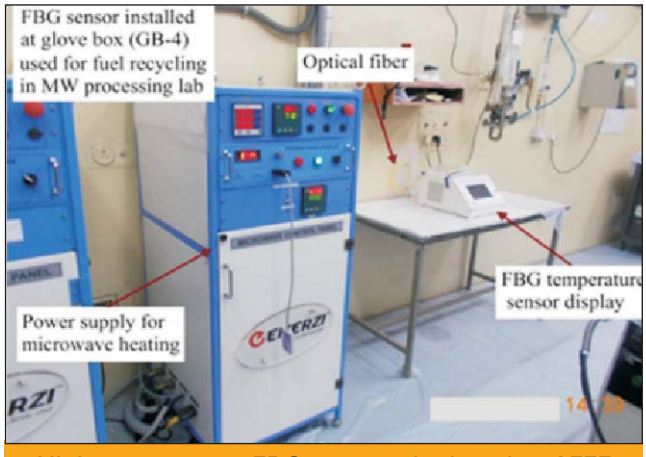
An ion-chamber electrometer is developed for the measurement of small charges or corresponding currents, in the range from pA to μA with resolution of 1 pA, generated by radiation monitors like ionization chambers. The programmable high voltage supply is integrated into the system and can be specified up to 300 V dc, which allows chambers for different dosimetry applications to be biased properly. A linearity better than 0.1% is achieved. The unit is installed and working satisfactorily at Electron Beam Centre, BARC, Mumbai.

Ion chamber electrometer eDAQ02 is a 2-channel meter with tri-axial connector inputs at the back panel

A fiber Bragg grating **(**FBG) based temperature monitoring system set-up is developed at RRCAT, to monitor high temperature (800 ^{o}C) of microwave heated chamber. Temperature monitoring in such chambers with conventional sensors is a difficult task because of very high Electromagnetic Interference (EMI). For high temperature sensing purpose, specialized thermally regenerated FBGs are fabricated at RRCAT utilizing in-house developed FBG inscription set up using high quality 255 nm UV beam. The FBG sensor is encapsulated in the ceramic tube of Õ 5 mm. Temperature monitoring and calibration system is also developed for these sensors. The FBG sensor was installed in the process chamber at AFFF, Tarapur.

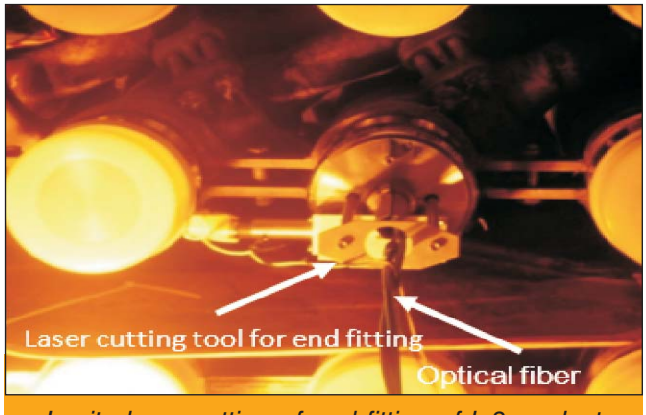


High temperature FBG sensor based temperature monitoring system developed at RRCAT

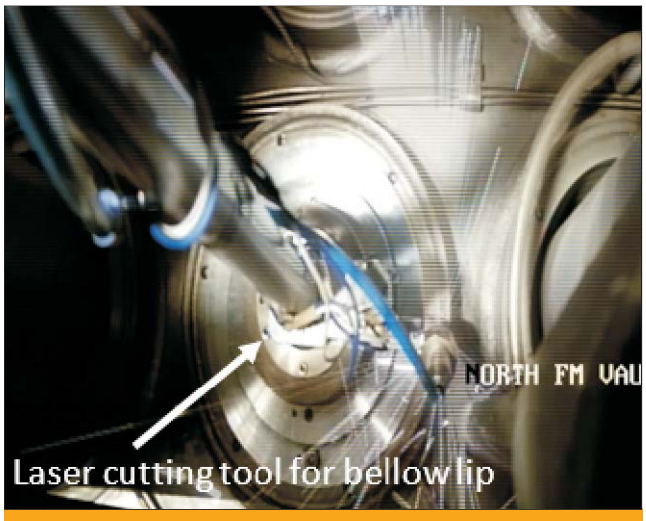


High temperature FBG sensor deployed at AFFF, BARC, Tarapur

Development of laser cutting technology using Nd-YAG laser system and laser cutting fixtures for removal of single selected coolant channel of 540 MWe has been carried out for the first time at TAPS-3&4. This laser cutting technology was deployed successfully and L-8 coolant channel and bellow lip of TAPS-4 reactor was successfully cut and removed with minimum radiation dose consumption.



In-situ laser cutting of end fitting of L-8 coolant channel of TAPS-4 reactor



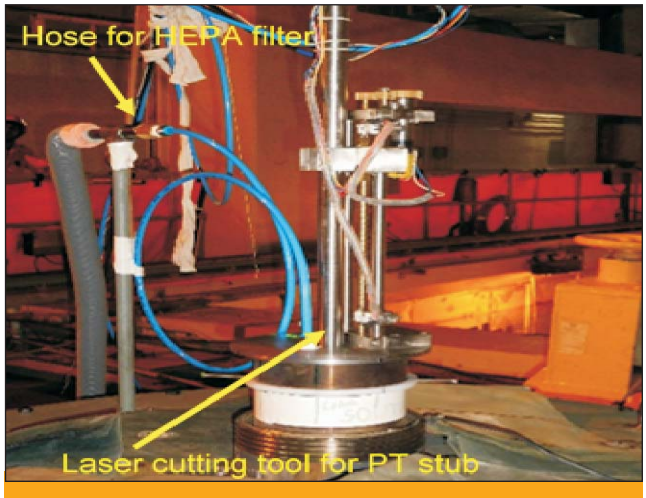
In-situ laser cutting of bellow lip of L-8 coolant channel of TAPS-4 reactor

Kaiga Generating Station Unit-1 started its commercial operation in 1999 and recently it set a world record of 962 days of continuous operation. However, in order to monitor health of its pressure tubes, it was decided by AERB to remove three selected coolant channels L8, K10 and F10 from a matrix of 306 coolant channels for PIE data. These coolant channels were surrounded with six number of feeder pipes in complex manner passing from top and bottom of end fitting and it was challenging task to remove these coolant channels by any means due to space restrictions. Indigenously developed remotely operated fiber coupled 250 W average power Nd:YAG laser with controller, three different laser cutting fixtures and miniature size nozzles was deployed. The in-situ laser cutting operation of L8, K10 and F10 coolant channels was successfully implemented with minimum radiation dose consumption and without any radiation hazard.

Laser cutting tool for liner tube and end fitting

Bellow lip cutting tool mounted on end fitting for mock up

Earlier, underwater laser cutting technology for retrieval of pressure tube (PT) stubs of 220 MWe reactors was developed and deployed successfully at KAPS-1, KAPS-2, MAPS-1 and RAPS-4 reactors. Now this technology was developed and deployed successfully for removal of L-8 coolant channel of 540 MWe TAPS-4 reactor for PIE data on its pressure tube (made of Zr-Nb2.5%). A new laser cutting tool of 1.5 m length along with controller and cutting process was developed and tool locking was done from ID of inboard end fitting. A vent was provided through laser cutting tool for connection with HEPA filter to filter air released from water during underwater laser cutting process. Each PT stub was ~125 mm long and four circumferential cuts were carried out. Total laser cutting time for each PT stub was ~3 hrs. This activity was successfully completed with minimum radiation dose exposure and without any radiation hazard. It is to be noted that there is no alternate technique for retrieval of PT stubs except underwater laser cutting.



Underwater laser cutting arrangement for PT stubs at TAPS-4

There are five Steam Generators (SG) around the core of the reactor at PRPD, Kalpakkam. It was required to replace one of the leaky steam generators with a new one. Indigenously developed 500 W average power fiber coupled pulsed Nd:YAG laser with different laser cutting manipulators and techniques was deployed for cutting operation which resulted in removal of one of leaky Steam Generator (SG) with minimum radiation dose consumption.

A 2 kW Fibre Laser based Directed Energy Deposition (LDED) was deployed to deposit clad layers (thickness 250 ìm) of Tungsten carbide (WC) on hollow cylindrical substrate (size: 15.5 mm OD, 10 mm ID and 15 mm length) of SS304L. Further it was machined to meet the dimension tolerances. 300 numbers of such bushes were delivered to BARC.

Laser based direct energy deposited tungsten carbide (WC) as deposited

Laser based direct energy deposited tungsten carbide (WC) after machining

ADVANCED TECHNOLOGIES

A design prototype of liquid nitrogen based refrigerated system has been developed for transportation of fruits and vegetables. The prototype has been tested in the laboratory and was subjected to exhaustive road trials with vegetables to prove its roadworthiness with participation of farmers in road trials. The road trials were successful. The full size refrigerated container (20 feet) is under assembly for carrying out the road trials.

Interaction with farmers at Tillore village, loading of vegetables and trial run

Fluidization-based vapour adsorption system for recovery of Trichloroethylene (TCE) vapours

An experimental set-up for adsorption and recovery of Tri-Chloro-Ehtylene (TCE) vapours on a fluidized bed of Activated Carbon (AC) was commissioned. Experiments were conducted to understand aspects such as hydrodynamic characteristics and adsorption isotherms of AC particles of different sizes starting from 355 μm and the effect of initial concentration of TCE vapour in air (100, 200 and 250 ppm). Produced during the fabrication of metal oxide fuel by sol-gel process, TCE vapours have a low vapour pressure of 100 mm Hg at 30^{o}C, and are highly harmful.

Experimental set-up for adsorption and recovery of Trichloroethylene

Experimental set-up of Fluidization based chemical vapour deposition technique

SiC coated Zr 2.5 Nb coolant tubes on display

Pure silicon carbide coating by Fluidization based chemical vapour deposition

Fluidization based Chemical Vapour Deposition technique (FCVD) has been developed for silicon carbide (SiC) coating on the surface of Stainless Steel (SS), high density graphite, Inconel etc. Coating on inner and outer surfaces of Zr 2.5 Nb coolant tube and SS pipes of 25 mm diameter and 500 mm long was successfully carried out. Adhesion testing of coated

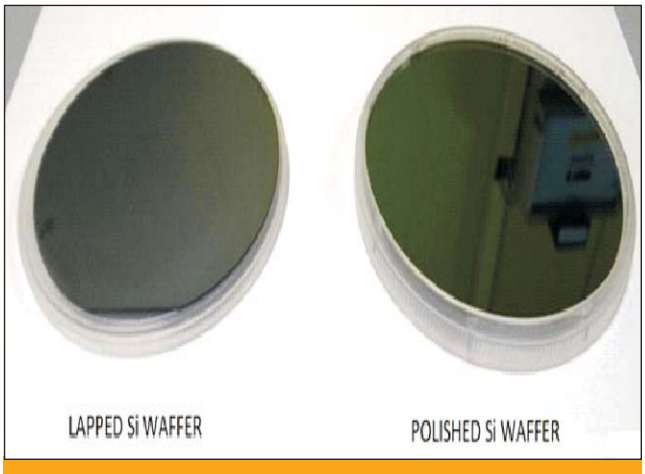
SiC on Zr 2.5 Nb coolant tubes was also carried out. It was found that coating can be used up to equivalent mechanical handling loads of 10N.

Hydrogen adsorption on molecular sieves

Helium Purge System (HPS) of the Indian Test Blanket Module at ITER was operated in round-the-clock shifts to study characteristics of molecular sieve based adsorption systems for removal of hydrogen and moisture from streams of Helium gas. Hydrogen adsorption capacity of the medium was observed to be about 1.5 mol/kg adsorbent at 77 K, higher than the internationally reported figure of 1.3 mol/kg adsorbent.

Production of mono crystalline silicon wafers

20 high purity monocrystalline silicon wafers of up to 4 cm diameter and 550 micron thickness were produced from in-house made silicon ingot. The wafers will be used for making large area pixel detectors. These wafers will later be fabricated at Bharat Electronics Limited (BEL) based on the BARC technology.



Mono crystalline silicon wafers

Demonstration of Integrated compact water electrolyser technology

A compact, low temperature alkaline water electrolyser was demonstrated at the user's site. Techno-commercial analysis was carried out for reducing the cost of hydrogen produced from this plant.

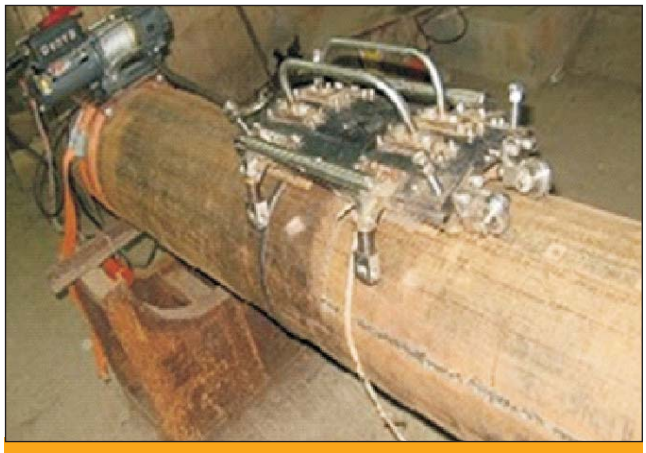
Electrolysis unit for production of Oxygen and Hydrogen

Ring-type Eddy Current based inspection system for Pipeline Inspection Gauges

Ring-type Eddy Current based inspection system for Pipeline Inspection Gauges

A full periphery ring type Eddy Current (EC) based inspection system was designed and developed for identification and inspection of external defects and very deep internal defects in carbon steel pipelines in a 10 inch pipeline. The tool is ready for field trials. A Magnetic Flux Leakage (MFL) based tool for sectoral inspection of pipelines was also developed. Multiple trial runs of the tool were carried out to calibrate the

empirical model for defect characterization and to generate a data bank. Field inspection of two spool lengths of pipe was conducted at Dhruva, BARC. The tool will be deployed to inspect 10 inch pipelines in BARC facilities.



Magnetic Flux Leakage (MFL) based tool for sectoral inspection of pipelines

An ultrasonic (UT) based online interface tracking system was developed to detect interface depth of liquid-liquid (organic-aqueous) interface. The system was validated for medium invariance (dodecane-water, petroleum ether-water, toluene-water), temperature invariance, effect of particle impurity and dynamic change of speed of sound (by adding other solvent) in various liquid-liquid systems. The signal-processing algorithm in the system de-noises and extracts meaningful parameters from the highly scattered/ attenuated UT signal to estimate the speed of sound in the media and subsequently estimate the interface depth and thickness in near real time.

Ultrasonic (UT) based online interface tracking system

FPGA based data acquisition system was installed for validation of 'attractor comparison method' to find 'S parameter' in near real-time, as part of studies in detection of agglomeration in fluidized bed reactors. The system will soon be installed as an early warning system at three de-nitration columns at DNP Kalpakkam. Fluidized bed thermal de-nitration technology is extensively used in nuclear fuel cycle to treat various product-nitrate streams (uranyl nitrate) as well as waste-nitrate streams (metal nitrate, ammonium nitrate).

Electronics & Instrumentation

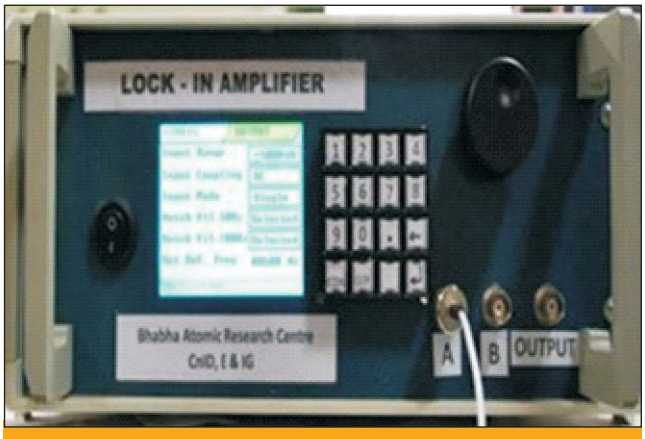
A new version of "ANU NISHTA" was developed with enhanced hardware features for ensuring cyber security of instrumentation and control systems in Nuclear Power Plants. Several enhancements have been incorporated, including in power supply circuit of the board (to take power from PCIe slot), in tamper detection enclosure, provision was made for terminal contacts for remote diagnostics and observation of non-secure behaviour of local network. UEFI based secure boot and UEFI runtime service based white listing have been implemented for UEFI based servers. Extensive testing of the version has been carried out in NPCIL, ECIL, and BARC Computer Division.

A secure NTP (Network Time Protocol) Time server module was developed for time synchronization in Control & Instrumentation applications. The module is a statum-1 time server and is designed to handle more than 30,000 NTP requests/sec with a maximum holdover time of 10 usec/day in case of GPS signal loss. Time synchronisation helps in proper chronological logging of event messages for post-event analysis.

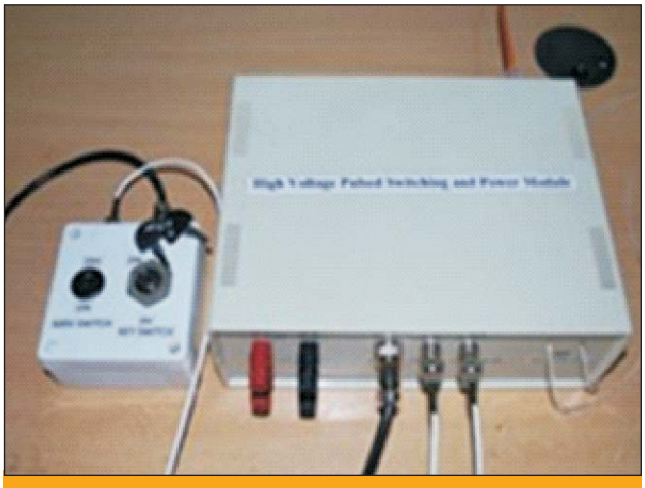
A Distributed Control System (DCS) integrated test facility comprising of 32 Node and 9 Node based NUCON-1000 PLCs interfaced with SCADA servers was set up at ECIL, Hyderabad. The facility will be used as test bed for performance evaluation of important parameters like cycle time, switchover time, system response time and evaluation with respect to safety, cyber security and reliability requirements for industrial scale Instrumentation & Control applications in all upcoming and future projects of DAE. The facility will be adopted in DCS of

INRP Tarapur. Programmable Logic Controllers (PLCs) are the workhorses for modern automation offering benefits of modular hardware, reusable design and graphical programming. Most of the commercially available PLCs are of foreign origin.

A digital lock-in amplifier to detect and measure very small AC signals and to eliminate phase dependency of the output was developed. The amplifier has a bandwidth of 250 kHz, dynamic reserve of over 100 dB, time constant of over 400 seconds and roll-off of up to 80 dB.



Digital lock-in amplifier



High voltage pulsed switching and power module

A high voltage power module (4kV, 4W) using battery based fly-back converter topology was fabricated using High Voltage High Frequency (HVHF) transformer, PWM controller, MOSFET and voltage multiplier with fast recovery diodes. This system was utilized in charging and switching of Capacitor-Spark gap modules of 50-500nF at 4.0kV for pulsed power applications.

A generic software platform for Antenna Controller and Simulator (GACS) control applications, consisting of I/O Configurator, Control Modules, Controller Configurator, Mechanical Model Viewer, was developed. The software framework was validated on a MACE Telescope Controller rack and TCU application.

BARC is involved in monitoring important strategic seismic events in the Indian Subcontinent and the assigned region of interest. A total number of approximately 700 events of magnitude more than 4 have been reported in the year 2019. Event detection capability in the north-eastern region of India was less than adequate due to unavailability of a well established seismic station in that region. To enhance the detection capability, a suitable site was selected after auditing seismic and logistic qualities. A seismic station was built and equipped with a three component broadband seismometer of very high dynamic range along with a high resolution seismic digitizer. A data communication channel was also established to provide acquired seismic data online at data centres. With this, the seismic activity in the north-eastern region, is being monitored in near real-time with higher detection accuracy and sensitivity.

Robotics

Mobile robot for radiation mapping of cyclotron area

Assessment of radiation levels inside bunkers of accelerator facilities is essential to avoid accidental human exposure and to protect sensitive electronic equipment from high intensity radiation exposure. A tele-operated mobile robotic system for 3D mapping of the radiation levels inside the K-130 room temperature cyclotron vault and experimental cave area during operation was completed. The system comprises of a robotic vehicle, which moves inside the cyclotron vault and a master control station located inside the cyclotron's control room. The robot is mounted on a vertical lifting platform which has a collapsed height of 600 mm and an extended height of 1500 mm from the ground level.

Tele-operated mobile robotic system for radiation mapping of cyclotron area

Special Programmes

BARC-ECIL developed RF seeker onboard long range BrahMos Missile. Flight trial of long range BrahMos Missile with BARC-ECIL developed RF seeker performed on expected lines. The RF seeker's guidance & control systems functioned with high accuracy to successfully meet the mission's launch objectives in terms of miss distance, measurement accuracies, search, detection, track and homing modes.

BARC-ECIL made RF seeker onboard long range BrahMos Missile, launched in December 2019.

ISOTOPE PROCESSING

The radioisotopes in India are produced in research reactors at Trombay, power reactors of NPCIL and accelerators at VECC. These radioisotopes are processed by BARC, and a vast array of high quality radioisotope based products and equipment is commercially produced by BRIT. All these products and services have wide applications in the fields of medicine, agriculture, industry and research.

RAPPCOF facility continued the tasks related with the safe supply of Co-60 for various uses, right from receiving the adjuster rods from various Indian PHWR power reactors (a by-product of neutron regulation), processing of the activity, fabrication of sealed sources, to supply of Co-60 sources (irradiator sources & teletherapy sources), are all carried out. At RAPPKOFF, Kota, total activity of Co-60 which was processed during the year was about 2.23 MCi during the financial year 2019-20, which is a milestone in the history of BRIT. This includes 134 Gamma Irradiator Sources and 12 Co-60 Teletherapy Sources (CTS). RAPPCOF transported 08 Adjuster rods from KAPS, Gujarat and 04 Regulating rods from NAPS, UP as special arrangement after getting AERB approval with Radiological coverage in 06 consignments. RAPPCOF received Appreciation Certificate of "Vyavahari Evam Sewa Pradata Samman Yojana-2019" from Rajasthan State Tax Department, Bhilwara.

Visit to RAPPCOF by Ex-Chairman, AEC, Dr. Shekhar Basu

AGRICULTURE

Crop Improvement

Trombay linseed variety TL-99 with improved oil quality was recently released for commercial cultivation by Sub-Committee on Crop Standards Notification and Release of Varieties, Government of India in the year 2019.

In breeder seed programme, a total of 251 quintals breeder seed of Trombay groundnut varieties were produced by BARC and distributed to 24 seed agencies in Bihar, Gujarat, Jharkhand, Karnataka,

Trombay linseed variety TL-99 with improved quality identified for release

Breeder seed multiplication of TG51 variety in Maharashtra

Maharashtra, Madhya Pradesh and West Bengal. These seeds are used for foundation seed production by these agencies for final distribution to farmers.

Large scale nucleus seed and breeder seed production was undertaken for the newly released rice variety at TCDM-1 at IGKV Research Farm, Raipur in Kharif-2019 and distributed to 100 farmers.

Nucleus seed production of 'TCDM-1' (Trombay Chhattisgarh Dubraj Mutant-1) (released & notified for Chhattisgarh state)

Breeders' seed production of rice variety 'TKR Kolam' (BARCKKV-13) (released for Konkan, Maharashtra)

A large scale breeders' seed multiplication was undertaken for 'TKR Kolam' (BARCKV-13) (developed under BARC-DBSKKV collaboration) at RARS-Karjat during Kharif-2019 and 20 Q breeders' seeds were produced.

Breeders' seed multiplication of Black gram variety TU-40, Cowpea variety TC901 and Pigeon pea variety TT401 was carried out at Vizag.

Musa-miR397 was cloned and over expressed in transgenic banana plants. The overexpression of this micro RNA significantly increased the plant growth by 2-3 folds, as compared with that of wild-type but did not compromise the plant's tolerance, either towards Cu deficiency or NaCl stress conditions. RNA-sequencing of transgenic and wild type plants revealed modulation in expression of 71 genes related to diverse aspects of growth and development, collectively promoting enhanced biomass.

Transcription factor, DREB1E from banana cultivar Karible Monthan was cloned in binary vector pCAMBIA

1301. T-DNA harbouring DREB1E under strong constitutive promoter was transferred to embryogenic cells of banana cultivar Rasthali. The 5'-upstream regulatory region of DREB1E transcription factor was amplified and its cloning upstream of reporter gene is being carried out. Similarly, to analyse the promoter activity of two WRKY transcription factors (MusaWRKY2 and MusaWRKY10), transgenic tobacco plants harbouring P_{WRKY2}-GUS and P_{WRKY10}-GUS showed variable levels of GUS induction in leaves under drought, salinity, methyl jasmonate, ABA and cold stress. Further MUG assay confirmed the induction of GUS in leaves of transgenic tobacco lines after application of theses stress conditions.

A peptide based bio stimulant for rice crop was developed, where urea is conjugated with a cationic peptide via linker residues. The phyto-stimulatory efficacy of HPU was evaluated by growing HPU imbibed rice seeds with hybrid peptides in hydroponic media. The designed peptide-urea conjugate HPU showed root-stimulatory effects in rice.

Seed priming with thiourea (a non-physiological thiol based scavenger of reactive-oxygen species) at the rate of 500-750 ppm for 8 h accelerated germination as well as seedling growth in rice variety IR64 in both normal and arsenic-contaminated fields. Tiller numbers increased by 50% in thiourea-primed plants as compared with that of non-primed plants. Besides, two foliar applications at pre-flowering and grain filling stage enhanced grain filling. Vetiver plants grown in the arsenic-contaminated field of Nadia district, West Bengal, showed significant arsenic remediation from soil. Mechanism underlying the heavy metal tolerance such as arsenic (As) and cadmium (Cd) was studied and it was observed that Adenosine Triphosphate Sulfurylase (ATPS) and Cysteine Synthase (CS) were significantly reduced under both As and Cd, suggesting the negative impacts of heavy metals on sulphur assimilation pathways in plants.

Trichoderma koningiopsis mutants with enhanced sporulation was identified. A total of 77 proteins were observed to be upregulated in T. virens in contact with banana roots, compared to T. virens incubated alone. Among these, 11 and 6 belonged to the glycoside hydrolases and Small Cysteine-rich Secreted Proteins (SSCPs) respectively. Field trials with the formulation (termed TrichoBARC) at Raipur and West Bengal showed significant increase in the yield of chickpea and lentil.

Multi-location field trials were undertaken for Btk based biopesticide at RAU, Raichur, Krishi Vigyan Kendras and Department of Agriculture, Karnataka for the management of pod borer on pigeon pea crop. Cage cloth based mass rearing protocol for tomato leaf miner has been optimized and different egg parasitoids have been tested.

The scope of the rapid composting technology for dry leaves has been broadened to include kitchen waste, floral waste (from temples) and paddy straw. Protocols have been worked out for each waste and for various scales of generation. Physicochemical characterization of compost for pH, WHC, macro and micro nutrients was done. Effect of kitchen waste compost on maize plant was studied; it showed significant increase in growth compared to control.

Gamma radiation induced superabsorbent hydrogel powder has been developed, which helps moisture retention in soil. Samples were supplied to LIGO-India, ICAR-NRCB, Trichy and Agriculture University Jodhpur for afforestation and agricultural field trials, which are currently underway.

FOOD PROCESSING

A radiation processing facility based on indigenously developed 10 MeV, 5 kW electron linacs, has been setup by DAE at Devi Ahilyabai Holkar Fruit and Vegetable Mandi Indore. Two linacs have been installed at the facility. The linacs for the facility were developed indigenously by RRCAT in progressive manner. A roller conveyor system is installed for batch mode of irradiation. Volumetric dosimetry measurements have been carried out to test the dose delivery capability in box sizes proposed for the products. AERB licence for plant operation has been obtained. Electron beam irradiation experiments on various research samples such as seeds for mutation breeding, grains for post-harvest treatment, electronic sensors for radiation damage study, precious gem irradiation for colour modification etc have been carried out for more than 15 institutes. Following photographs show some of the samples irradiated at the facility.

Electron accelerator based radiation processing facility at Indore

Two 10 MeV, 5 kW linacs installed at the facility

Ornamental crop Irradiation for mutation breeding from ICAR-DFR, Pune

Soybean seed irradiation for mutation breeding from NABTD, BARC, Mumbai

At BARC, a technology was developed and transferred for preparation of shelf-stable dehydrated preservative-free Jamun strips. The technology is a solution to minimise post-harvest losses of Jamun fruits.

Shelf Stable Dehydrated Preservative free Jamun Strips Sea route simulation of Kesar mango for export to USA

Radiation processed mango fruits are currently exported to USA by air freight. BARC developed a protocol wherein an additional GRAS (Generally Recognized as Safe) food preservatives-based solution dip treatment is introduced in the existing USDA approved protocol. The protocol was simulated in a static reefer container as well as cold room with total 8 tons of mangoes. The container was sealed and opened after 40 days (after harvest). The mango fruits were found to be in good condition without ripening and spoilage. A proposal has been sent to APEDA (Agricultural and Processed Food Products Export Development Authority) for obtaining USDA (United States Department of Agriculture) approval for the protocol.

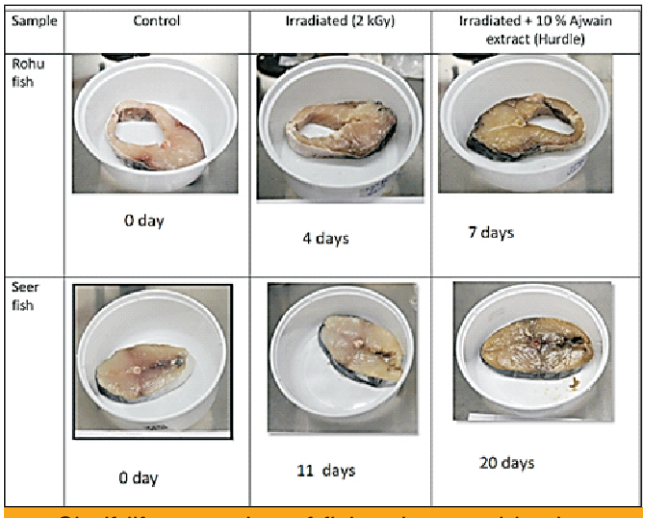
Technology for safe and shelf stable legume sprouts and sweet corn kernels

Storage of hydrogen peroxide (3%) treated pineapple at 10°C for 20 days

Combination processing, including gamma irradiation, was developed for ensuring safety and shelf life of legume sprouts and shelled sweet corn kernels. Anti-nutritional factors were found to be significantly reduced upon treatment.

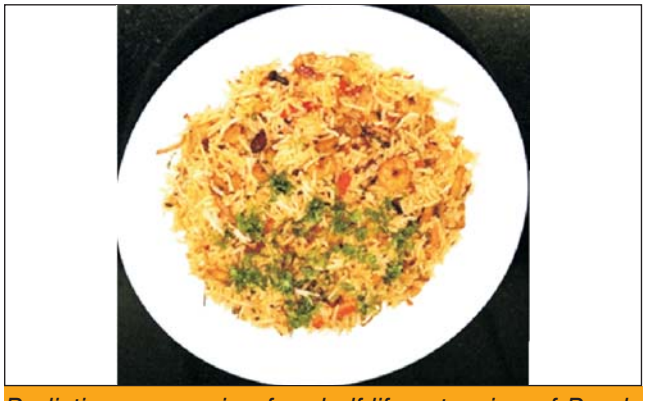
A large scale storage study of pineapple was carried out. At 10°C, pineapples have a shelf life of more than 20 days. Further, 3% hydrogen peroxide spraying increased shelf life, by reducing fungal load on the pineapple.

Shelf life of onions was extended to 10 months by treating with 60 Gy of gamma radiation, followed by storage at ambient temperature (25±2!, RH 60-65%) under ample ventilation. Rotting and sprouting were significantly inhibited in 0.5 tonnes of treated onions. It was observed that for reduction in physiological weight loss, storage at low temperature and RH of 60-65% would be required.



Shelf life extension of fish using combination treatments under chilled conditions

Hurdle technology with irradiation was found to be effective in extending the shelf-life of seer fish by 20 days, whereas irradiation alone gave an extension of 11 days. The fresh water fish rohu had a shelf-life extension of 7 days by hurdle technology, including irradiation, while irradiation alone gave an extension for 4 days. The control samples of the fishes got spoiled in 4 and 1 day, respectively.



Radiation processing for shelf-life extension of Ready to Eat prawn pulao

Development of low glycaemic chapati using radiation-processed psyllium

Prawns and different vegetables were combined to prepare RTE pulao and its shelf life extended using irradiation and chilled storage. The product was prepared using a standardized recipe, packed in multi layered pouches and irradiated at 2 and 5 kGy. Storage studies showed its acceptability up to 3 months at chilled storage with acceptable microbiological and organoleptic quality.

Recipe for low glycaemic chapati was standardized by fortifying 10-14% (dry weight basis) Radiation Processed Psyllium (RPPs). A better score for softness and chewability was observed with RPPs chapati compared to controls.

At BARC, studies on shelf life extension of various meat products, viz., chicken sausages, chicken salami, fish fillet (Basa and Surmai), prawns, pork sausages and pork salami among others were carried out using electron beam (EB). It was observed that the shelf-life of all the meat products increased by 2-3 times with no effect on the texture, nutritive and sensory quality, when irradiated at a dose of 3 kGy of electron beam.

Radiation Procession Services

Radiation Processing Plant (RPP), Vashi

Radiation Processing Plant, Vashi has provided gamma radiation processing services for Spices, Ayurvedic raw material, healthcare products and pet feed etc. to customers from all over the country. Thirty-eight new customers were registered during the current year. This has resulted in improved product availability throughout the year. Source strength of the plant was increased up to 712 kCifrom 612 kCi, which resulted in reduction of waiting period for the customers.

During the current financial year, 2019-20, 4540 MT of spices, Ayurvedic raw material, healthcare products and other products were processed against the annual target of 4500 MT.

RPP facility was re-certified for ISO 22000:2005. Surveillance audits for ISO 9001:2015 (Quality Management System) was also carried out by certifying agency and found in full compliance with the Standard's requirement. Gamma Radiation Processing Services are provided for hygienization of spices, ayurvedic raw materials, pet feed and packaging materials.

The activities of the Dosimetry Group of RPP, Vashi included the Plant commissioning dosimetry for M/s Avantee Megafood Park which was completed during the reported period; Plant re-commissioning dosimetry was carried out in eight Gamma Radiation Processing Plants in India for low, medium and high dose applications; Dose rate certification was provided to four blood irradiators and two gamma chambers which were supplied to various cancer hospitals and research universities respectively; Production & supply of ~1.9 Lakhs Ceric-Cerous Sulphate Dosimeters were done for various gamma irradiators in the country for the measurement of absorbed dose and about 1500 nos. of Ceric-Cerous Sulphate Dosimeters was exported to Atomic Energy Regulatory Board, Sri Lanka.

New MoU for Radiation Processing Plants in Private Sector

BRIT signed an MoU with Department of Agricultural Marketing and Agri Business (DAMAB), for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products at Krishnagiri, Tamilnadu - 635001. A MoU was signed with M/s Akshar Gamma Sterile LLP for setting up a Gamma Radiation Processing Plant for disinfestations, shelf life extension of food products and sterilization applications of healthcare products at Ambernath (E), Mumbai, Maharashtra - 421506. A MoU was signed with M/s Infrastructure Development Authority, Ministry of Industries, Bihar, Patna - 800004 for setting up a Gamma Radiation Processing Plant for disinfestations, shelf life extension of food products and sterilization applications of healthcare products.

MoU signed with Department of Agricultural Marketing and Agri Business (DAMAB), Krishnagiri, Tamilnadu

MoU signed with M/s Akshar Gamma Sterile LLP, Ambernath (E), Mumbai

MoU was signed with M/s Infrastructure Development Authority, Ministry of Industries, Patna, Bihar

HEALTH

Radioisotope based formulations, techniques and equipment are widely used in the diagnosis and treatment of various diseases. BARC, BRIT, RRCAT and VECC are major contributors in this field.

Radioisotopes are produced, processed and technologies are developed at Trombay for varied applications in the medical field. BARC's Radiation Medicine Centre, a premier centre in the field of radio-diagnosis and radiotherapy in Mumbai, is a regional referral centre of the World Health Organization (WHO) for South East Asia.

BRIT produces and supplies radio-pharmaceuticals for diagnosis and treatment of diseases, teletherapy and brachytherapy sources, radioisotope based kits, various instruments, and radio processing services. Jonaki Laboratory at Hyderabad produces and supplies P-32 labelled nucleotides for research in biology, biotechnology and drug discovery. Jonaki also markets S-35 labelled amino acids produced by labelled compounds at Vashi.

Radioisotopes for medical applications are also manufactured at VECC. The Regional Radiation Medicine Centre in Kolkata meets the radio-diagnostic and radiotherapy requirements of the eastern region of the country.

Radiopharmaceuticals

Radiopharmaceuticals are meant for in-vivo use, mainly for diagnostic and therapeutic purposes. Since they are meant for in-vivo use as pharmaceutical grade products, compliance to Good Manufacturing Practices (GMP) is mandatory. In-vitro Radio-immunoassay (RIA) and Immunoradiometric Assay (IRMA) Kits and C-14 Urea capsules are used mainly for diagnostic use. Positron Emitting Tomography (PET) is a powerful imaging agent through which quantitative information on the distribution of positron-emitter labelled radiopharmaceuticals (PET radiopharmaceuticals) in the body can be realized. ^{18}F-FDG is currently the most widely PET radio-pharmaceutical in clinical oncology in addition to its clinical applications in cardiology and neurology. The application of PET in clinical oncology is increasing since many molecular targets relevant to cancer can be labelled with positron emitter radiopharmaceuticals and also these products needs to be produced in strict GMP compliance.

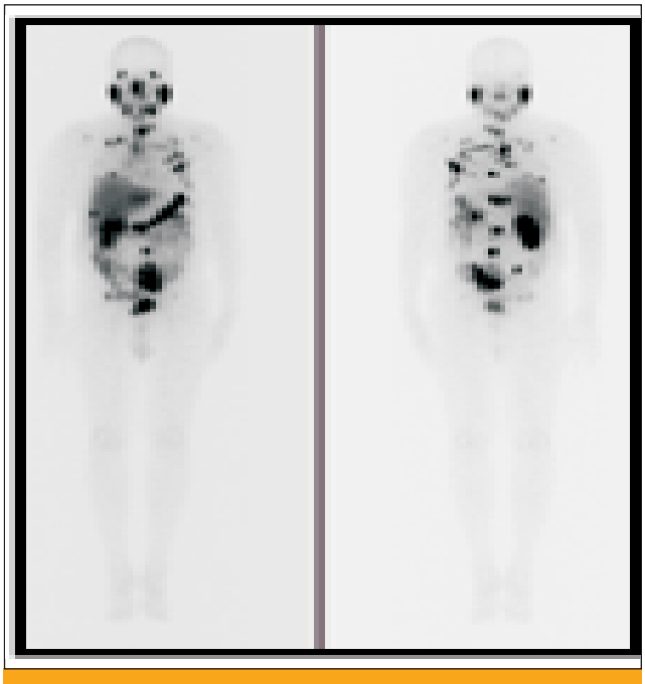
Regular, uninterrupted, production and supply of radiopharmaceuticals, all over India, was continued. However, efforts were made towards expanding the production capacity by introducing some new products based on ^{99m}Tc, ^{177}Lu, ^{68}Ga and ^{188}Re radiopharmaceuticals.

^{131}I as Na^{131}I is one of the most important isotopes which is mainly used for diagnosis and therapy of various thyroid disorders, including the treatment of thyroid cancers. Approximately 200 Ci of Na^{131}I and over 7000 consignments were processed, formulated and supplied to various nuclear medicine hospitals all over India in the form of solution and capsules. This also includes I-131 labelled mIBG, which is supplied as sterile injections and is used for

the diagnosis and treatment of Neuro Endocrine Tumors (NET) and ^{131}I-Lipiodol used for the treatment of Liver Cancer.

Under 12th Plan Project, "Advanced Facilities for Radiopharmaceuticals Production (AFRP)", 740 GBq (20Ci) capacity GMP compliant ^{131}I-mIBG Production Facility (Procured from ITD, Dresden, Germany) had been installed last year. Cold commissioning, trial cold runs for pharmaceutical validation followed by its regular use for the production of diagnostic ^{131}I-mIBG batches were the highlights during the reported period.

GMP compliant facility for ^{131}I-mIBG Production



^{177}Lu-177-PSMA-617 Post Therapy Scan

Amongst the other therapeutic products supplied by BRIT, such as P-32 [Samarium Phosphate Colloidal Injection] for radiation synovectomy, ready-to-use ^{153}Sm-EDTMP & ^{177}Lu-EDTMP injections for bone pain palliation due to the spread of cancer in bones, new therapeutic radiopharmaceuticals, namely, ^{177}Lu-DOTA-TATE which was launched last year for treatment of metastatic (somatostatin receptor positive) Neuro Endocrine Tumors (NET) & ^{177}Lu-PSMA for the treatment of Prostate Cancer, which was launched during the reported year, has gained a lot of importance in the clinical field. About 20 Ci in 174 consignments, were supplied to nuclear medicine centres all over India during the reported year 2019-20.

BRIT also continued the supply of recently launched two ready-to-use diagnostic radiopharmaceuticals based on Gallium-68 (Ga-68) isotope labelling for PET imaging, namely ^{68}Ga-Prostate Specific Membrane Antigen (PSMA) for diagnosis of Prostate Cancer and ^{68}Ga-DOTA-TATE for the diagnosis of Neuro Endocrine Tumors (NET). These radiopharmaceuticals were supplied to the nuclear medicine centers in and around Mumbai only (short half-life of Ga-68 radionuclide, which is only 68 minutes) after the installation of ^{68}Ge-^{68}Ga Generator at BRIT.

During the year 2019-20, more than 8500 nos. of cold kits for formulation of ^{99m}Tc radiopharmaceuticals (19 products; BRIT Code-TCK) in nearly 6000 consignments were formulated, lyophilized, QC tested and supplied to various nuclear medicine hospitals all over India.

Nearly 225 Ci of ^{99}Mo, in 1500 generators in the form of Sodium Molybdate solution, for solvent extraction generator, Coltech generators and Geltech generators is supplied to the Nuclear Medicine Centres in India during 2019-20.

More than 2,50,000 In-vivo diagnostic investigations are estimated to have been carried out this year with varied diagnostic radiopharmaceuticals, the major one being, ^{99m}Tc based cold kits and ^{99}Mo-^{99m}Tc generator systems and around 17000 therapeutic applications are estimated to have carried out during the reported year using BRIT therapeutic

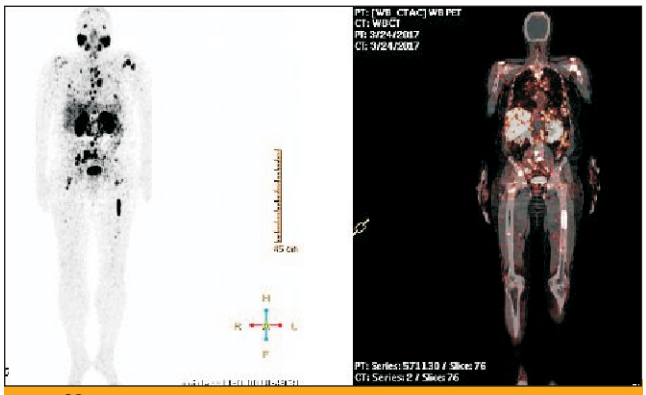
radiopharmaceuticals including $Na^{131}I$ for treating hyperthyroidism and thyroid cancer therapy.

'Facility for the production of cold kits for the preparation of Tc-99m Radiopharmaceuticals' was re-certified for the compliance to WHO cGMP requirements by M/s URS Certification Ltd (a member of URS Holdings Group, U.K.) (Recertified as per Current Standards).

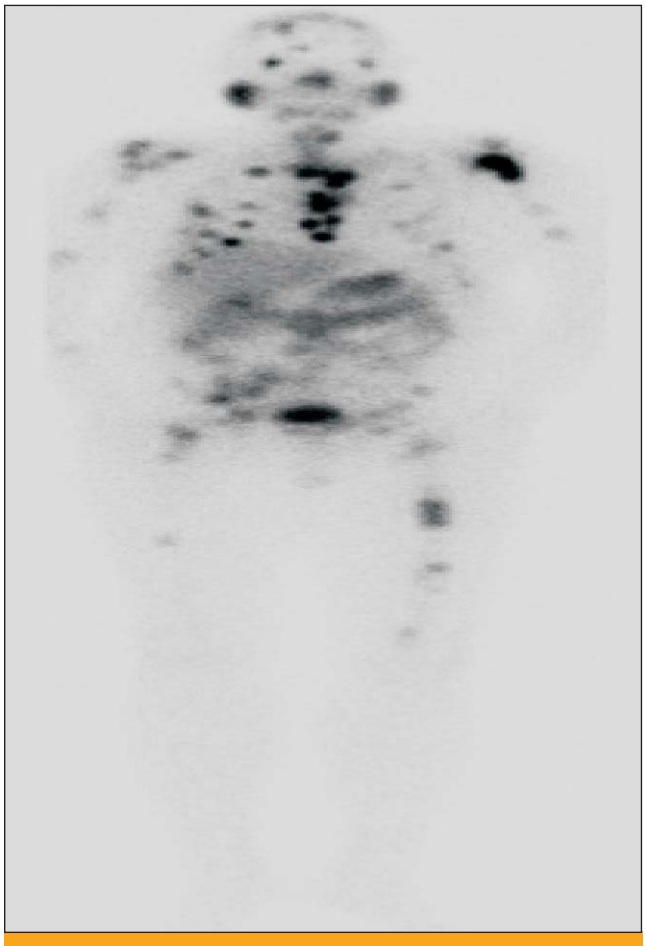
The Medical Cyclotron Facility (MCF), Parel continues the production and supply of Positron Emission Tomography (PET) radiopharmaceuticals, mainly ^{18}F-FDG and ^{18}F-Sodium Fluoride and to a lesser extent ^{18}F-Flurothymidine (FLT) and newly launched [F-18]-Fluro Ethyl–L-Tyrosine (FET). Regular and uninterrupted supply of about 276 consignments of PET radiopharmaceuticals such as ^{18}F- FDG, ^{18}F-NaF, ^{18}F-FLT, and ^{18}F-FET to various hospitals in and around Mumbai accounting for nearly 303 Ci of radioactivity during the year 2019-20. More than 15000 patients benefitted with PET investigations in the reported year. New automated F-18 radiochemistry module has been installed inside the new lead hotcell for production of non-^{18}F-FDG based radiopharmaceuticals (^{18}F-DOPA & ^{18}F-PSMA) during the reported period of 2019-20.

The 16.5 MeV Medical Cyclotron Facility (MCF) at RMC produces ^{18}F-labeled radiopharmaceuticals (RPhs) in a new Mini Lead Hot Cell installed recently. PET radiopharmaceuticals such as ^{18}F[FDG], ^{18}F[NaF] , ^{18}F[FET] and ^{18}F[FLT] with a total of 8980 GBq were produced and supplied to 14 Nuclear Medicine Centers. RMC also produced 9300GBq ^{99m}Tc based SPECT RPhs. ($Na^{99m}TcO_4$, MIBI, DTPA, MDP, DMSA-III, MEBROFENIN, PHYTATE, EC), 152.9169 GBq of ^{68}Ga based PET RPhs (^{68}Ga-DOTATATE and ^{68}Ga-PSMA-11) and 5502.186 GBq of ^{177}Lu based therapeutic RPhs (^{177}Lu-DOTATATE and ^{177}Lu-DOTA-PSMA-617).

RMC treated 3206 patients for thyroid cancer, thyrotoxicosis, neural crest tumors, neuroendocrine tumors, -prostate cancer and bone pain palliation using various RPhs ^{131}I, ^{131}I-mIBG ,^{177}Lu-DOTATATE, ^{177}Lu-PSMA, and ^{153}Sm-EDTMP. Patients admitted were administered high dose radioiodine, ^{177}Lu-DOTATATE and ^{177}Lu-PSMA-11.



^{68}Ga-PSMAdiagnostic PET-CT in a patient of metastatic Prostate Carcinoma



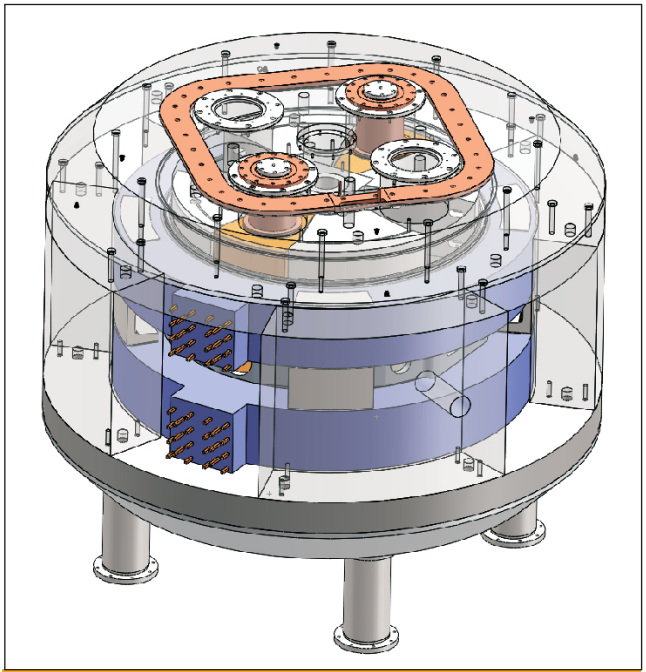
^{177}Lu-PSMA therapy in a patient of metastatic prostatecarcinoma

BARC remained involved in production of various radioisotopes and radioactive sources and supply to various hospitals in the country either directly or through BRIT. BARC also carried out R&D on new radioisotopes and radiopharmaceuticals for various applications. A total of 661 units of irradiations were carried out in Dhruva reactor producing MoO_3, TeO_2, Ir, Sm_2O_3, $LuCl_3$, etc. 50,000 Ci of ^{192}Ir activity for

industrial radiography and 3,185 Ci of ^{99}Mo, ^{131}I, ^{177}Lu, ^{153}Sm and ^{125}I for healthcare applications were produced during the year. Around 438 Ci of $^{177}LuCl_3$ was directly supplied to 15 nuclear medicine centers pan-India. More than 1000 cancer patients were treated with therapeutic radiopharmaceuticals such as ^{177}Lu-DOTA-TATE and ^{177}Lu-PSMA-617 formulated using $^{177}LuCl_3$. About 16 units of irradiation in the newly-commissioned APSARA-U were carried out for production of radioisotopes with applications in healthcare, industry and research. Regulatory clearance was obtained from Radiopharmaceutical Committee of DAE for manufacture and supply of 'ready-to-inject' radiopharmaceuticals - ^{177}Lu-labeled hydroxyapatite (HA; ^{90}Y-labeled HA (both for radiation synovectomy); ^{177}Lu-labeled Prostate Specific Membrane Antigen (PSMA) inhibitor (for treatment of prostate cancer) and freeze-dried DOTMP kits for the formulation of ^{177}Lu-DOTMP (bone pain palliation). Clinical studies were conducted with several freeze-dried kits - ^{177}Lu-DOTA-TATE for treating neuroendocrine cancer patients; ^{177}Lu-DOTMP for treating patients suffering from bone pain due to metastatic skeletal carcinoma; ^{99m}Tc-HYNIC-TATE for neuroendocrine cancer diagnosis and ^{99m}Tc-UBI for imaging of infection.

Patient doses of ^{131}I-labeled Lipiodol Injection were formulated using ^{131}I[NaI] activity processed in-house and supplied to Kovai Medical Centre and Hospital (KMCH), Coimbatore for the treatment of patients suffering from inoperable metastatic hepatocellular carcinoma. Multiple batches of Human Serum Albumin (HSA) nanocolloid were prepared and supplied to BRIT for the formulation of freeze-dried HSA nanocolloid kits, useful for prognosis and management of cancers of breast, head & neck and skin among others. Several freeze-dried DEDC/Lipiodol kits were supplied to AIIMS, New Delhi for the formulation of patient dose of ^{188}Re-Lipiodol for radionuclide therapy of liver cancer.

For societal application VECC has set up a 30 MeV H^- cyclotron-facility for the production of radioisotopes for medical applications, i.e., application in Positron Emission Tomography (PET), specifically ^{18}F, which is used in Fluorodeoxyglucose (^{18}FDG), as well as in Single Photon Emission Computed Tomography (SPECT). However, production of other isotopes like ^{68}Ga, ^{124} I, ^{64}Cu, ^{99m}Tc etc. using cyclotron is limited in India, though these isotopes are very useful in nuclear medicine. Several batches of FDG produced through automated system and their test report have already been sent to Radiopharmaceutical Committee of India (RPC) for obtaining clearance of human applications. VECC has conceived a project to design and develop an 18 MeV H^- cyclotron and associated technologies for the production of a variety of medically useful radioisotopes, like ^{18}F, ^{68}Ga, ^{124}I, ^{64}Cu, ^{99m}Tc, etc. The goal is to transfer this technology to the Indian industries, which in turn will reduce the cost of nuclear imaging. This will also enhance the availability and export of a range of radio-isotopes, patient care and medical research. The basic physics design and engineering modelling of the cyclotron magnet has been carried out.



3D Model of the 18 MeV H^- Cyclotron

To extend DAE's contribution towards societal benefits, HWB is shouldering responsibility for production and supply of ^{18}O enriched water ($H_2{}^{18}O$) of 95.5% O-18 enrichment required for PET scanning and 10% O-18 enrichment is useful in metabolic studies. Nuclear grade Heavy water is used as raw material in the first indigenously developed O-18 production plant at HWP, Manuguru. The unit is under steady operation and has reached the enrichment of O-18 up to 85% during the report period.

Radiation technology equipment

Indigenous rechargeable phantoms

Rechargeable phantoms for use in quality assurance of gamma cameras and SPECT systems installed at nuclear medicine centers in Mumbai were fabricated in-house at BARC. Two consignments of ^{141}Ce and three consignments of ^{51}Cr were supplied to RMC (Mumbai) for uniformity assessment of gamma cameras and SPECT systems in clinical settings.

Blood Irradiator

Four Blood Irradiators-2000 units with Cs-137 source (9116 Ci) have been supplied to hospitals in India.

Radiography Camera

Production and supply of 47 new indigenous radiography camera, model ROLI-2, and servicing and inspection of 388 numbers of BRIT manufactured as well as imported ROLI cameras, were the highlights during the reported period.

Gamma Chamber 5000

Three units of GC-5000 were loaded with Co-60 source and transported to different institutions in India. Out of these, one Gamma Chamber – 5000 unit was exported to NEAD-Technology Application and Development Company Ltd. VIETNAM.

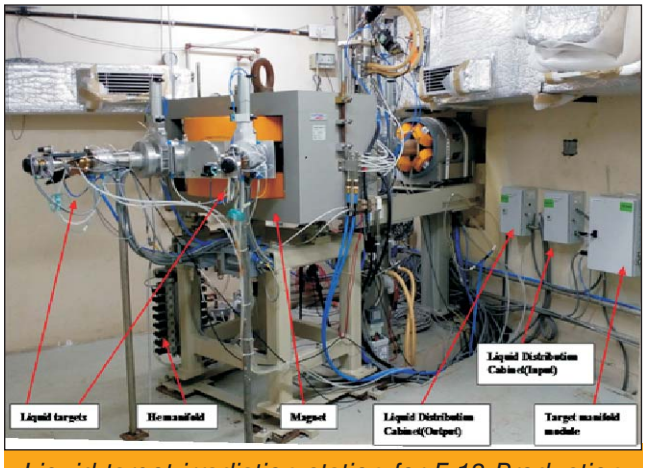
Radio Diagnostic & Treatment Services

A total number of about 1700 Radioimmunoassay (RIA) and Immunoradiometric assay (IRMA) kits to serve about 1,12,250 in-vitro investigations, were supplied to various hospitals, research centres and immunoassay laboratories throughout India.

Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) Kits manufacture, supply and R&D accredited for compliance to ISO 9001:2015 and ISO 13485:2016 by UKAS (United Kingdom Accreditation Services) during the reported period.

Regional centres at Delhi, Dibrugarh & Kolkata, Hyderabad (also known as Jonaki), Bengaluru, and Kota continued their respective services towards the supply of ready-to-use-radiopharmaceuticals to surrounding nuclear medicine hospitals, rendering RIA & IRMA diagnostic services for the benefit of patients in the entire North-Eastern region, PET Radioisotopes production in Cyclotron (VECC), preparation & supply of labelled compounds, radioanalytical certifications and processing of Co-60 sources for their various uses in Engineering Programme of BRIT. Around 3,000 consignments of in-vivo and in-vitro kits were supplied to RCR's for providing extended services to nearby hospitals, research centres, or institutions at and surrounding these cities.

Regional centre BRIT, Dibrugarh located at Assam Medical College & Hospital is rendering RIA and IRMA diagnostic services for the benefit of patients of the entire North-Eastern region. The Radiopharmaceutical products produced and supplied by BRIT, Vashi complex are extensively used by the RC, Dibrugarh for the diagnosis & investigation of various diseases. More than 7000 patients of the region availed the services from this centre. During the year 2019-20, approximately 209 nos. of Technetium cold kits for formulation of ^{99m}Tc-radiopharmaceuticals were supplied to various Nuclear Medicine Hospitals in Kolkata. Production of Fluorine-18 isotope was successfully achieved by irradiating $H_2{}^{18}O$ target using 18MeV, 25-30mA average proton beam current for 1-1,7h in DAE Medical Cyclotron, CYCLONE-30, Kolkata, during the reported period 2019-20. Installation and Commissioning of liquid target assembly for ^{18}F-FDG production, dispensing of the radiopharmaceutical in hot cells and the validation of clean rooms for the Production and Quality Control of radiopharmaceutical have been completed.



Liquid target irradiation station for F-18 Production and its associated systems/modules

FDG Synthesis module

Regional Centre, BRIT, Bengaluru supplied 88 Ci of ready-to-use ^{99m}Tc-pertechnatate to nuclear medicine hospitals and 577 TCK cold kits were sold through retail outlet and door delivery for the preparation of ^{99m}Tc-radiopharmaceuticals to nearby nuclear medicine centres. Gamma irradiation unit, BI-2000 with Cs-137 source is received at RCR, Bengaluru and is ready of its installation and commissioning. Radioanalytical Laboratory analyzed and certified 179 samples for the measurement of residual radioactivity in various commodities such as food items for human & animal consumption, medicine and miscellaneous items.

Regional Centre for Radiopharmaceuticals, Delhi continued the supply of clinical grade, ready to use diagnostic ^{99m}Tc-radiopharmaceuticals injections in compliance with GMP and RPC, ready-to-use radioactive therapeutic injections of ^{131}I-mIBG, ^{177}Lu, ^{153}Sm, COLTECH/GELTECH Generators and TCM-2 (^{99}Mo Generator kit for Solvent Extraction), for nuclear medicine centres in Delhi and NCR regions. During the period, 2019-20, Regional Centre, Delhi has been involved in production & supply of 18.7 Ci of clinical grade, ready-to-use Tc-99m radiopharmaceuticals injections. The radioactive waste disposal authorization was renewed from AERB where the disposal limits have been recalculated as per WHO Standards for drinking water, keeping the acceptable public dose limit criteria. RCR, Delhi has received automatic peptide labelling module for Ga-68 labelling and radio-TLC scanner for QC testing. The procurement of hot cell, and automatic dose dispenser for setting up of ^{68}Ge/^{68}Ga generator facility at Regional Centre, Delhi is in progress.

During the period, Regional Centre of BRIT, Hyderabad (Jonaki) supplied ready-to-use Tc-99m as Sodium Pertechnatate to local Nuclear Medicine Centres. It has supplied 1050 nos. of TCK Cold kits (produced at BRIT, Vashi Complex). It has also initiated the setting up of Radiopharmaceuticals laboratory for the preparation and supply of ready-to-use Tc-99m and Ga-68 formulations to these local Nuclear Medicine Centres. Currently, RC, BRIT, Hyderabad is in the process of setting up of clean room facility for Tc-Cold Kits Production. Also, during the Year 2019-20, RC, BRIT, Hyderabad continued the synthesis and supply ^{32}P labelled nucleotides (330 consignments – 210.5 mCi) and around 70 kits of molecular biology reagents such as Taq DNA Polymerase (63000 Units), PCR master mix and enzymes (12,500 Reactions), for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research of the country.

Labelled Compounds and Diagnostic Kits

Labelled Compounds Programme of BRIT is involved in the synthesis & supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products and various types of Tritium-Filled Self-Luminous sources. During 2019-20, Labelled Compounds Programme has supplied 13000 Tritium Filled Self-luminous (TFS) sources of various sizes and shapes to defence establishments and used for illumination of various types of gadgets and instruments.

A proposal is submitted for setting up of tritium gas facility at CIRUS reactor building, BARC, Trombay, and the associated work has been initiated. Once this facility is ready for operation, the tritium gas handling operation related to Tritium filled light sources and tritium labelled compounds production activity will be shifted to CIRUS building.

Custom synthesis of variety of labelled compounds along with ^{35}S-labelled amino acids, having very high specific radioactivity and radiochemical purity, are also supplied. Labelled Compounds Laboratory also continued the production and supply of ^{14}C-Urea Capsules which is used for diagnosis of Helicobacter Pylori infection which causes stomach ulcers.

Deuterium substituted polymers have shown outstanding signal transmission characteristics with reduced loss of intensity and better transmission efficiency. HWB is also engaged in producing and supplying Deuterium gas through D_2 Gas Generation and Bottling Plant at HWP, Baroda to various manufacturers of deuterium based gas mixtures, which are used in producing stabilized low water peak optical fibers, calibration of analytical instruments and other R&D works. This year HWP, Baroda has supplied Deuterium gas amounting to 30.59 Nm3 to M/s Air Liquide India and 1.96 Nm3 to M/s Clearsynth Labs.

Radio Analysis

Radioanalytical Laboratory (RAL) carried out the assay for the following measurement and certification services of Man-made (artificial) radioactivity levels in large number of food items for human & animal consumption; Naturally occurring radioactive materials (NORMs) in environmental samples such as coal, fly ash, soil rock phosphate, gypsum etc.; Co-60 contamination in steel samples helped; Survey & certification for surface radiation dose of steel consignments at factory premises and warehouses; Gross alpha, gross beta and other specific radioisotopes such as ^{226}Ra & ^{228}Ra in water samples and Total Uranium in water samples by assay using Fluorimeter.

During the year 2019-20, Radioanalytical Services at Vashi Complex carried out more than 4850 tests on export/domestic commodities and 800 tests on water samples (gross alpha, gross beta ^{226}Ra & ^{228}Ra). Radioanalytical Testing Services were provided for food samples (Apples) received from Bhutan Agriculture and Food Regulatory and water samples from M/s. Varun Beverages, Sri Lanka. The laboratory is accreditated by NABL for certifying many of the parameters and empanelled by BIS for the testing of gross alpha and gross beta in water samples.

Radiation Sterilization Plant for Medical Products (ISOMED)

Gamma Radiation Processing Plant facility at ISOMED for terminal sterilization of the medical products is being revamped and is under renovation during the reported period 2019-20.

New Projects

Setting up of Fission based ^{99}Mo Production Facility

Supply of all the plant machinery equipment has been completed. All individual sub-systems are being tested. Cold commissioning process of the plant is in progress.

External and internal view of Fission Molybdenum Project (FM) building

Advanced Facilities for Radiopharmaceuticals Production

Civil construction of first floor over RPL extension building is completed in all respects is completed and occupied by staff. 740 GBq (20Ci) capacity GMP compliant, I-131 mIBG production facility (procured from Dresdon, Germany), has been installed and cold commissioning is completed. New lyophilizer (LYOMAX), is procured and installed.

Technology Development for Radiation Technology Equipment

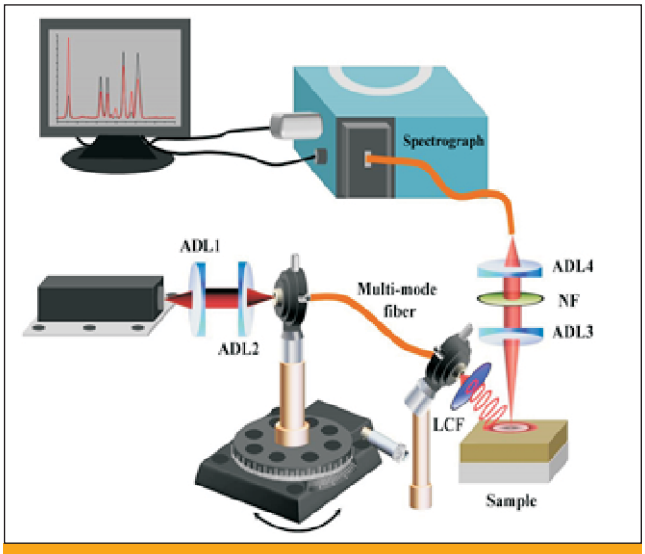
Civil construction for setting up of manufacturing facility for I-125 seeds as brachytherapy sources, which would be useful for the treatment and management of Prostate Cancer, is completed. Tender for the procurement of plant on 'turnkey' basis has been raised. Transportation cask, BLC-200, for Co-60 has been developed and the design is approved by AERB.

Recovery of Rare Elements and Rare / Strategic Gases

HWB has now ventured in to new technology demonstration initiatives viz. recovery/ production of Cobalt, Gallium, Helium gas and Hydrogen. Facilities for the same are set up at the Technology Demonstration Plant, Mumbai.

Biomedical Applications

At RRCAT, an axicon-lens free scheme for implementing inverse Spatially Offset Raman Spectroscopy (SORS) is developed. It uses ring illumination and point collection through two multi-mode optical fibers. The system developed based on the proposed scheme to measure Raman spectra of the subsurface layers was demonstrated in chicken tissue till a depth of ~3-4 mm.

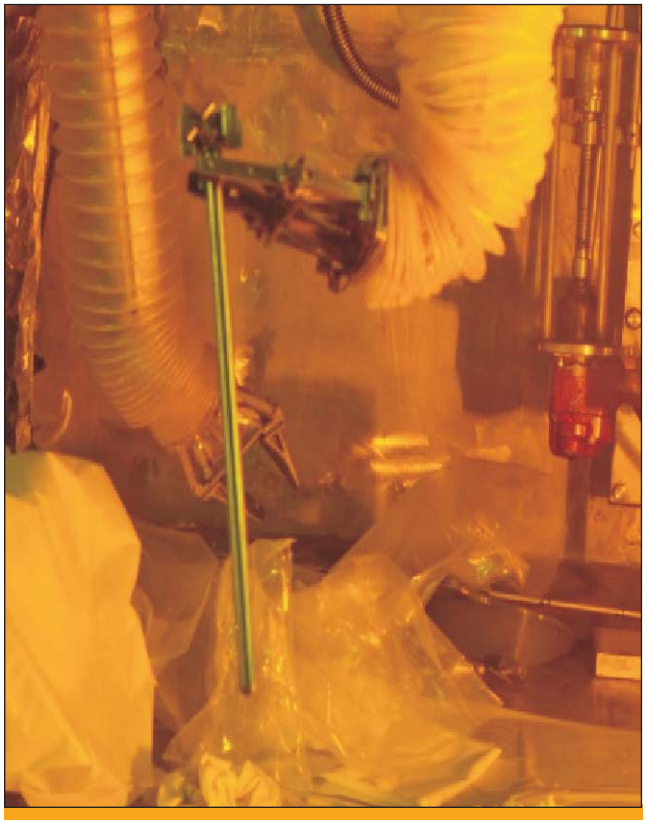


Experimental setup of inverse SORS based on the proposed approach

Evaluation of Quality Control parameters for ^{89}Sr source produced in FBTR

The radioisotope ^{89}Sr, a biological analogous of Ca, is a â$^{-}$ emitter with half-life of 50.57 days. Carrier free ^{89}Sr can be produced in a fast reactor via ^{89}Y(n,p)^{89}Sr with a required threshold energy of 720 keV. Sintered yttria pellets were prepared and were irradiated in FBTR in stainless steel irradiation capsule. The irradiated pellets were extracted from the irradiation capsule through laser cutting using the hot cell facilities in Radio metallurgical Laboratory and Radiochemistry Laboratory at Indira Gandhi Centre for Atomic Research. The irradiated yttria pellets of 25 g batch were dissolved in 9M nitric acid under high pressure and temperature in a Ti container. The dissolver solution contained various radio-isotopic impurities such as the activated products of the target impurities, the clad material and the sintering aid ZnO along with the by-products ^{88}Y and ^{86}Rb. Purification of ^{89}Sr from the yttrium matrix of the dissolver solution was carried out by selectively removing Sr by solvent extraction using the Sr specific crown ether 4,4'(5') tert-butyl cyclo-hexano-18-Crown-6 (DtBuCH18C6). The final Sr fraction was purified from undesirable anions and dissolved organic materials, made up to a known volume in the desired medium and quantified using various radiometric techniques. Various quality control (QC) measures such as appearance, pH, residual anion ion content, spectral identification, radioactive and non-radioactive impurities were carried out using various techniques. Biological quality control studies such as sterility and bacterial endotoxin were also carried out with the actual ^{89}Sr source and found to satisfy the required quality control criteria and in agreement with the Inter-laboratory comparison through Radiopharmaceuticals Division, BARC.

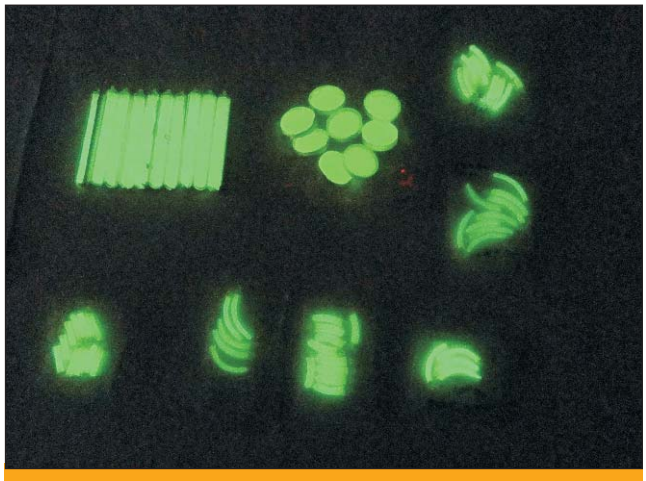
The process of obtaining purified ^{89}Sr through six identical radiochemical reprocessing of irradiated yttria for the clearance by Radiopharmaceutical Committee (RPC) is also in progress. The number of doses at the end of the different irradiations varied between 5-275; where a single dose corresponds to 4mCi of ^{89}Sr in 4 mL solution.



Processing of bone palliative Sr-89 in hot cells from irradiated yttria at FBTR, IGCAR

Alternative Applications of Heavy Water

Based on the MoU signed between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers. All the solvents that were supplied had more than 98% Deuterium abundance.



Tritium Filled Luminescent Sources

Deuterium and heavy water find significant applications in life sciences, pharmaceuticals and technology. India has potential to become a global leader in production and supply of D-labeled NMR solvents, APIs and drug entities which are presently being imported. HWB has successfully navigated through multiple synthesis routes over the last two decades for production of d-labeled compounds. Collaborative agreements have been signed with Indian pharmaceutical companies for regular supply of heavy water from HWB and producing deuterated NMR solvents. For synthesizing deuterated NMR solvents, processes have been developed at HWP, Baroda in laboratory scale. As part of MoU signed between BRIT& HWB, BRIT is marketing Chloroform-d, DMSO-d6, Acetone-d6, Acetonitrile-d3, Benzene-d6 and small quantities of Heavy Water to various reputed research institutes in the country.

Heavy water is being regularly supplied to pharmaceutical companies in India like M/s Clearsynth and M/s SyNMR for production of D-labeled compounds, enabling them to expand their production capacities. DMSO D6, Chloroform D and Methanol D4 synthesized by M/s. SyNMR have been approved for supply to Israel and France. In FY 2019-20, HWB has executed several orders and supplied about 216 kg of heavy Water to institutions like BARC, M/s Advent, M/s Florentis, M/s Anabond.

D-labeled compounds produced by M/s. SyNMR Chemicals Pvt. Ltd. in collaboration with HWB

Cancer Diagnostics and Treatment Services

The Tata Memorial Centre (TMC), an autonomous institution under the administrative control of the Department of Atomic Energy, Government of India. TMC comprises of Tata Memorial Hospital (TMH), the Advance Centre for Training, Research and Education (ACTREC) and the Centre for Cancer Epidemiology (CCE) in addition to new and upcoming cancer centres at Sangrur, Visakhapatnam, Mohali, Varanasi and Guwahati.

The Tata Memorial Centre (TMC) with benevolence from the Department of Atomic Energy (DAE) continued to implement successfully the Hub-and-Spoke cancer care models across India.

The current and future expansion of TMC would increase the number of new cancer patients being treated from 70,000 to 1.5 lakh per year. The bed capacity would be augmented from the current 700 to 3300 beds.

The year 2019 saw the inauguration of the 9th Cancer centre, the second in Varanasi, the Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC) of 350 beds by the Honourable Prime Minister of India Mr. Narendra Modi on 19th February 2019. A book, “Where Light Enters the Earth” curated

by Ms. Nishu Singh Goel was released to mark the occasion. The Prime Minister of India Mr. Narendra Modi also acknowledged the fully operational first cancer centre in Varanasi, the Homi Bhabha Cancer Hospital (HBCH) of 179 beds. In April 2019, foundation stone for the Annex Building at Homi Bhabha Cancer Hospital, Varanasi was laid by Secretary DAE, Dr. KN Vyas in presence of Director TMC, Dr. RA Badwe. The patient load at HBCH, Varanasi has been increasing and more facilities were being introduced for cancer patients. The Raja Ramanna Centre for Advanced Technology (RRCAT), Indore donated to HBCH, Varanasi, a "Low-cost compact laser based diagnostic instrument, the OncoDiagnoScope for screening large population for oral cancer in early 2019.

MPMMCC was opened to cancer patients, initially, as a Day Care facility & to evaluate follow-up patients of HBCH, Varanasi from May 2019. The diagnostic services were initiated from July 2019 and surgical & radiation treatment began from December 2019. The full-fledged services are expected to be offered soon.

The 10th satellite cancer centre is proposed to be in Muzaffarpur, Bihar. This cancer centre would be set up on the 15-acre land given by the Bihar government in the campus of Sri Krishna Medical College in Muzaffarpur. DAE has allocated a fund of ₹ 20 crore for this project. The engineers were issued the work order on 26.03.2019 and the boundary work would be executed through Central Public Works Department (CPWD), Patna.

At the Dr. Bhubaneswar Booroah Cancer Institute (BBCI) in Guwahati, a state-of-the-art Linear Accelerator was inaugurated by Shri K N Vyas, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy, Govt. of India on 08.02.2019. The Chairman also inaugurated the St. Jude India Childcare Centre with facility for accommodation of 24 childhood cancer patients on 10.02.2019. Here, the treatment was provided free of cost to all childhood cancer patients through the Aparajaya Scheme of Assam Gas Company Limited. The Director TMC, Dr. RA Badwe graced both the occasions.

The Buildings of the Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) in Mullanpur were almost complete and the centre is expected to be commissioned by May 2020.

Plastic Surgery services began at HBCHRC, Visakhapatnam from 25th May 2019 and the Radiation Treatment (RT) block was commissioned in July 2019. The first Linear Accelerator was used for cancer treatment from December 2019.

The HBCH, Sangrur was growing rapidly with plans to procure newer diagnostic equipment and to introduce more surgical facilities. Fellowship courses in post-doctoral subjects and BSc courses for paramedical staff were started from June 2019.

There was seamless patient referrals that ensured that patients did not have to re-register on being referred / or opt for treatment at any TMC satellite cancer centre.

All TMC centres were filmless and almost paperless. The use of smart cards across all centres ensured cashless transactions. Patients could avail of online registration facility and of viewing their medical records in the hospital through internet. Smart card transactions from all the satellite centres amounted to about ₹60 crore. In Maharashtra it crossed ₹350 crore.

The costs of diagnostic investigations, treatment and cancer related drugs & consumables for patients in TMC and all its satellite centres were substantially cheaper than the private sector and significantly lower than the Maximum Retail Price (MRP). For the poor and needy patients, further subsidy was provided under the various Central and the local State Government healthcare schemes. The poor patients availed of, of the local and national concessional schemes. The Ayushman Bharat scheme was availed of by over 7% of the new patients in Varanasi and, 35% availed of the local concession schemes provided by the State government in Punjab. About 7% of the new patients made use of the various concessional schemes in Maharashtra.

The unique and uniform aspect of the cancer services offered across TMC and its satellite centres were based on Disease Management Groups (DMGs) that bridged all medical disciplines, including those of prevention, diagnosis & treatment to focus on the specific anatomic region of cancer origin. There were eleven (11) such DMGs that covered the entire human body, viz: Adult Hematolymphoid, Bone & Soft Tissues, Breast Oncology, Gastrointestinal, Gynecological, Head & Neck, Neuro-oncology, Pediatric

Hematolymphoid, Pediatric Solid tumor, Thoracic Oncology and, Uro-oncology. These DMGs will pave way towards offering the eventual goal of individualized cancer management. Every patient's cancer was discussed by the specific DMG members from various specialties in medicine. This unique approach is in place in Tata Memorial Hospital (TMH) & at the Advanced Centre for Treatment, Research & Education in Cancer (ACTREC) in Mumbai and Navi Mumbai respectively for the past 12 years. This DMG concept is being implemented at the recently started TMC satellite centres after adequate medical staff recruitment.

Educational facilities in the satellite centres are also being implemented. Bachelors and Masters (Bsc & MSc) courses in paramedical subjects were started in Punjab. Conferences and Continuing Medical Education (CME) programmes were held in Sangrur, Visakhapatnam and at HBCH, Varanasi. There were staff publications from Sangrur and Visakhapatnam. BBCI offered Masters Degrees (MD & MCh) in Radiotherapy & Surgical Oncology respectively. They also offered many Fellowship courses in various branches of medicine along with certificate & diploma courses in paramedical branches. Many conferences & workshops were conducted during the year along with publication of over 40 articles in medical journals.

The commissioning of the above centres resulted in marginal reduction of patient registration at TMH, Mumbai to around 72,000 from about 74,000 of last year; however, the new patient registrations at the satellite centres increased to over 30,000 in year 2019. The General to Private patient ratio was 55:45. Almost 25% of the General patients were provided with financial assistance through the various local, State and National schemes and 15% General patients were provided with the accommodations.

The year 2019 saw over 20 community outreach programs by the Department of Preventive Oncology that evaluated almost 900 individuals who would otherwise have to visit the hospital.

The work on the plot of land in Haffkine's Institute (to be called the Platinum Block) is ongoing and, the structural work till the 14th floor of the 15 storeyed Dharamshala was completed. Simultaneously, the interior works of the Dharamshala were ongoing from the ground floor upwards. The Dharamshala is scheduled for commissioning soon. Architects and project management consultants have been appointed for the construction of the hospital building in the same land.

The Department of Radiation Oncology was augmented with a new Linear Accelerator in the Golden Jubilee Building that was inaugurated by Mr.G. Nageshwara Rao, Chairman Atomic Energy Regulatory Board (AERB) on 7th June 2019. The Department of Radiodiagnosis replaced its analog radiography system with the latest Digital Radiography machine in the Main Building that was commissioned by Dr. RA Badwe in November 2019. To reduce long waiting periods for radiodiagnostic investigations, the Department of Radiodiagnosis extended its services to 12 hours, 8am – 8pm for 6 days in a week. Now, new patients have waiting of only 3-5 days for their CT or MR examinations.

The National Cancer Grid (NCG) grew to a large network of nearly 200 cancer centres, research institutes, patient advocacy groups, charitable organizations and professional societies. Between the member organizations of the NCG, the network treated over 7,00,000 new patients with cancer annually that is over 60% of India's entire cancer burden. It is expected that with this standardization of cancer care across these centres, the survival of cancer patients would improve by 5 -7 %. The process of Group negotiations is being continued to achieve reduced cost of cancer equipments, drugs and consumables. The NCG organized travelling schools in varied subsets of oncology to reach out to geographically inaccessible areas in the country like the Northeast.

On 17th September 2019 in Vienna on the sidelines of 63rd General conference of International Atomic Energy Agency (IAEA), Shri K. N. Vyas, Secretary DAE & Chairman AEC launched the "NCG-Vishwam Cancer Care Connect" (NCG-Vishwam 3C). The NCG was thus made open to the cancer hospitals and other relevant institutes from foreign countries. Dr. RA Badwe, Director, TMC gave the details of NCG and how it could be extended to the foreign hospitals and the benefits which they shall accrue. This global cancer network would share best practices of the NCG and will work towards eliminating disparities in cancer care

worldwide by creating uniform standards of patient care, developing human resource for cancer prevention and management globally and collaborate multicentric cancer research. Countries like Sri Lanka, Bangladesh, Russia, Kazakhstan, Vietnam, Nepal, United Arab Emirates, Afghanistan, Jamaica, Myanmar and Zambia agreed to have their premier hospitals to be part of NCG-Vishwam.

The demand for the popular TMC-Navya second opinion cancer services grew, and, their services were availed of from 68 countries and they guided over 38,000 cancer patients.

Research at TMC continued and, Clinical and Basic research positively impacted the care of cancer patients in India. Basic and animal research was carried out in ACTREC. The three Institutional Ethics Committees (IEC) recognized nationally and internationally, ensured the highest scientific and ethical standards of research at TMC. Two IEC were in TMH and one in ACTREC. TMH Institutional Ethics Committee extended all the support, training and guidance for constituting the fourth IEC at Varanasi satellite centre of TMC. The IEC was functional from Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMC), Varanasi in 2019. The Standard Operating Procedures (SOPs) for this IEC were based on the TMH Institutional Ethics Committee SOPs. The newly constituted IEC members and researchers were trained by the IEC Team of TMH.

In the period of Jan to Dec 2019, ethics committees have received 273 projects for review. The committees approved 245 projects over 36 meetings conducted in 2019. Out of these 245 projects, majorities were Investigator initiated - 71% and 22% were Thesis for post-graduation students for Homi Bhabha National University (HBNI).

TMC also provided the financial support to the research studies through the grants available from DAE. Sixty five percent of the projects were funded through IM grants and 35% projects received grants from other sources (Extra Mural). Seven theses were submitted to HBNI from research projects completed in 2019.

The Centre for Cancer Epidemiology (CCE) in Navi Mumbai established the countries first fully automated Biobank on 22nd March 2019.

The Advanced Centre for Treatment, Research & Education in Cancer (ACTREC), Navi Mumbai has been expanding rapidly. The Animal Laboratory has been commissioned in January 2019 to enhance surgical skills. The Robotic Neuronavigation Testing Laboratory has been established in collaboration with Bhabha Atomic Research Centre (BARC). The Prototype Robot is in place and, validation using phantoms is ongoing. The state-of-the-art Hadron Therapy facility will provide the extremely expensive and precision based radiation therapy at affordable cost to the patients. The Cyclotron for the Proton Beam Therapy reached the site and testing and commissioning should begin by end 2020. The structure, till 5th floor of the Radiation Research Unit (RRU), a joint collaboration between TMC, RMC and Radiological Physics and Advisory Division (RPAD) BARC and supported by Power Grid Corporation has been completed. The RRU is expected to be commissioned by the end of 2020. The outer structure of the Hematolymphoid, Women & Children Cancer Centre (HWCC) is almost complete. This would have facility for 70 day care beds, 14 Operation theatres, wards with 165 beds, 18 ICU beds, 26 recovery beds and 6 casualty beds. The Infosys funded ASHA NIWAS, a patient dormitory to accommodate 265 patients and their family for long term stay should be functional by the end of 2020. Major upgrades were added to the infrastructure at ACTREC that included dedicated patient hold area, patient counseling room and improved patient facilities. The Intensive Care Unit bed strength has been increased from 7 to 13. All laboratories have got NABL accreditation till April 2021. The “World Patient Safety Day” on 17th September (as per WHO declaration) was celebrated with a weeklong function for patient & staffs’ awareness. The HLA laboratory with the Department of Transfusion Medicine has been relocated as an independent unit at ACTREC for the benefit of bone marrow transplant patients. The first dialysis unit has been installed in December 2019. The IEC-III at ACTREC has been reaccredited by NABH (March 2019) and SIDCER (November 2019).

^{60}Co Teletherapy Sources for Cancer Hospitals

^{60}Co-teletherapy sources with total activity of about 224 kCi in the range of 151 and 206 RMM were supplied to various cancer hospitals in India during the

reported year 2019-20. Co-60 Teletherapy source of 206 RMM was exported to Joseph Ravoahangy Andiavavalona Hospital, Madagascar, South Africa through Panacea Medical Technologies Pvt. Ltd. Bengaluru. These sources were fabricated at RAPPCOF, Kota using Co-60 produced indigenously in nuclear power reactors. RAPPCOF transported 08 Adjuster rods from KAPS, Gujarat and 04 Regulating rods from NAPS, UP, as special arrangement after getting AERB approval for radiological coverage in 06 consignments.

WATER

Water Purification, Desalination of water & Isotope Hydrology

Advanced Effluent Water Treatment Demonstration Plant

At BARC, a 600 litre/hour Advanced Effluent Water Treatment Plant (AEWTP) was piloted to demonstrate the feasibility of a process for treatment of industrial effluent water to cater to irrigation. Experiments showed the process of Ozonation and advanced dispersion helped process around 5 kL of effluents present in the water contaminated with oil and salt. Further, Total Organic Concentration (TOC) of the effluent could be reduced from 100 to 35 parts per million in 3 hours with ozone dosage of around 45 g/h. Work is in progress on integrating reverse osmosis system and others in the pilot plant.

Advanced Effluent Water Treatment Plant (AEWTP) pilot plant

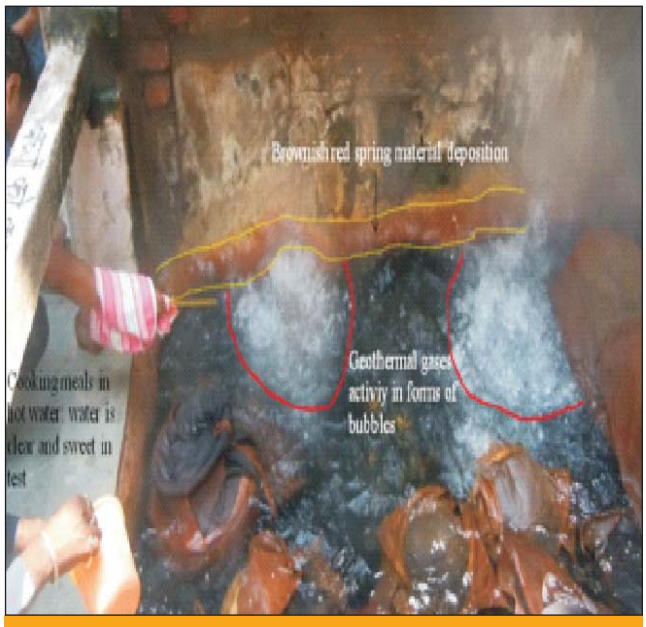
RO based drinking water facility inaugurated at Somthana Village in Maharashtra's Nanded district on 27th November, 2019

Reverse Osmosis drinking water facility commissioned in Nanded

A 1000 litres/hour Reverse Osmosis (RO) based drinking water facility was commissioned at Somthana Village in Maharashtra's Nanded district in November, 2019. The facility would effectively treat beyond permissible levels of nitrate (140-150 ppm) and high salinity (1200-1400 ppm) in ground water to supply clean and safe drinking water of Indian Standard 10500 quality to the village of 2500 households. The reject water from the facility is redirected for cattle use, non-potable applications and ground water recharge. The facility was implemented as part of DAE sanctioned project 'Deployment of Water Purification Technologies in 50 Villages in India'.

Isotope hydrological investigations were carried out to identify water recharge sources and deep aquifers in the semi arid Patan district of Gujarat. Stable and radioactive isotopes along with water quality parameters were used for characterisation of the region's groundwater system to implement sustainable measures for improving the water table in the region.

Groundwater sampling in progress at Patan district in Gujarat



Geothermal spring at Manikaran in Himachal Pradesh (Temp = 94^0)

Isotope hydrology of geothermal areas of Odisha and Himachal Pradesh were carried out. Investigations were carried out to identify the origin of thermal water to estimate sub-surface reservoir temperature and analyse gases associated with the hot springs. Results indicated that most of the hot springs are of meteoric origin. The mixing of thermal water and shallow ground water was substantiated using tritium and chemical data. ^{14}C dating showed that the age of Odisha's geothermal water thermal water varies from 9952 years to 18663 years. The subsurface geothermal reservoir temperatures in Odisha and Himachal Pradesh were estimated to be 130 ± 10^oC.

INDUSTRIAL APPLICATIONS

Digital Imaging and Volume Computed Tomography facility for advanced non-destructive evaluation

An upgraded X-ray based digital imaging and volume tomography facility was used for advanced industrial Non-Destructive Examination (NDE) of critical specimen. The X-ray imaging facility is equipped with filmless industrial radiography and computerised image processing and analysis.

X-ray based Industrial Digital Imaging and Volume Computed Tomography facility

Prototype Gamma Ray Transportable industrial tomography scanner

A prototype tomography scanner based on gamma ray beam generator and discrete nucleonic scintillation detectors and associated data acquisition system was developed for low-resolution cross-sectional imaging of columnar structures for Non-Destructive Evaluation (NDE). Laboratory experimental data was found satisfactory confirming to the prescribed design criteria for NDE under certain special conditions. The department is in the process of applying for an Indian patent.

Segmented tomographic gamma scanning system for quantification of special nuclear materials

An Integrated Segmented and Tomographic Gamma Scanning (ISTGS) system was commissioned for assay of plutonium in 200 L waste drums. The system can operate in either of the three modes, viz., Segmented Gamma Scanning (SGS) mode for measuring nearly homogeneous waste; Tomographic Gamma Scanning (TGS) mode; or heterogeneous waste with non-standard geometry.

Gamma Radiometry Investigation of Lead Shielded Casks

Gamma radiometric evaluation methods using 180 mCi source of ^{60}Co were employed to test the shielding integrity of five units of Lead-shielded casks and of Mini Hot Cell Facility, Radiation Medicine Centre.

Large scale production of super absorbent cotton developed using Electron Beam

A process for large scale production of super-absorbent cotton using gamma and electron beam radiation was developed. The super cotton was found to selectively absorb organic compounds from different kinds of organic-water mixtures such as water-crude oil, water-kerosene, water-benzene, water-xylene, water-toluene, etc. A patent was filed on the process and the technology was transferred to M/s Welknit Fab LLP, Surat, Gujarat for large-scale production of the super-absorbent cotton.

Training and Certification in Industrial Radiography and Radiation Safety

Radiography Testing Level-2 training programme was conducted during 2019-2020 in collaboration with IDEMI (Institute for Design of Electrical Measuring Instruments), Mumbai – a Government of India Society under Ministry of Micro, Small and Medium Enterprises (MSME) to impart training in non-power applications of radioisotopes and radiation for non-destructive evaluation and radiation safety. The course extensively covers radiation safety as specified in AERB/RF/Training-Syllabi/2012 approved by AERB.

Radioisotope Sources supplied by BRIT

Industrial Irradiator Sources

Total 53 nos. of W-91 irradiator sources & 83 nos. of BC-188 Irradiator sources with total activity of around 2109 kCi were supplied in thirteen consignments to various processing plants within the country.

Radiography Sources

A total of 693 consignments of Ir-192 & Co-60 radiography sources with total activity 26897 Ci were supplied from April 2019 to March 2020.

Custom Made Sources (CMR) and Reference Sources

About 824 consignments (27 Nos.) with total activity of 1.38 Ci of Custom Made Sources (CMR) of Co-60 were supplied up to March 2019.

About 612 consignments of sealed radioactive sources containing beta, gamma, positron, conversion electron, X-ray and low energy gamma emitters were supplied to customers by BARC through BRIT. Custom-made sources such as $^{90}Sr/^{90}Y$ and ^{60}Co large-area sources for calibration of portal monitors, ^{60}Co polymer film sources for use as PIP tag sources in oil and gas industry and ^{57}Co electrodeposited sources for nuclear fuel assay were supplied.

Ir-192 Pt wire for Brachytherapy

One consignment containing 0.8345 Ci of Ir-192 was supplied to the cancer hospital for its use in brachytherapy was supplied during the reported period.

I-125 Brachytherapy Seeds for Cancer Treatment

At BARC, eighteen consignments of ^{125}I brachytherapy seeds were fabricated and supplied to Sankara Nethralaya (Chennai), P.D. Hinduja Hospital (Mumbai), Sri Ramakrishna Hospital (Coimbatore) and Government Medical College & Hospital (Chandigarh) for the treatment of eye cancer patients. Kidwai Memorial Hospital (Bengaluru) became the second hospital to start prostate brachytherapy treatment in India with ^{125}I seeds.

P-32 Skin Patches

About 5 numbers of ^{32}P skin patches (74 MBq each) were supplied by BARC to Jawaharlal Institute of Postgraduate Medical Education & Research (JIPMER), Puducherry for the treatment of keloids.

Isotope Application Services

Gamma scanning of Extractive Distillation Column (ED)

Radioisotope techniques were applied for troubleshooting in 10 process columns at 5 different petroleum refineries such as BPCL (Kochi), RIL (Jamnagar), HPCL (Vizag), BORL (Bina), Nayara Energy (Vadinar). These columns were scanned successfully and scanning data was interpreted to locate the problematic area in the column which helped refinery engineers to take important decisions regarding shutdown. This activity renders huge economic benefit to the refineries as well as it generates good revenue for BRIT.

ED Column pressure drop in top section (tray 11 to 34) and packings has been increased after the lighters/gas ingress incident. Potential damage to tray / packing was suspected looking at the sudden rise in pressure drop with this event.

To identify the location of the problem, five scan lines were identified around 52 m. Column was scanned by 80 mCi Co-60 source hanging through pulleys installed at the top of the column. The radiation data was recorded by scintillation detector hanging similarly as source. Source and detector were moved automatically to collect the radiation with the help of automatic column scanning machine. The collected radiation data was plotted as elevation versus count rate and obtained density profile was interpreted. The column was found mechanically intact, however, all the multi down comer trays were severely flooded. That may be due to blockage/obstruction in the lower most tray.

In the reported year, 10 such columns were scanned to find out the problematic zone of the column at different petroleum refineries.

Gamma scanning of Extractive Distillation Column (ED)

Identification of Leaky Heat Exchanger

Final product contamination issues were solved by identification of leaky heat exchanger from a series of heat exchangers at four different refineries such as BORL (Bina), HPCL (Vizag), HMEL (Bathinda), Nayara Energy (Vadinar). Mo-99 in organic form was used as radiotracer in these applications and identification of leaky exchanger helped to bypass them during operation and to save maintenance cost as well as to reduce downtime during shutdowns.

In DHDT unit of HPCL, Vizag refinery, sulphur content in the diesel product was very high. It was suspected that any of the feed preheating heat exchangers may be leaking due to which final diesel product was contaminated with sulphur. Online identification of the leaky heat exchanger was carried out by injecting organic Mo-99 as radiotracer in shell side inlet (high pressure) and leakage was detected by placing leakage detectors on the tube side outlet (low pressure). Out of the six exchangers in the series, one heat exchanger was found leaky. This study helped HPCL to reduce their shut down time and hence save the valuable revenue.

Radiometry Inspection Jobs

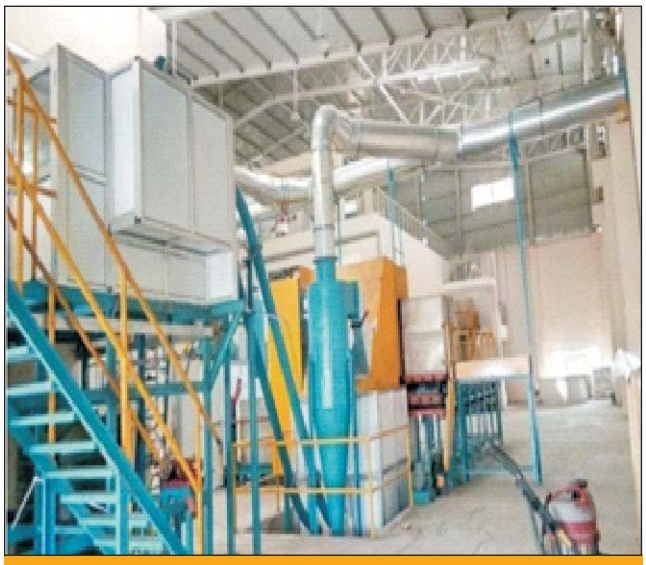
Radiometry of following jobs were carried out successfully:

- Tray rod facility (TRF), APSARA, BARC: Tray rod handling facility at APSARA reactor building was to be made functional before start-up of the reactor. Radiometry inspection was carried out to assess the shielding integrity of the concrete walls as well as to find out any radiation leakage or hotspots. About 6 Ci of Co-60 was transported from BRIT to BARC. The lead cask containing the radiation source was transferred inside the tray rod facility and source capsule was taken out with the help of MSM operation. By placing the source capsule at various locations inside the TRF, radiometric survey was carried out on outer walls, lead glass window, lever arm etc.
- Calibration source housing, BARC, Tarapur
- Transportation casks, ISOMED, BRIT

Sludge Hygienisation Plant

The technology demonstration pilot Sewage Sludge Hygienisation Plant in Ahmedabad, which began operations in 2019, successfully treated more than 350 tons of sludge with the 150 kCi Cobalt-60 source supplied by BRIT. The organically rich hygienised sludge is then enriched with Nitrogen, Phosphorus and Potassium for use in farms to improve soil fertility. The Ahmedabad Municipal Corporation decided to employ the plant's processed sludge for carpeting all barren lands in Ahmedabad for achieving dense greenery under its 'Mission Million Trees' project.

BARC-established Sludge Hygienisation Plant in Ahmedabad



Inside the Sludge Hygienisation Plant

Hygienised sludge arranged in bags

CHAPTER 5

Indigenously developed neutron detector array at VECC, Kolkata

BASIC AND APPLIED RESEARCH

A new type of wideband Hybrid Megawatt (MW) Level Continuous Wave (cw) Radio Frequency Combiner/Splitter has been designed and developed by IPR, Gandhinagar

The Department of Atomic Energy has contributed significantly towards strengthening of basic research in India. The Department pursues basic research in its R&D centres that ranges from Mathematics to Computers, Physics to Astronomy and Biology to Cancers. It also provides grants-in-aid to nine institutes of national eminence. Following were the major activities and achievements of DAE in basic research, during the period of report.

MATHEMATICS & COMPUTATIONAL SCIENCES

The celebrated conjecture of Parthasarathy-Ranga Rao-Varadarajan from the 1960s and its extensions by Kostant, Verma, Kumar and Montagard were the subject of recent research by members of the mathematics group at IMSc. Topological Data Analysis (TDA) is an emerging field which employs tools from combinatorial and algebraic topology to study the shape of data. It reveals higher-order patterns within the data that remain hidden to classical methods of investigating the structure of data. High-volume data that emerges from large networks such as Facebook can be studied using TDA. IMSc has developed a new method to study persistent homology in unweighted networks based on discrete Morse theory. This method produces an efficient algorithm to obtain a discrete Morse function that not only helps to capture the higher-order relations in an unweighted network, but can also be used in the lossless compression of such data. This function is also used to compute the persistent homology of the network in an efficient manner.

At TIFR, work was carried out on several questions and problems in Algebra, Analysis, Lie Groups, Number Theory, Algebraic and Differential Geometry and Combinatorics. In Algebraic Geometry and Representation Theory, a Verlinde formula for general crossed modular categories was given. In Geometric Group Theory, researchers gave general combination theorems for indiscrete isometry groups of hyperbolic space which apply to Fuchsian and limit groups. In Number Theory, the existing upper bound for higher moments of Riemann zeta-function on certain lines was improved and the techniques were used to improve the existing upper bound for the mean-square of the error term related to the Abelian group problem. In another study, a zig-zag conjecture was made describing the reductions of irreducible crystalline two-dimensional representations of the Galois group of the p-adic number field of half-integral slopes and exceptional weights. It was explained how zig-zag can be deduced from known results for half-integral slopes at most 3/2. In Complex Analysis, researchers related the theory of univalent polynomials to the field of conformal dynamics, and introduced quasiconformal deformation techniques to the study of univalent polynomials. In Spectral Geometry, the Hot spots conjecture for triangular domains was proved.

At the TIFR Centre for Applicable Mathematics, Bengaluru, under Partial Differential Equations, a study extended the classification of Schrodinger operators in terms of whether they are critical or not to operators with singular potentials not considered so far in the literature. Researchers also studied the structure of solutions for the Balance Laws in one space dimension with a source term. Adams inequality which describes the embedding of a Sobolev space was proved for Carton Hadamard manifolds with curvature bound. In Numerical Methods for Differential Equations, a new adaptive order scheme blending quartic, cubic and quadratic polynomials was developed. These techniques were applied to solve compressible flow problems where their superior performance was shown. In Probability Theory, researchers obtained a closed form expression for the mean Euler-Poincare characteristic of excursion sets of a class of random fields identified as Gaussain related fields. Certain modifications like the Metropolis adjustment to MCMC algorithm were introduced to improve the efficiency and broaden the applicability of MCMC algorithm.

Some of the research works that were pursued in the areas of computer science as well as systems science includes the design of a new state-of-the-art deterministic algorithm for the combinatorial problem of approximately counting proper colourings of graphs. In Algebraic Complexity Theory, researchers showed how to construct a generator to build hitting sets from suitable algebraic hardness. A consequence of this is

that even improving the size of the "trivial" hitting set by one point can be used to polynomial sized hitting sets. In Computational Game Theory, the complexity of computing equilibria in discrete preference games was studied and it was shown that even in very simple settings, such as where agents have very few neighbours, equilibrium computation is hard. In Mathematical Finance, a study analysed the equilibrium behaviour of a large network of banks in presence of incomplete information, where inter-bank borrowing and lending is allowed, and banks suffer shocks to assets. Monte Carlo based numerical methods were developed to compute the fixed point of a general distribution-valued map and theoretical guarantees were developed illustrating the effectiveness of proposed algorithms.

The concept of a group is the mathematician's way of describing symmetries in various problems of mathematics and the natural sciences. At HRI, Prof. Manoj Yadav and his collaborators used their work in group theory to enumerate skew left braces of small orders, which in turn provided them a number of set theoretic solutions of the quantum Yang-Baxter equation, arising in Physics.

Algebraic Geometry is the study of solutions sets of systems of polynomial equations, called algebraic varieties. Familiar examples are the conic sections from high school analytic geometry, which are solution sets of homogenous second degree polynomial in two variables. A central problem in algebraic geomtery is problem of the classification of algebraic varieties. Fundamental to the study of this problem is the notion of moduli spaces. These are spaces that parametrise intersting families of geometrical objects such as curves, surfaces etc. Prof. Umesh Dubey and his collaborators have obtained a number of results on moduli spaces as a part of their programme of resolving questions of V. Balaji and C. S. Seshadri related to functorial construction of moduli of parabolic bundles.

The representation theory of infinite dimensional Lie algebras is of great interest in both mathematics and physics. An important question in this topic is the classification of simple integrable modules over these algebras. The classification of such modules for certain infinite-dimensional Lie algebras called twisted full toroidal Lie algebras was obtained by Prof. Punita Batra and her collaborators. These Lie algebras are universal central extensions of twisted multiloop algebras which are additionally enlarged by adding certain derivations.

Given an integer $k \geq 1$, the problem of finding k-additive bases for the set of the non-negative integers has been an important problem in additive number theory. This means that we are looking for subsets A of the non-negative numbers such that every non-negative can be written as the sum of k elements of A. The interest in studying such sets of natural numbers stems from a number of famous theorems and unsolved problems in mathematics such as the classical Lagrange Four squares theorem and the Goldbach conjectures. Prof. Gyan Prakash, together with research scholar E. Pramod and Prof. F. Hennecart, have obtained a number of results on a generalisation of the concept of additive bases of the natural numbers.

They study subsets A of the natural numbers such that every natural number is expressible as a sum of a product of k numbers in A with a product of l numbers in A, where $k,l \geq 1$ are given integers. These sets are called (k,l)-sum-product bases for the natural numbers. Their conclusions include new results for the asymptotics and density of such subsets of natural numbers. For instance, they show using methods borrowed from probability theory that there exist "thin" (k,l)-sum-product bases for the natural numbers, for certain values of k and l.

Some of the fundamental questions in Number Theory are concerned with whether various special numbers that occur in mathematics, such as e, π, etc., are expressible in terms of each other by simple linear relations, for example, linear relations that have rational number coefficients. Veekesh Kumar, a research scholar with Prof. R. Thangadurai, made a number of interesting contributions to this research area in a thesis completed this year.

PHYSICS

In Astronomy and Astrophysics at TIFR, a study determined the precision with which Gaia can astrometrically measure the orbits and with additional observations the component masses, for luminous

stars hosting hidden companions. Another study derived analytic expressions that provide the Fourier domain Gravitational Wave (GW) response function for compact binaries inspiraling along moderately eccentric orbits. Solar flares-bursts of high-energy radiation responsible for severe space weather effects—are a consequence of the occasional destabilization of magnetic fields rooted in Active Regions (ARs). Machine Learning algorithms were trained to classify between vector-magnetic-field observations from flaring ARs, producing at least one M-/X-class flare, and nonflaring ARs. TIFR Balloon Facility, Hyderabad extended its support to launch various types of balloons with different types of aerosol payloads to NASA-Langley Research Centre (USA), ISRO-National Atmospheric Research Laboratory (Gadanki) and French National Center for Scientific Research (CNRS) during the 2019 monsoon season (July 2019). This was the fifth successful balloon campaign conducted from the TIFR Balloon Facility to study the Asian Tropopause Aerosol Layer (ATAL) over Indian (Hyderabad) region using various balloon-borne aerosol instruments.

At the National Centre for Radio Astrophysics, Pune**, t**he Giant Metrewave Radio Telescope (GMRT) completed a major upgrade that had been ongoing for the past six years, and the upgraded facility was released to the world-wide user community from the GMRT observing cycle starting April 2019. This upgrade provides a major increase (by upto three times) in the sensitivity of the GMRT for continuum imaging and pulsar studies, and also makes it a much more versatile facility for spectral line studies. The upgraded GMRT was used to carry out a deep observation of the Extended Growth Strip, to measure the average neutral hydrogen mass and median star formation rate of star-forming galaxies. The study indicated that the star formation efficiency does not change significantly over the redshift range 0-0.4. The GMRT was used to discover a diffuse radio source that turns out to be a rare transition system in the galaxy cluster RXCJ0232.2-4420. The upgraded GMRT was also used to uncover Electron Cyclotron Maser Emission (ECME) phenomenon in four magnetic massive stars. Prior to these discoveries, only one magnetic massive star was known with the ECME mechanism for past 15 years.

In Nuclear and Atomic Physics, Anderson localization is a quantum effect arising from the wave-particle quantum duality of electrons. Researchers designed and implemented semiconductor nanostructured samples to replicate the same effect with light, and have successfully demonstrated Anderson localization of light waves. The study experimentally measured the optical conductance and proved that the sample was in the insulating phase. This work was chosen to be highlighted as an Editors' Suggestion by the Editorial Board of Physical Review B. A detailed noise characterization, investigation of various noise sources, and its mitigation to improve the performance of a cryogenic bolometer detector for the TIN.TIN experiment was carried out. The stability of various Sn-rich alloys against tin pest and consequences for TIN.TIN were studied, and Sn-Bi alloy was found to be most resistant to tin pest. The Pelletron LINAC Facility (PLF), joint facility of TIFR and BARC, was operated for research in nuclear physics and other allied interdisciplinary areas.

In Theoretical Physics at TIFR, new, previously unknown, shapes of CMB spectral distortions were discovered. It was shown that the amplitude of the spectral distortions is sensitive to the energy injection mechanism. An important problem in astrophysics is how to infer 3-D shapes of astrophysical objects from 2-D images taken by telescopes. A new method to infer the probability distribution function of 3-D shapes of galaxy clusters was proposed using methods from the field of Stereology employing Minkowski functionals. It was demonstrated that this way of statistically inferring the shapes of galaxy clusters would be a powerful way to extract new information from the future X-ray and microwave surveys which would observe hundreds of thousands of galaxy clusters. Using the computational facility of the Indian Lattice Gauge Theory Initiative (ILGTI), a set of exotic nuclei have been predicted, which are not to be found in the Periodic Table. These predictions may aid in discovering these new subatomic particles at experimental facilities.

A portable digital holography microscope was developed and integrated with a standard pathological microscope at Photonics & Nano technology laboratory of BARC – Vizag. The system consists of a miniaturized laser interferometer coupled to a

pathological microscope and a smartphone camera. Android Apps were developed to acquire, process and reconstruct 3-dimensional images of transparent objects such as biological cells. The system is capable of both, 2D and 3D imaging of biological cells, where white light is used for 2D images and laser is used for 3D images. 3D phase images of red blood cells, white blood cells and HeLa cells were recorded using this system.

At BARC, a UHV compatible Pulsed Laser Deposition (PLD) system, based on Q-switched pulsed Nd:YAG laser, was developed for In-situ PES studies at Angle Resolved Photo Electron Spectroscopy (ARPES) beamline. The PLD chamber is equipped with six targets of one-inch diameter and two mass flow controllers to control the gas flow. The ambient pressure, substrate temperature (upto 800 ^{o}C), deposition rate can be controlled for growth of epitaxial films of complex oxides required for ARPES measurements.

Enhanced gamma-ray emission was observed from the extragalactic object Mrk 421 during the period April-June, 2019. Analysis of the data collected for 68.7 hours indicated presence of 284 ± 60 gamma-ray like events at a statistical significance of 4.7s. Analysis of around 94.3 hours of data collected on another extragalactic object Mrk 501 did not indicate any significant gamma-ray signal (182 ± 70 gamma-ray like events with a statistical significance of 2.6s). Multiwavelength data, recorded for 37.1 hours between December, 2016 and February, 2017, from radio galaxy NGC 1275, revealed the 3s upper limit (2.9 x 10^{-11} erg cm^{-2} s^{-1} above 0.85 TeV) obtained from TeV Atmospheric Cherenkov Telescope with Imaging Camera (TACTIC) observations is consistent with the low emission state of the source. The multiwavelength spectral energy distribution of the source was constructed by using observations of the source from Fermi-LAT, Swift-XRT/ UVOT and OVRO.

BARC is setting up a 21 m diameter large gamma-ray telescope MACE (Major Atmospheric Cherenkov Experiment) at the high altitude astronomical site Hanle, Ladakh to explore the high energy universe in the energy range from 30 GeV to 3 TeV. The 21 m diameter paraboloid shape basket of the telescope has 356 spherical mirror panels of size 984mm x 984 mm mounted on it. The telescope deploys a 1088 PMT (Photomultiplier tubes) based imaging camera at its focal plane with a uniform pixel resolution of 0.1250. All the subsystems of the telescope i.e. mechanical structure, light collector, drive control unit and camera electronics with 68 CIMs (Camera Integrated Modules) have been fully installed. Mounting of the light concentrator plate along with CPCs (Compound Parabolic Concentrators) and 1088 PMTs has also been completed. Software required to operate, control and monitor various subsystems of the telescope has been tested and the results obtained so far indicate satisfactory performance. Detailed engineering trial runs of the telescope with 356 mirror panels and 68 CIMs are currently underway.

MACE telescope along with 356 mirror panels and imaging camera with 68 CIMs at its focal plane

BARC is developing Electromagnetic Isotope Separator (EMIS) for enrichment of ^{176}Lu, which will be irradiated to produce ^{177}Lu. ^{177}Lu is used in preparation of radiopharmaceuticals. Stigmator dipole magnet is a key component of EMIS. The 0.5 Tesla, 6-Tonne electromagnet has 1000 mm bending radius, 90-degree magnetic sector and homogeneity better than 200 ppm in 12000 mm^2. The magnet was installed and tested for its desired performance.

A permanent magnet based electromagnetic pump was developed for pumping liquid metals such as PbLi, PbBi, Na, Hg, Pb, etc., which find application as a coolant in advanced nuclear reactors. Electromagnetic design and optimization for sizing of pump parameters were carried out to meet the required Head Flow (P-Q) characteristics.

Electromagnetic induction pump is integrated with room temperature calibration loop and its P-Q characteristics established.

Gyrotrons generate high power, high frequency microwaves by cyclotron resonance of electrons in a strong magnetic field, produced by a pulsed electromagnet to match beam physics requirements. The accelerated electron beam generates coherent EM waves. A 3.65T pulsed electromagnet with a field uniformity of 0.1% in a ±13mm region along the axis was developed.

Notable studies have been carried out in the field of gas sensor development. These include role of sensitizers in imparting the selective response of SnO_2/RGO based nanohybrids towards H_2S, NO_2 and H_2 gas sensors, TiO_2/ZnO heterostructure nanowire based NO_2 sensor, XPS and Kelvin probe studies of SnO_2/RGO nanohybrid based NO_2 sensors etc. Pellistor type hydrogen sensors based on palladium thin film were developed for ambient hydrogen area monitoring and installed at two locations in BARC.

An indigenous multi Position Sensitive Detectors (PSDs) based on ^3He was installed in Small Angle Neutron Scattering (SANS) facility at Dhruva. The geometry of multi PSDs allows measurements with better statistics and at wider length scales (1-50 nanometer).

Purnima Neutron Generator facility (PNGF), a state-of-the-art fast neutron facility in DAE, was extensively used for experiments such as fast neutron radiography, for irradiation of seeds and biological samples, cross-section measurements and neutron detector performance testing and ADS related studies.

Nuclear Level Density (NLD) plays a crucial role in understanding microscopic and thermodynamic properties of atomic nuclei and their reactions relevant to nuclear technologies and astrophysics. It is often necessary to know NLD of excited nuclei as a function of excitation energy, angular momentum, isospin and other constants of motion. Collective enhancement of NLD and it's fadeout with excitation energy in deformed heavy nuclei and isospin dependence of NLD in mid mass nuclei were measured using the detector arrays developed at BARC-TIFR Pelletron LINAC Facility (PLF). A charged particle detection setup consisting of 10 double sided silicon-strip detectors was developed covering a wide angular range to further this type of work using the PLF. A simulation code was developed using the Monte Carlo technique involving 3-body kinematics for the proper identification of different reaction modes.

Intrinsic deformation lengths corresponding to low lying quadrupole and octupole excitations in Sn isotopes have been obtained using heavy ion probes. Homogeneous nature of surface vibrations for the 2^+ and 3^+ states is observed, when probed with isoscalar ^{12}C nucleus. However, the results using ^7Li projectile showed damped neutron vibrations for the 3^+ state, implying that such measurements are probe-dependent. A systematic study of different probes ranging from Z = 1 to 6 was made to remove the effects of finite projectile size in the extraction of nuclear potential shapes, leading to the intrinsic transition matrix elements of Sn nuclei.

Measurements of antineutrinos were performed at DHRUVA reactor using 0.16 ton detector mini-ISMRAN with a 5 ton shielding and candidate like antineutrino events have been identified. The assembly of the Full ISMRAN detector (1 Ton + 14 Ton shielding) is in progress. It is proposed to explore reactor flux anomaly, antineutrino spectral anomaly and search for sterile neutrinos using this facility.

At VECC, the effect of liquid drop model parameters on nuclear liquid gas phase transition was studied in the framework of canonical thermodynamic model and it was found that the surface term significantly affects the transition temperature. It has been shown that the fractionation property of the liquid-gas phase transition leads to very different isotopic ratios in equilibrium multi-fragmentation, with respect to the predictions of the spinodal instability. An isospin dependent Thomas-Fermi model is developed for calculating the ground state density and energy of finite nuclei and is successfully applied for generating initial conditions of isospin dependent transport model (BUU@VECC-McGill) calculations. The formation of fission fragments in case of spontaneous fission has been studied using microscopic nuclear energy density functional theory. In addition, a Langevin dynamical code is implemented using MPI parallelization technique and has been successfully

applied to study the fission time-scale in heavy-ion induced reactions.

VECC is also actively involved in the study of single and multi-strange hadron production using the transport equation. Recent microscopic study favours a sequential freeze out of strange species from hot-dense matter formed at LHC. Studies of directed flow of photons in symmetric and asymmetric collisions of heavy nuclei at relativistic energies show that initial state fluctuations dominate over initial collision geometry in determining the flow parameter.

Various aspects of strong interactions in the presence of intense magnetic fields have been extensively investigated. In particular, the inclusion of anomalous magnetic moment of quarks, which is usually ignored, is found to have significant effects on the thermodynamics and phase structure of hot and dense matter. Formulations for the thermal field theory of Tsallis statistics has been developed.

Research activities carried out in the field of experimental nuclear physics includes New high precision study on the decay width of the Hoyle state in ^{12}C; Giant Dipole Resonance (GDR) Studies; Nuclear Structure Studies using Gamma ray Spectroscopy and Nuclear Data activity. Under developmental activities, the major activity was the fabrication of 50 detectors for the VECC TOF array which has been successfully completed and the detectors have been installed in the array structure. VECC neutron time-of-flight array is being constructed for the understanding of nuclear reaction dynamics at intermediate energy and to study the structure of highly excited neutron rich ejectiles formed in these reactions. The detail characterization of the array is expected to be carried out soon.

Indigenously developed neutron detector array at VECC

Institute of Physics (IOP) is a major centre for research in basic and applied physics. The research is carried out in the following broad areas of physics, namely, theoretical high energy physics, theoretical condensed matter physics, theoretical nuclear physics, experimental condensed matter physics, experimental high energy physics, and quantum information.

At IOP the broad areas of research in theoretical high energy physics are string theory, high energy physics phenomenology, and cosmology. String theory research focused mainly on properties of black holes, holographic correspondence in AdS and asymptotically flat space, applications of AdS-CFT duality to strongly coupled gauge theories and interface between quantum information theory and string theory. The activities of the high energy physics phenomenology have a special emphasis on collider physics, neutrino physics, dark matter, astroparticle physics and physics beyond the standard model. A significant part of the research was aimed towards exploring the physics potential of various ongoing and upcoming experiments in particle physics like LHC, the proposed 100 TeV collider, CLIC, ILC, India-based Neutrino Observatory (INO), DUNE and Hyper-Kamiokande. The group remained active in the field of quark-gluon plasma, cosmology and astroparticle physics. In this area, the main focus is simulation of the quark-gluon phase transition and magnetohydrodynamics to understand the flow of the plasma. The group members are also studying the emerging issues in astroparticle physics like dark matter, dark energy, baryogenesis and properties and detection of gravitational waves. Very recently, one of the HEP group members, Prof. Sanjib Kumar Agarwalla has won the prestigious B. M. Birla Science Prize in Physics for the year 2018.

The condensed matter theory group at IOP is remained actively involved in pursuing research with the main focus in understanding the organization of bacterial chromosome, active matter, fluctuation

theorem, topological aspects of quantum condensed matter systems, quantum transport in Dirac/Weyl materials, quantum magnetism, and interplay of strong correlation and topology in artificial lattice systems. The group members have investigated impact of strong correlation and periodic drive in topological band properties of different lattice systems, Floquet engineering of higher-order Topological insulators, transport properties of driven semi-Dirac materials, unusual spin-wave spectrum for helical spin configuration for the á-MnO_2 materials, an absence of order by disorder attributed to newly found macroscopic conserved quantity and abelian anion excitations in H_2SQ materials etc.

The experimental high energy physics groups at IOP are participating in the collider-based experiments at various international laboratories, such as CMS and ALICE experiments at CERN-LHC, STAR experiment at RHIC, BNL (USA), and the proposed CBM experiment at FAIR, GSI (Germany). The groups contribute to the studies of the properties of the observed Higgs boson and searches for beyond the Standard Model particles in proton-proton collision events at LHC as well as the studies of Quark-Gluon plasma, a state of matter in the early universe, which are recreated in heavy ion collisions. Furthermore, the groups contribute to the R&D of the state-of-the-art detectors for future experiments.

In experimental condensed matter physics, major activities included studies on accelerator-based materials science, surface and interface physics, advanced functional materials, and nanosystems. The Ion Beam Laboratory houses the NEC 3 MV tandem Pelletron Accelerator, which is one of the major facilities used by researchers from all over the country. The accelerator provides ion beams of energies typically 1-15 MeV starting from protons and alphas to heavy ions. Different users (both internal and external) and research scholars are using this facility for their research. During this period, the accelerator facility has catered several users from the Institute of Chemical Technology-Indian Oil Bhubaneswar, Indraprastha University-New Delhi, SOA University-Bhubaneswar, UGC-DAE Kolkata Centre, NISER, Bhubaneswar. Other important activities include studies on solar energy photovoltaics, self-organized pattern formation on semiconductor surfaces and their nanoscale functionalization by growing metallic nanostructures and magnetic thin films on patterned substrates to study anisotropic plasmonic and magnetic properties, and tunable metal oxide-based resistive switching devices for neuromorphic applications using energetic ion beams.

In Condensed Matter Physics at HRI, there have been works on three aspects: topological materials, strongly correlated systems and materials for applications. In topological materials, our work has encompassed topological phases of matter, concentrating on topological insulators of higher order, edge physics in the integer quantum Hall effect and topological phase transitions using the renormalisation group procedure. Earlier work on Weyl semi-metals and on graphene edges were continued. In strongly correlated systems, the dynamics of phonons and spins in correlated systems were explored, this should help in understanding the spectroscopic data in real materials. Works on the voltage driven breakdown of Mott insulators was also done. Doped cobalt clusters to understand origin of large magnetic anisotropy in these systems important in designing permanent magnets were studied. Alpha-MnO2, a material used in Li-air batteries, have been studied under high pressure, and has been found to transform to the delta-MnO_2 phase. Stability and electronic properties of lanthanum oxide clusters have also been studied in collaboration with experimentalists.

The astrophysics group at HRI have been working in the field of astrophysics, general relativity and gravitation, and dynamical systems phenomena.

At HRI several contributions of significance have come from High Energy Phenomenology in the context of beyond standard model physics search at present and future accelerator experiments, dark matter experiments as well as Astrophysics experiments such as the Square Kilometre Array (SKA1). The contributions have been mainly focussed in analysing new phenomenological ideas Beyond the Standard Model (BSM) of particle physics that involve extended scalar sectors and super symmetry. New ways of unravelling such scenarios at experiments have been proposed. New ideas on dark matter content of the Universe and proposed search strategies for new particles such as charged Higgs bosons at collider

experiments have been generated. Efforts to address the open issue of dark matter of our Universe in the contexts of theoretical model-building and studying gamma-ray signals and radio data signals from outer space were continued. Members of the Neutrino group are a part of new experiments planned to study neutrino properties such as the INO and DUNE collaborations and physics studies at these experiments are one of the major efforts carried out. In addition, impact of new physics such as signatures of dark matter and neutrinoless beta decay and baryogenesis has been also looked at.

The area of Quantum Information and Computation (QIC) is a science at the interface of physics, mathematics, computer science, and engineering, and promises to revolutionize the future of our abilities to communicate and compute. The QIC group at HRI works on a large spectrum of topics in this area and its interface with other areas including ultracold gases and quantum optics. Among the research works performed by the group members in the last academic year, is one on the quantum Chesire Cat, a counterintuitive phenomenon that provides a new window into the nature of the quantum systems in relation to multiple degrees of freedom associated with a single physical entity. In another work, they showed that one can have enhancement in performance of quantum battery by ordered and disordered interactions in a quantum spin chain. In yet another one, they show how one can beat the detection loophole in nonlinear entanglement witnesses in generic shared quantum devices.

String theory provides us with a theoretical framework which can lead to a unified theory of all forces of nature. The string theory group at HRI has examined various aspects of the theory over the last one year. On the more theoretical side, research has been carried out in string field theory. One interesting result in this area is certain exact computations in two dimensions which have given exact information about the structure of the string effective action. Another direction has been systematic study of the low energy effective action of strings, by making use of the method of modular graphs. Also, the theoretical tools of string theory have been applied to the SYK model to gain insight into non-equilibrium systems. Finally, cosmological implications of moduli fields (which arise generically in string theory) have been examined.

Facility for Research in Nuclear Astrophysics (FRENA), a national facility at SINP is built around a high current 3MV Tandetron Accelerator. The machine is equipped with three ions ources that can deliver Hydrogen (H), Helium (3,4He) and other heavy ions, respectively. The machine can also deliver pulsed H- and He-beams. The terminal voltage can be varied from 200 kV to 3 MV with a resolution of 10^{-5}. Nitrogen gas is used as stripper for anion to cation exchange at the terminal. The machine is now being being prepared for commissioning. All the vacuum systems are running maintaining high vacuum in the system. Accelerator tank has been charged with SF6 gas. The regeneration cart for SF6 gas has been installed and connected to the tank for maintaining a low moisture level in the gas to avoid sparking. Stability of the voltage generator has been tested by raising the Terminal Voltage to the maximum value of 3.3 MV. Hydrogen and helium ion source gases have been mounted in multicusp ion source station and connected to the gas delivery system. Door interlocks, radiation area monitors and beam-on glow signs are in position. Interlock signals are now connected to the machine control system. Final commissioning of the machine and the beam testing will commence in February, 2020 following the clearance from AERB.

Optimization of muon telescope design parameters through numerical simulation based on Geant4 and CRY was continued at SINP. The area of application has been identified to be discrimination among materials among different Z values. Once validated, such a telescope can be used to carry out non-destructive testing of any static large structures, such as buildings, bridges, monuments of archaeological interest etc. A muon hodoscope based on these studies is being fabricated and its characterization is being carried out. An improved design of the micro-mesh (procured from the Indian market) based detector has been fabricated and its characterization is under way. This detector, if successful, will be an entirely Indian product.

The Underground Science Laboratory is operational at 555m of UCIL, Jaduguda mines. The laboratory has been continuously working round the clock and scientists and students from SINP and BARC have been visiting the facility on regular basis. The data of muon flux, gamma-rays, neutrons, radon etc. is being monitored and recorded.

An Electromagnetically Induced Transparency (EIT) based atomic vector magnetometry experiment has been performed in the laboratory of light–matter interactions in SINP. How the effective polarization components with respect to the arbitrary quantization axis modifies the EIT selection rules has been addressed. The explicit dependency of the polarization angle and the magnetic field direction in the probe transmission is calculated analytically. Furthermore, the direction along with the strength of the unknown magnetic field has been derived.

The nuclear physics group members of SINP have been successfully continuing their activities in Accelerator-based Nuclear Physics (In-Beam gamma spectroscopy and Reaction studies) using National and International Accelerator Facilities as well as in their in-house laboratories. It is a constituent member of the Indian National Gamma Array (INGA) collaboration. During this period, the group has done gamma spectroscopy experiments with INGA array at IUAC. Nuclear instrumentation and developmental work like fabrication of nuclear radiation detectors and chambers, developing algorithms to acquire and analyze data effectively, are pursued.

The plasma physics group carried out the experimental activities in the MaPLE (Magnetized Plasma Linear Experiment) and Double Layer Experimental (DLX) devices to study various types of waves and instabilities.

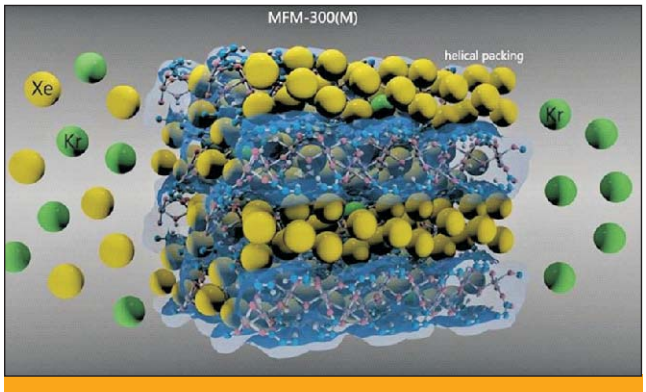
The Astroparticle Physics & Cosmology (APC) Division of SINP remained involved in advanced research in the interface areas spanning High Energy Astrophysics, Cosmology, Particle & Nuclear physics and Gravitational waves and research on a variety of topics in observational, experimental and theoretical astroparticle physics were carried out.

One of the major directions of the Condensed Matter Physics division of SINP is to synthesize novel materials and their device structures with an aim to improve of magneto-caloric and magneto-electric properties, enhancement of thermoelectric figure of merit etc. Recently, SINP have also found a series of intermetallic compounds that form in two different crystal structures, despite having same chemical compositions, and therefore have different physical properties. SINP has fabricated voltage sensitive devices with single atomic layer carbon material for sensor applications.

The School of Physical Sciences, NISER Bhubaneswar has discovered the superconductivity in Silver-ion implanted in Au film. This work was performed with a team of scientists from NISER, IOP and Institute of Minerals and Materials Technology (IMMT), Bhubaneswar. The team has observed superconductivity below 2K. Some of the major research facilities and equipment added to NISER include; Light Sheet Microscope, 400 MHz NMR Spectrometer, Picosecond Fluorescence lifetime Spectrometer, Electrospray Ionization-Mass Spectrometer (ESI-MS), Inductively Coupled Plasma Optical Emission (ICP-IOS), Femtosecond Up-Conversion Spectrometer, Pico-second Fluorescence Lifetime Imaging Microscope, Focused Ion-Beam Lithography System.

CHEMISTRY

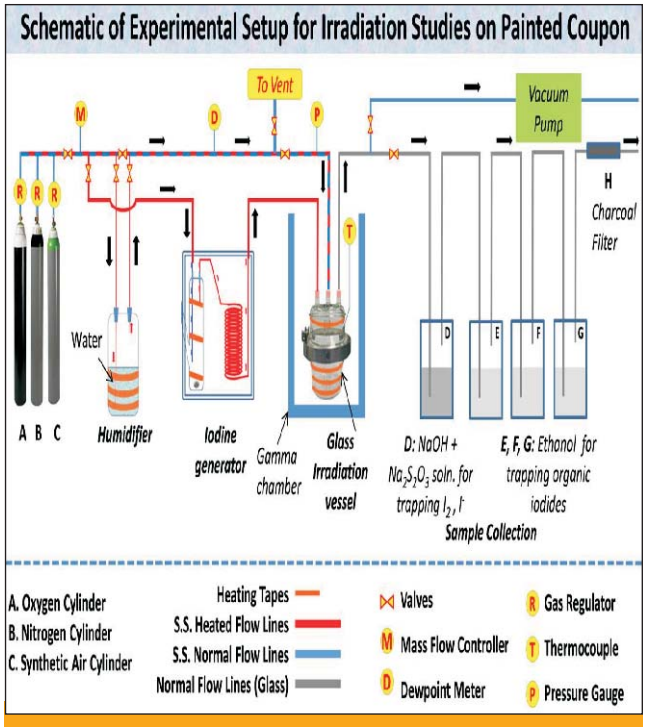
Management of spent fuel containing a large number of long lived fission and activation products is one of the key issues in nuclear fuel cycle. Xe and Kr produced during spent fuel reprocessing need special methods to store owing to their long half lives: ^{85}Kr - 10.73 years and ^{127}Xe - 36.4 days. All other isotopes have shorter half-lives. Adsorptive separation of Xe and Kr using adsorbent materials such as MOFs is economically viable alternative to the energy intensive cryogenic distillation. It is found that MFM-300(In) has the highest selectivity for Xe over Kr and ideally suited for nuclear spent fuel reprocessing.



Snapshot depicting the separation of Xe and Kr through MFM-300 Metal Organic Framework

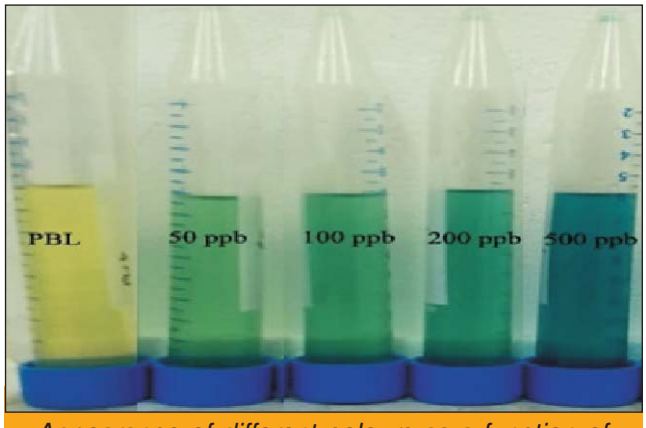
In a nuclear accident, a significant amount of iodine is released as volatile organic iodides, which are formed by interaction of iodine with containment structural surfaces (paint, epoxy, thinner, etc.) and

stainless steel. To understand the mechanism of formation of organic iodides, an irradiation facility was established. A set up for irradiating painted specimens under iodine atmosphere was developed to understand the effect of radiation, atmosphere and temperature. Now, the facility is equipped to carry out controlled experiments to understand the formation of alkyl iodides from interaction of iodine with painted surface on gamma irradiation.



Schematic of Experimental Setup for Irradiation Studies on Painted Coupon

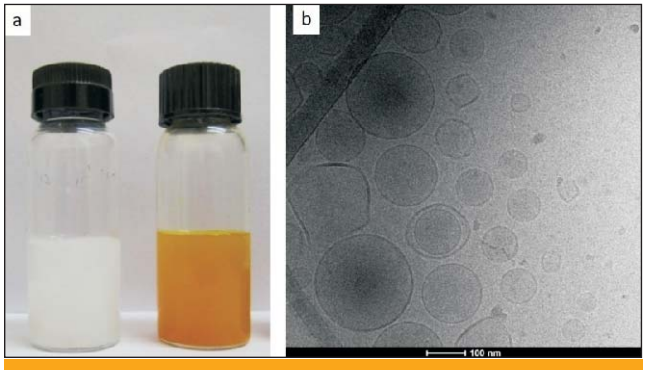
A spectrophotometric method for use in Nuclear Power Plants was developed to detect ammonia in 10-500 ppb range in the secondary coolant water of nuclear power reactors. The method can be easily adapted for the on-site detection of ammonia, in the aqueous systems.



Appearance of different colours as a function of Ammonia concentration

Chemistry of fuel salt, blanket salt and coolant salt systems and the interactions of these salts with structural components play an important role in the design and operation of MSBR. Thermo-physical and thermodynamic properties of fuel salt, blanket salt and coolant salt systems such as LiF-NaF-KF (46.5-11.5-42) mole % (FLiNaK) were studied. Thermodynamic activities of FLiNAK components were determined from high temperature mass-spectrometric studies.

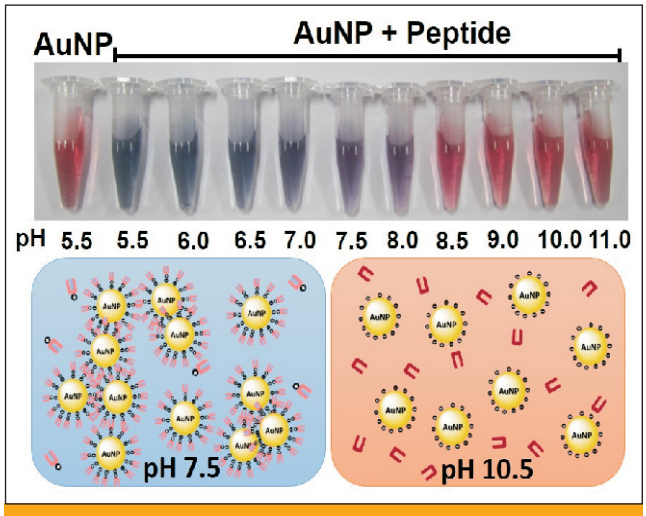
Lipid based nanocarriers are biocompatible and often employed for drug delivery. A method was developed to produce liposomes using supercooled micelles as a matrix for lipid solubilisation. Dissolution of lipid based supercooled matrix in water leads to spontaneous formation of vesicles or liposomes with controlled surface charge. Cryo-TEM studies revealed that unilamellar vesicles of size ~200 nm are formed by supercooled micelle/emulsion dissolution process. To investigate the suitability of this method for drug encapsulation, curcumin is employed as a model hydrophobic compound. It was observed that up to 5 mg/ml of curcumin can be loaded, leading to liposomes having aqueous colloidal stability more than six months.



(a) Colloidally stable lipid based nano-formulations with size less than 200 nm and 5mg/ml curcumin loading efficiency and (b) Cryo-TEM image of liposomes formed by SEMSOL process

Lanreotide Peptide (LP) is a synthetic octapeptide and structural analogue of somatostatin with high affinity for somatostatin receptor type 2 (SSTR2). In order to achieve site-specific targeting towards tumor cell expressing SSTR2, LP coating was introduced onto the surface of gold nanoparticles using electrostatic binding. The flow cytometric analysis indicated a preferential targeting and delivery of AuNP-

LP complexes into high SSTR2 expressing cells (MCF-7 and AR42J). Furthermore, the targeted delivery of AuNP-LP complex causes significantly higher radio sensitisation of SSTR2 cells as compared to as prepared AuNP.



pH-dependent binding of Gold Nanoparticles (AuNP) and Lanreotide Peptide (LP)

Porosity issues for efficient utilization during sulphuric acid decomposition step in S-I process were addressed for engineering scale thermochemical hydrogen generation. $Fe_{1.8}Cr_{0.2}O_3$ catalyst was prepared in foam form and evaluated at 850 °C at a WHSV (weight hourly space velocity) of 2.8 g acid g^{-1} cat h^{-1} continuously for 110 h, during which activity of the catalyst remained constant and the SO_2 yield at 85%, which is close to the equilibrium yield at 850 °C.

Field trials of portable sensors at ONGC Plant, Uran, using nanocrystalline SnO_2 thin films to detect H_2S gas at room temperature were satisfactory in terms of performance comparable to commercial sensors. Gas samples containing 98% hydrocarbons, 2% CO_2 and H_2S in ppm concentration were used in the trials. Another field trial in BARC to detect H_2S in manholes also showed satisfactory performance under gas flow conditions.

At BARC, the Analytical Chemistry provided user specific analytical solutions to ensure quality in analytical data and develop standard reference materials. Apart from DAE, other beneficiaries of the service are Law Enforcement Agencies, Academic Institutions, Public Sector Undertakings and Private Firms. Some of the important analyses are high purity Ge for ultratrace levels of impurities; quartz, boron carbide and Pb Li for trace impurities. In addition to the service support, some of the analytical instruments are developed for carbon & sulphur analyser and dissolved oxygen meter.

Hydrogel beads, synthesized by graphene oxide impregnation in calcium alginate matrix (Gra-Alg) using sol gel method, were used for selective removal of gold from a scrap solid state detector. Copper from the solution was recovered using conventional chemical separation whereas gold was selectively isolated using Gra-Alg hydrogel beads. The maximum uptake capacity of the hydrogel beads is observed as 81.87 mg g^{-1}. The sorption capacity of the hydrogel beads depends on the pH of the solution and more than 95% uptake of gold was observed at pH range 2-4. The equilibrium contact time of the sorption of gold on the hydrogel beads was 22 hours.

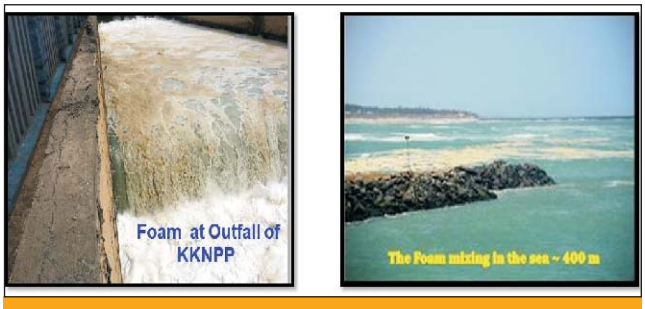
NABL has evaluated the Analytical Chemistry Division (ACD) laboratory of BARC and granted accreditation in accordance with ISO/IEC 17025:2017 in the discipline of Chemical testing (trace elements in low alloy steel and water matrix). Accreditation Certificate No. is TC-8406 for Chemical testing with issue date 20.03.2019 and is valid till 19.03.2021.

^{94}Nb and ^{231}Pa are two long lived radionuclides present in high level nuclear waste and their release into natural hydrothermal systems from the deep underground vaults is a matter of concern. Sorption of ^{94}Nb and ^{231}Pa on silica, iron oxides and manganese dioxide was studied using the corresponding radiotracers along with effects of different physico-chemical parameters. The sorption mechanism was evaluated based on ionic strength, temperature dependent sorption phenomena and EXAFS spectroscopic investigations. Both Nb and Pa are strongly associated with colloidal silica, iron oxides and manganese dioxide especially in the neutral pH to mildly basic pH region and probably follow chemisorption mechanism. The quantitative sorption in neutral to near neutral pH region indicates that in the natural aquatic conditions, migration of ^{94}Nb and ^{231}Pa may be assisted by colloids present in the medium.

Supercritical water is a viable option as a coolant in nuclear as well as thermal power plants, as it offers high thermal efficiency. An experimental loop made of Stainless Steel 316, equipped with adequate safety features, was set up to study the chemical impact of

supercritical water on structural materials. Corrosion studies on Zr-2.5Nb alloy was initiated in a once through flow system operating at 350 °C and 250 bar pressure. The specimens were exposed to pH10.2 water where dissolved oxygen was maintained at 350 ppb. The specimens were removed after 120 hours for characterization.

The cooling water discharge region (outfall) of both the units of Kudankulam Nuclear Power Plant (KKNPP) has been experiencing brown foam formation along the coast before it is dispersed by the waves. The foam presents an aesthetically unpleasant and gives an impression that some pollutants are being discharged from KKNPP. Studies showed that the foam is formed by fine colloidal sediments in seawater, which are agglomerated by the hydrodynamic forces. It was suggested to deploy fenders / skimmers in series to break the consistency of the foam before discharge into the sea.

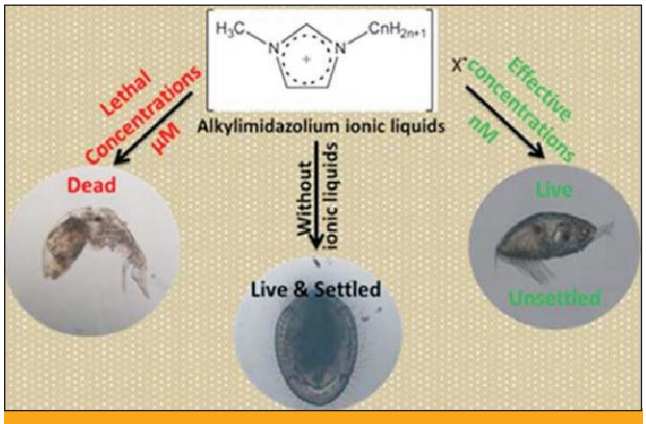


Foam Formation in Waters of Kudankulam Power Plant

Pilot Photo-bioreactor for Wastewater Treatment was commissioned at sewage treatment plant Kalpakkam. It is a low maintenance, energy positive process for simultaneous wastewater treatment, carbon dioxide sequestration and algal biomass generation. The phototrophic granules are Self-Sustaining triple consortium of bacteria, cyanobacteria and microalgae. This special type of granular biomass is developed in photo-bioreactors, operated in sequencing batch reactor mode.

Demonstration scale photo-bioreactor

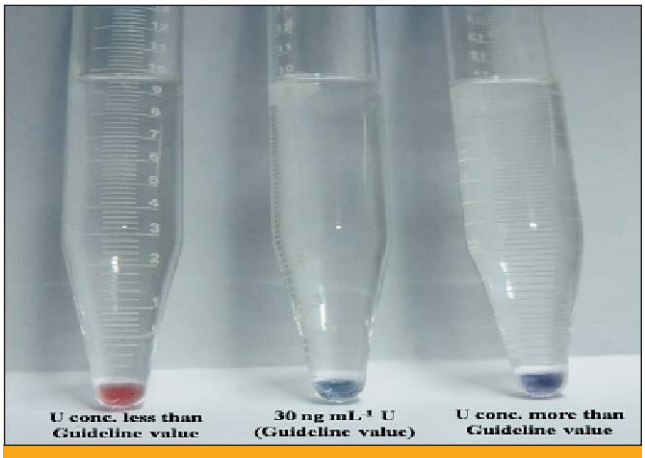
Barnacles are notorious marine organisms associated with biofouling in cooing water systems. The life cycle of barnacles begins with swimming larvae and passes through distinct stages within days and eventually settles on a surface and metamorphoses into a sessile adult. Compounds that interfere with the settlement of barnacle larvae are important for developing antifouling strategies. Alkylimidazolium ionic liquids that differ in alkyl side chain length ([CnMIM]+X-; n=4, 12, 16) were evaluated for determining antifouling potential in terms of survival and settlement barnacle larvae. The antifouling activity of the tested ionic liquids on larvae decreased in the following order: [C12MIM][I] > [C16MIM][Cl] > [C4MIM][Cl]. Ionic liquid with –dodecyl alkyl chain was found to be more potent in preventing the attachment. Larval mortality was caused in the presence of micromolar concentrations. However, settlement of barnacle larvae was inhibited at nanomolar concentrations. The results show that imidazolium ionic liquids are prospective candidates for developing environmentally-benign antifouling strategies.



Summary of effects of imidazolium ionic liquids on barnacle larvae

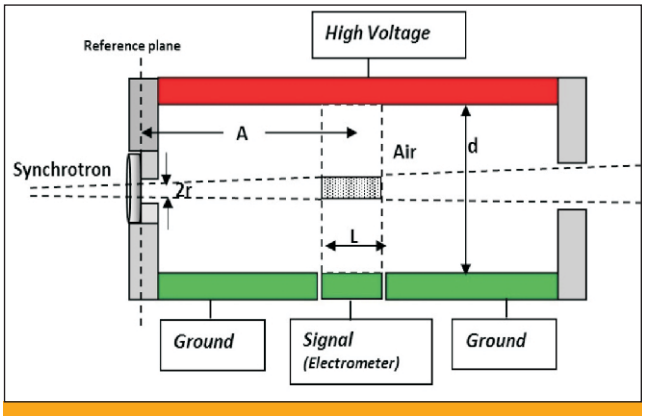
Electrochemistry of uranyl ion in presence of trivalent lanthanide ions in chloride medium was studied using modified electrode. This study shows that the uranium can be selectively separated from the mixture as UO_2. A method was developed for the simultaneous determination of Pu and U in carbide and oxide fuels using voltammetry employing PEDOT:PSS modified Glassy carbon electrode without adding any additives. The electrochemistry of Pu(IV) in task specific ionic liquid was studied. The plutonium can be quantitatively deposited from the solution by electrochemical method

Visual detection kit was developed for visual detection of ultra-trace amounts of uranium in water using 3-mercaptopropylamidoxime capped Au nanoparticles, which enables onsite examination of water without any instruments. System shows red colour when the uranium concentration is below the permissible level of 30 ppb while the colour turns blue when the concentration is around the permissible level and deep blue when it exceeds the permissible level.



Development of Visual Detection Kit

A Free Air Ion Chamber (FAIC) (suitable for dosimetry of synchrotron radiation from Indus-2 is designed and fabricated (see figure below). The chamber is designed for absolute measurement of air kerma from synchrotron radiation in the range 5-50 keV. Characterization of the same has been carried out with white beam from beamline-4 of Indus-2. With the 8 mm slit, the chamber was found to saturate at 7 kV whereas it saturated at 2 kV with 1 mm slit. The air kerma rate extrapolated for 200 mA stored current @2.5 GeV from the measured value at 8 mA stored current with 1 mm slit was found to be as high as 10^6 Gy/h.

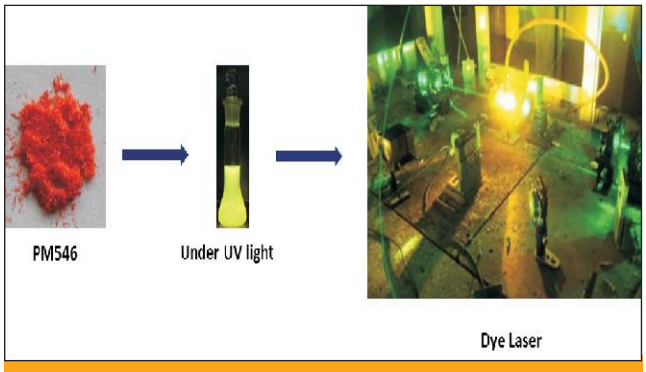


Schematic Diagram of the FAIC

Linear Energy Transfer (LET) spectrometry is implemented for measuring neutron dose (for radiation protection) using CR–39 detector, when the information about the radiation source term is unknown. Neutron dose was measured for ^{181}Ta + p reaction at proton energies ranging from 8 to 20 MeV. Track density in CR–39 increasing exponentially with proton energy has been empirically established. The dosimetric quantities viz. absorbed dose D_{LET} and dose equivalent H_{LET} determined from LET spectra were found to increase with the proton energy. The dosimetric data from this study would enable radiation protection of occupational workers working in the accelerator radiation environment.

Melting point for fuel salt mixture LiF-NaF-MgF_2-ThF_4-UF_4 in presence of MgF_2 was determined. The density and viscosity of molten $F_{1.675}$ $Li_{0.775}Th_{0.1995}U_{0.0255}$ salts were measured in the temperature range 840-950 K. The thermal expansion of this melt was derived from measured density. The standard molar Gibbs energy of formation of Na_2ThF_6(s) has been determined and phase diagram for NaF and ThF_4 is drawn. The electrochemistry of UF_4 and ThF_4 under molten salt condition is evaluated.

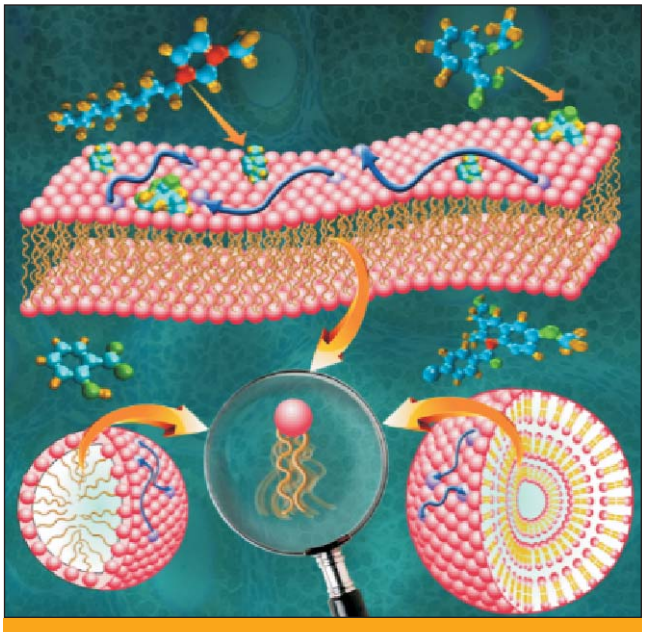
Laser dyes PM567 and PM597 required for the AVLIS programme were indigenously synthesised at BARC. The method was optimized for producing the new dye PM546 in gram scale. Purified laser grade dye PM546 obtained is comparable to imported dyes but at a much lesser cost.



Synthesis of BODIPY Laser Dye as an Import Substitute

The functional properties (such as wetting and emulsification) of self-assembled surfactant systems are dictated by dynamic behaviour of the surfactants at the molecular level. The dynamic landscape in various self-assembled surfactant aggregates such as

micelles, vesicles, bilayers, was investigated using neutron scattering and molecular dynamics simulations. The study showed that the dynamics of surfactants in the self-assembled aggregates depend on various factors, including the molecular architecture of the surfactant and temperature. Increase in the chain length and the presence of an additional phenyl ring near the polar headgroup restricts both the long-range lateral and localized segmental motions of the surfactant in the ionic micelles. The incorporation of an electrolyte affects not only the structure but also the microscopic dynamics of the ionic micelles. In the fluid phase of the lipid bilayer, the lateral diffusion coefficient of the lipid is an order of magnitude higher than in the gel phase. This observation has far-reaching implications in the sense that while living cells are found to be in the fluid phase, higher lateral diffusion helps them to maintain their fluidity.



Dynamics (lateral motion on the surface of bilayer, and segmental motion in a lipid molecule of self-assembled surfactant aggregates (micelles, vesicles, bilayers)

At TIFR, the researchers have developed an improved computational description to provide a complete analysis of UV-vis photoexcitations in the new band for Lysine-Glutamate dimers. In order to evaluate the role of the Golgi apparatus as a manganese-ion storage compartment under sub-cytotoxic manganese levels, researchers used a combination of confocal microscopy using a sensitive “turn-on” fluorescent manganese sensor, M1 developed in the group, and nanosynchrotron X-ray fluorescence imaging to show that manganese ions are stored in the Golgi apparatus under micro-molar manganese exposure concentrations. Carbene being highly electron deficient species plays a significant role in various organic transformations. Hydrogen bonding interaction of various solvents with carbenes is predicted to be a key intermediate in determining the reaction mechanism, transition states, etc. A variety of carbene precursors were successfully synthesized and seeded in the supersonic jet to form a cold molecular beam. The cold molecules in the beam were probed by laser induced fluorescence, resonance enhanced multiphoton ionization coupled with time of flight mass spectrometry, fluorescence depletion IR spectroscopy to identify the contents of the beam and the complex formation with water and alcohols. In another study, electronic and infrared spectroscopies were applied to the benzene-$(H_2S)_n$ clusters under the molecular beam condition. The isomer-selective infrared spectra demonstrated that at least two isomers of n = 1 coexist under the present beam condition, and both of them have the SH-ð bound structures.

At SINP, the scientists have come up with a new mechanism of ozone depletion by taking into consideration of degradation of sulphuric acid. They’ve also shown that geoengineering mission with sulphur compounds and volcanic eruptions are all connected with ozone depletion. The paper appeared in Communications Chemistry and highlighted in the OzoNews by the United Nation Environment Program.

BIOLOGY

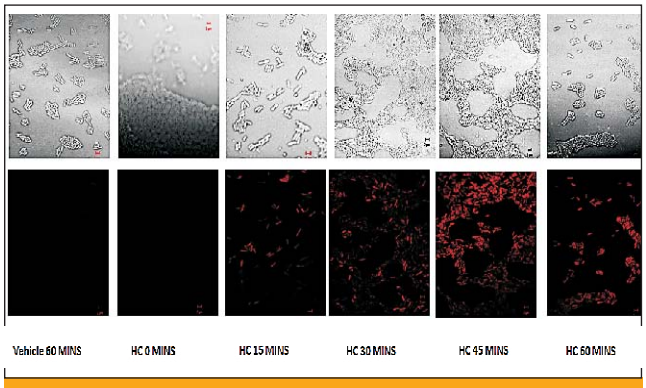
Boron Neutron Capture Therapy (BNCT) is an efficient technique to treat radiation resistant melanoma cancer cells. Gemcetabine (2,2-difluoro-2-deoxycytidine) is a known anti-cancer drug which has been successfully used for different types of cancer. It is a novel deoxycytidineanalog and pyrimidine antimetabolite. To prevent its deamination by cytidinedeaminase, gemcitabine was converted to its sulphonamide derivative using dansyl chloride. The resulting derivative is a fluorescent material which can act both as protecting agent against deamination as well as a bio-imaging agent. Fluorescent labelled gemcetabine hydrochloride was further made into sugar borate ester enriched with B-10 isotope to 90%, which can now be used for the treatment of melanoma.

Chiral organosilanes are attractive targets owing to their growing applications in medicinal chemistry as sila-analogues of various drugs, amino acids and peptides or improvement of the pharmacological properties of bio-active compounds. Cinchona-alkaloid derived bifunctional thiourea derivatives catalysed conjugate addition reaction of nitroalkanes to â-silylmethylenemalonates providing direct access to densely functionalized organosilanes in good yields (up to 88%), excellent diastereoselectivities (up to 97:3) and good enantioselectivities (up to 90%). Using pseudoenantiomeric catalyst, both the enantiomers of nitromethane conjugate addition products were easily accessible. The synthetic potential of these organosilanes was demonstrated by employing one of the conjugate addition products in the formal asymmetric synthesis of nontropic drug (R)-oxiracetam, ã-Amino-Butyric Acid (GABA) agonist GABOB and total synthesis of sila-analogue of the PAR-2 agonist AC-264613.

A third lot (3 mg) of NOTA-bisphosphonic acid conjugate has been prepared and delivered to RPhD for clinical studies. Initial studies show that very small metastatic lesions can be picked up by the ^{68}Ga-trace, which is otherwise not possible in conventional 99mTc-MDP scan.

Copper tetraMIBItetrafluroborate [Cu(MIBI)$_4$].BF$_4$ is a precursor of [^{99}mTc(MIBI)$_6$]$^+$, a radiopharmaceutical for myocardial perfusion imaging, being supplied by BRIT (Kit code TCK-50) to hospitals across India for more than 15000 patients annually. Synthesis of [Cu(MIBI)$_4$].BF$_4$ involves two complexation steps leading to the formation of Cu-chelate ligand. So far, synthesis of the complex was to the tune of few milligrams per batch, due to high volatility and poor isolation yield. After a prolonged research, BARC has scaled it up to 4 g/batch. This is an important import substitute and was handed over to BRIT.

We identified the amplification of reactive oxygen species (ROS) due to damage to Fe-S proteins and DNA as key events in the antibacterial activity of HC. Further, it was shown that membrane damage ensues within few minutes of HC treatment. Recently, it was shown that the HC treated bacteria undergo rapid lysis compared to untreated bacteria. Competitive assay with Mg^{2+} and EDTA proved the role of membrane damage induced by HC in bacterial cell death. Since outer membrane of bacteria was compromised by HC, we envisaged it would facilitate the entry of larger antibiotics into the bacterial cells. This hypothesis was proved by revealing the enhanced sensitivity of HC treated bacteria towards rifampicin, novobiocin, erythromycin, vancomycin and kanamycin. Our mechanistic study of antibacterial action of HC has revealed a potential use of it towards combating antibiotic resistant bacteria.



Detection of membrane compromise in bacterial cells (E. coli) by propidium iodide uptake after treatment with 500 µg/mL Hydroxychavicol.

The researchers at TIFR showed that the neurotransmitter serotonin enhances the production and functions of neuronal mitochondria, the powerhouse of the cell, and protect against stress. This study identified a previously unknown role for serotonin in regulating neuronal energetics. In another study, it was shown that insulin stimulation could induce lipid secretion from the liver cells by harnessing the molecular motor, kinesins-1, to the lipid droplets inside the cells. This work revealed fundamental mechanisms behind the maintenance of lipid homeostasis across metabolic states. A study found a class of hepatic fed microRNAs that target fasting-induced genes and are essential for a refed transition. These findings highlight the role of these fed microRNAs in orchestrating system-level control over liver physiology and whole-body energetics. Using the segmented embryonic epidermis whose flanks fuse during Drosophila dorsal closure, researchers demonstrated that epidermal flanks modulate cell numbers and geometry of their fusing fronts to achieve fusion fidelity. The work uncovers genetically constrained and mechanically triggered adaptive mechanisms contributing to fusion fidelity and epithelial continuity

At TIFR's National Centre for Biological Sciences, Bengaluru, researchers reported that successful inverted landing in flies involves a serial sequence of well-coordinated behavioral modules, consisting of an initial upward acceleration followed by rapid body rotation and leg extension, before terminating with a leg-assisted body swing pivoted around legs firmly attached to the ceiling. Statistical analyses suggest that rotational maneuvers are triggered when flies' relative retinal expansion velocity reaches a threshold. Also, flies exhibit highly variable pitch and roll rates, which are strongly correlated to and likely mediated by multiple sensory cues. When flying with higher forward or lower upward velocities, flies decrease the pitch rate but increase the degree of leg-assisted swing, thereby leveraging the transfer of body linear momentum. Soil nitrogen mineralisation (Nmin) which is the conversion of organic into inorganic N, is important for productivity and nutrient cycling. In this collaborative study, across 30 grasslands worldwide, the findings indicated that realised Nmin is largely explained by temperature of the wettest quarter, microbial biomass, clay content and bulk density. In another study, researchers suggested simple physico-chemical principles that determine how isogenic cells spontaneously self-organize into structured assemblies in complimentary, specialized states.

At SINP, newer initiatives have been taken up in the activities of the Biophysical Sciences group in the areas of synthetic biology, membrane proteins, epigenetic implications in cancer and trafficking of proteins inside cell. The epigenetic regulation was shown to regulate breast cancer metastasis in a recent publication in Nature Communications. Another publication in the journal Traffic highlighted a lesser known effect of cytosolic aggregates on non-translocated precursor proteins – how their presence and persistence affects endomembrane damage, hallmarks of neurodegenerative diseases. Ongoing work in Alzheimer's disease, on metabolomics, biophysical and structural studies on membrane proteins such as Mg(II) ion channel and other proteins have been reported in reputed journals. Important work on single molecule spectroscopy in DNA strand break and damage and catalytically efficient Au-Ag alloy a nanoparticle appeared in reputed journals. Initial work on the design of drug and nanocarriers in different types of cancer are in progress.

CANCER

The immune microenvironment of Soft Tissue Sarcomas (STS) is not completely understood and knowledge of the relationship between immune and tumour cells is essential for employing immunotherapy strategies. Studies carried out during this year revealed that murine fibrosarcoma induced T regulatory cells (Treg) through the generation of B regulatory cells (Breg), resulting in immunosuppression. Though these tumour evoked Bregs (tBregs), produced both IL-10 and TGFâ, inhibition of T cell responses was abrogated in vitro only by the small molecule inhibitor of TGFâ receptor type I, SB431542. Administration of SB431542 in Tumour Bearing Mice (TBM) significantly reduced Treg cells and rescued proliferation of T cells in response to mitogen and allo-antigen. In addition, this treatment also significantly reduced the tumour burden. These results show that immune suppression by tumour evoked Breg is through TGFâ mediated pathway and that targeting the Breg-Treg axis can be potentially used as an immunotherapy agent.

G1-4A, an arabinogalactan polysaccharide was isolated from the plant Tinospora cordifolia. G1-4A treatment increased phenotypic and functional activation of splenic and bone marrow Natural Killer (NK) cells. In addition to the direct effect on NK cells, they were also activated by dendritic cells matured in presence of G1-4A. Both phenotypic and functional activation of NK cells was observed through NK-DC crosstalk. G1-4A treatment activates NK cells directly as well as through NK-DC crosstalk and can be used as an immunomodulator in tumour bearing mice.

SYNCHROTRON & THEIR UTILISATION

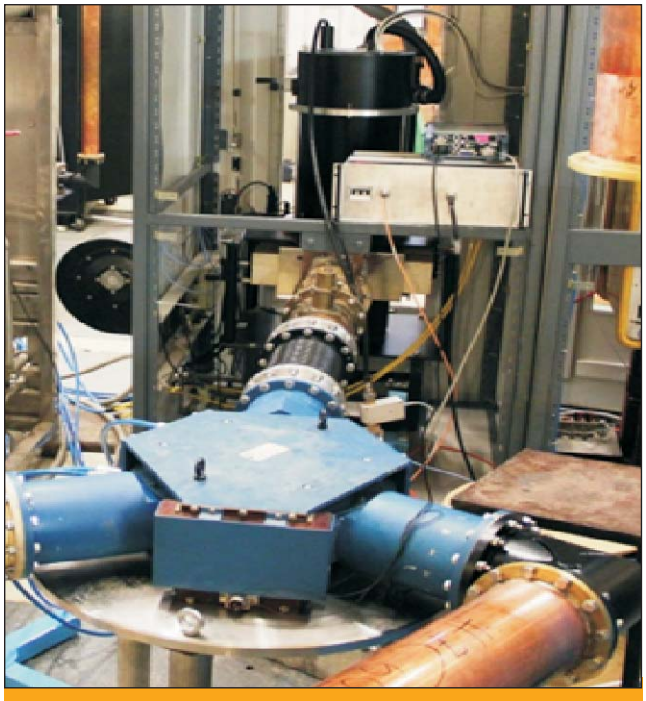
At RRCAT, both the synchrotron radiation sources, Indus-1 and Indus-2 were operated as national facility. Indus-1 operated at 450 MeV energy, 125 mA current, and Indus-2 operated at 2.5 GeV beam energy and stored current up to 200 mA. From April 2019 to December, 2019, Indus-1 and Indus-2 were operated round-the-clock reliably for 242 days. Indus-1 was operated at the designed parameters with the beam availability of 5267 hours from April, 2019 up to 15th December, 2019 for the users. Similarly, in

Indus-2, the beam availability was for 4171 hours from April, 2019 up to 15th December, 2019 to the x-ray synchrotron radiation users. With this performance, the projected beam availability from April, 2019 to March, 2020 shall be 7000 hours for Indus-1 and 5550 hours for Indus-2. The beam lifetime in Indus-2 measured at 100 mA beam current at 2.5 GeV, improved significantly to more than 80 hours due to improvement in ring vacuum. The number of users at various Indus beamlines have increased greatly over the years which depicts the growing utilization of this national facility in the users' community. The number of user experiments at Indus-1 and Indus-2 beamlines from April 2019 to December 2019 is in excess of 670. By March 2020 this number is expected to cross 880.

From 16th December machine is under planned shutdown till 5th Jan 2020 for the installation of vertical pinger magnet in one of the straight sections of Indus-2. This will help in carrying out advanced beam dynamics studies in the machine. Installation of Inductive Output Tube (IOT) based RF amplifier is also commissioned in Indus-2. With this, four out of the six RF cavities will be energized with solid state RF amplifiers, one will continue to be fed by klystron-based RF amplifier, and IOT-based amplifier will feed the remaining one. Indus facility is operated by trained and licensed personnel as per AERB guidelines. For operation of Indus facility, a new batch of twenty nine operation staff was trained and licensed. Since September 2019 the newly trained batch has been successfully operating the machines with all safety guidelines.

An IOT based RF power system was commissioned, as an alternative to klystron based RF power system for energizing Indus-2 RF accelerating cavity, to deliver 50 kW RF output at 505.8 MHz in CW mode with 1dB overrun of RF output level. It has a multistage amplifier configuration with each amplifier having 50 W output. The overall system consists of 50 kW IOT based Final Power Amplifier (FPA), 300 W solid-state driver-amplifier stage, and a 10W wide band pre-driver amplifier stage connected in cascade, providing overall power gain of 77 dB, efficiency more 60%, operational bandwidth of 2 MHz, along with harmonic and non-harmonic spurious output being less than -36 dBc and -50 dBc respectively. A negative HV supply, consisting of six numbers of parallel connected modules configured in master slave configuration, is installed and interfaced with IOT amplifier, and is commissioned to provide -36 kV of beam voltage between cathode and body of the IOT. High power RF output from IOT RF power system is fed to the Indus-2 RF cavity by means of 6-1/8" rigid coaxial line system consisting of high power Y-junction circulator, 50 dB directional coupler, 100 kW dummy load, straight sections, various bends, all connected as per the required layout and made for required RF performance.

IOT amplifier system in Indus-2



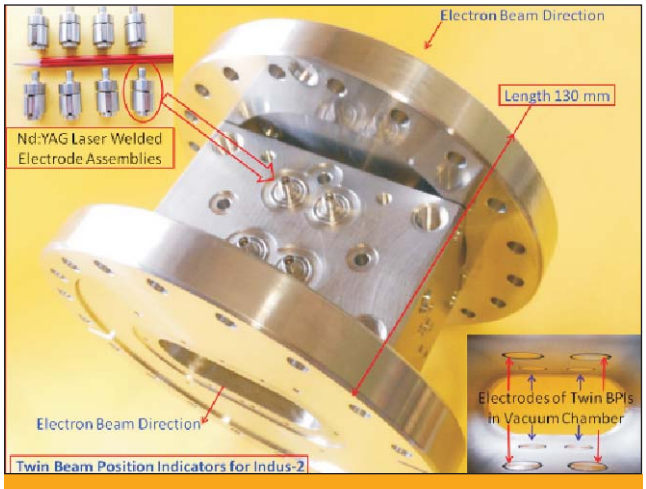
IOT with transmission system

Indus-2 is being equipped with a pinger kicker system to enhance the probing capabilities for the dynamics of electron beam. A pinger magnet system consists of two types of magnets namely horizontal and vertical pinger magnet. These pinger magnets energized by two separate power supplies will generate betatron oscillation in the stored beam of Indus-2. These magnets, along with BPMs, will act as a tool to probe the linear and non-linear dynamics of the beam. A power supply to energise vertical pinger magnet has been designed and developed. This power supply delivers a 1 μs half sinusoidal pulsed current of 5700 A of peak at a pulse repetition of 1pulse per second. The vertical pinger magnet was energised with this power supply to study the magnetic field profile.

In-house developed vertical pinger magnet power supply

Two new power converters (170 A / 120 V, ± 50 ppm output current stability) for LS2Q1D and LS1Q2F quadruple magnets in Indus-2 ring have been developed, tested, installed and commissioned in Indus-2 for replacing the 15 year old power converters. The main features of the new design are: high efficiency, smaller size, less cooling requirement, low audible noise, small size of filters, better maintainability and less development time due to standardized and modular design. Deployment of this power converter at site would help in increasing the uptime of Indus machine.

Design and development of ultra-high vacuum compatible twin Beam Position Indicators (BPIs) have been done for in situ characterization of in-house developed electronic processing units of BPIs for Indus-2. The electrode assemblies are mounted in two transverse planes, each having four electrode assemblies. Presently, for testing of electronics we use one of the BPIs of Indus-2, which makes it unavailable for Indus-2 orbit measurement system during the period of testing. Further, the position read by the electronics under test has to be correlated with the electron beam position read by the nearby BPI which is typically at a distance of ~2.2 m from the BPI under test. The Twin BPIs will provide a dedicated BPI device for testing of processing electronics. One BPI can be connected to the processing electronics under test and the second one to an already characterized processing electronics. Furthermore, since the two BPIs in this assembly are very close (35 mm) to each other, it provides a better way of correlating the beam position measured by the electronics under test. Twin BPIs has been installed in Indus-2 ring during Dec-2019 shutdown.



Ultra-high vacuum compatible twin beam position indicators for Indus-2

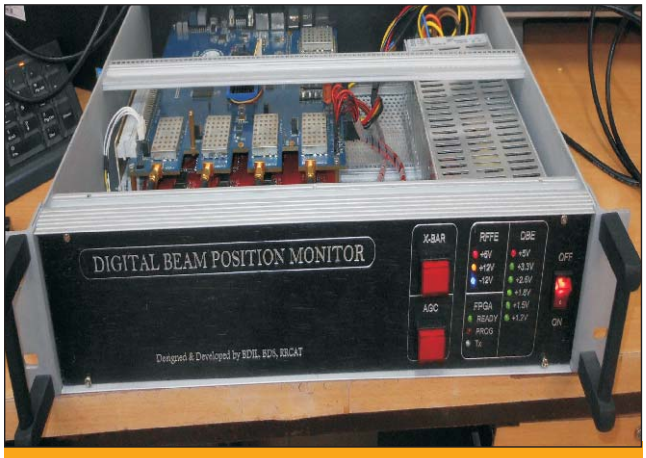
A new Precision Cooling Station (PCS) has been installed and commissioned in a newly constructed building adjacent to the Indus-2 building near the RF area to cater to the cooling requirement of the fifth and sixth RF cavities installed in the Indus-2 ring. The PCS units have the provision for setting the RF cavity supply water temperature in the range of 25 °C to 79 °C with

temperature stability of ± 0.1°C, and for extracting up to 60 kW thermal load from the connected RF cavity. The complete system has been integrated with Indus-2 and put into operation in round-the-clock mode.

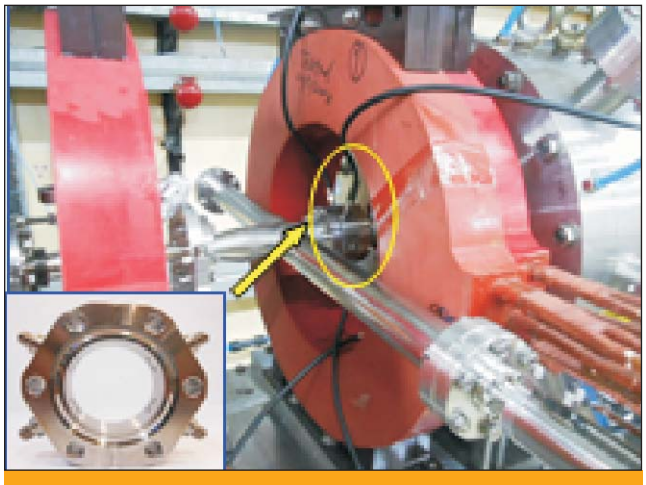
Precision cooling systems installed at newly developed area

New centralized secondary water pump unit with pipeline and manifold system

A processing electronics for digital beam position monitor has been indigenously developed and deployed in the low energy transport section of the Infra-red Free Electron Laser (IRFEL) to monitor the electron beam position. It has capability to measure the position of beam having pulsed time structure i.e. macro-pulses of few ms duration and repeating at a certain rate, such as in linear accelerators; hence it is termed as “single pass”. It consists of two parts namely 4-channel RF front-end designed to operate at 505.75 MHz with band width of 10 MHz and a Spartan-6 FPGA based digital back-end. Testing of the processing electronics was carried out in laboratory using in-house developed calibration set-up. The RMS position resolution is 25 mm at input RF signal power level of -74 dBm. The Beam Position Monitor (BPM) device used for the measurement is also indigenously developed.



Single pass digital beam position monitor unit



Beam position monitor installed in IRFEL set-up

Booster synchrotron is the common injector for Indus-1 and Indus-2 synchrotron radiation sources. 20 MeV electron beam from the microtron is injected into booster synchrotron through the Transport Line-1 (TL-1). The beam energy of the injected beam is ramped to 450/550 MeV within 250 - 350 ms for beam injection in Indus-1/Indus-2, at a repetition rate of 1 Hz. Earlier, the operator had to manually optimize settings of more than ten parameters in order to achieve a good accelerated electron beam current in the booster synchrotron. A real coded genetic algorithm (RCGA) based system has been developed and implemented for the automatic optimization of microtron and Transport Line-1 (TL-1) parameters to achieve an average accelerated beam current ≥5 mA in the

booster synchrotron. The RCGA based system enhances the beam current in the booster synchrotron by optimizing the parameters of the injected beam with a view to improving the beam transmission efficiency of TL-1. A data communication module has been developed on MATLAB server, a control system entity, for setting and readback of the parameters. A user support system has been developed for the deployment of this system in the Indus control room.

Electron beam energy ramping from 550 MeV to 2.5 GeV in Indus-2 involves synchronous ramping of magnetic fields of all magnets and RF cavity voltages. The overall energy ramping process involved a distributed and multilayer control system. A system for software-based analysis and verification of the correctness of ramping of all 117 Magnet Power Supplies (MPS) participating in electron beam energy ramping of Indus-2 has been developed using WinCCOA SCADA (Supervisory Control and Data Acquisition) and Matlab modules. The current read-back of each MPS during nearly twelve-minute ramping process is recorded and analyzed to verify that all MPS have participated and followed the standard or desired current ramp profile without any tracking error. The software was designed and developed, consisting of various interconnecting modules having specific function. The software application has been deployed for regular operation and has resulted in quick identification of any abnormality in the complex ramping process. The verification analysis history is also maintained in a database and can be accessed from web application.

The Indus-2 Timing Control System (TCS) provides accurate synchronisation trigger pulses to various pulsed power supplies which energise the fast magnets to extract electron beam from booster synchrotron and inject the same into Indus-2 Synchrotron Radiation Source (SRS). It also controls and monitors different parameters of the Pulsed Power Supplies (PPS) for energising the kicker and septum magnets. Existing Indus-2 Timing control System (TCS) has been enhanced to accommodate the new requirement for operating two more pulsed magnets, namely pinger magnets in Indus-2 for studying beam dynamics of stored beam in Indus-2. A new FPGA based multi-channel delay generator board has been developed to generate remotely adjustable timing delays through trigger signals with 0.5 ns timing resolution and sub nanosecond (<1 ns) timing jitter. The software at various layers has been updated to incorporate the new channels and functionalities. Integrated testing of the enhanced system is done successfully and has been deployed in Indus-2.

FPGA based delay generator board

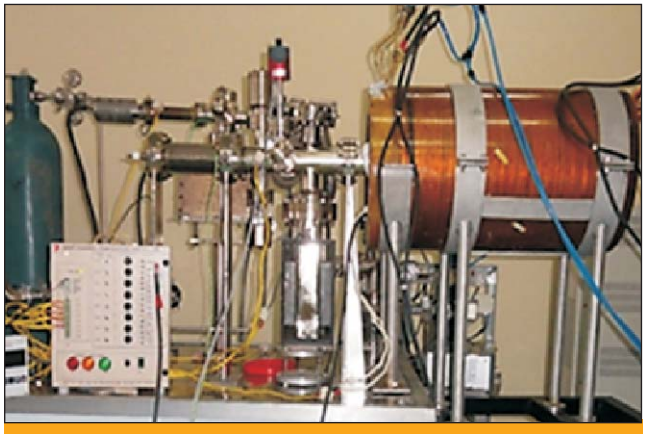
Magnet ready for magnetic measurement

A pair of dipole magnets for bending the electron beam in linac-3 by 270^{o} achromatically was designed, developed and characterized. The magnet is part of the energy filtering system necessary for Agricultural Radiation Processing Facility (ARPF). It consists of two dipole magnets which bend the beam in two stages by 195^{o} and 75^{o}, thus making the total bend of 270^{o}. The mean electron energy is 9.5 MeV, and the objective of using this energy filtering system is to eliminate the electrons having 10 MeV or higher energy. Structural simulations using FEM software were done for computing the forces on the coils and

the forces between the poles. Magnets were characterized and handed over for use in linac-3.

Operation of any synchrotron radiation storage ring with low momentum compaction optics is carried out to obtain short electron bunches. These short electron bunches provide two additional tools for synchrotron radiation beamline scientists. Firstly, one has the incoherent short synchrotron radiation pulses up to the x-ray regime to perform the time resolved experiments, and secondly, there is generation of coherent synchrotron radiation in THz regime. Trial operation of Indus-2 was performed to demonstrate the short electron bunches in the storage ring. For this, a modified optics was applied in Indus-2 by reversing the polarities of two quadrupole and two sextupole families of magnets in the achromat section of the storage ring. Beam accumulation was successfully carried out at injection beam energy of 550 MeV. For increasing the beam energy, power supply currents of Indus-2 dipole, quadrupole and sextupole magnets were increased synchronously and RF voltages are set appropriately for energy gain and replenishing the energy loss due to synchrotron radiation. Initially, there was substantial beam loss at the beginning of energy ramping. After 2-3 iterations of tune corrections, beam loss was minimized. At final beam energy 2.5 GeV, transition from larger bunch length (high momentum compaction) to smaller bunch length (low momentum compaction) was performed by changing the strength of Q5D family of quadrupoles. During this transition, the changes occurring in betatron tunes were carefully monitored and controlled using the quadrupoles in Q2F and Q3D families. The measurement of synchrotron frequency during this demonstration of electron bunch length lowering confirms that the momentum compaction factor of Indus-2 ring was reduced by a factor of 25. As a result, the natural bunch length of the electron beam is expected to be reduced by a factor of 5 (i.e. from 50 ps to 10 ps). The measurement of bunch length is yet to be confirmed as the present bunch length measurement set-up needs to be upgraded to directly measure the electron bunch length in low momentum compaction operation mode.

Process of Ti thin film coating on alumina ceramic substrate was developed in-house using DC magnetron sputtering technique. This coating of Ti is required on the inside surface of alumina ceramic vacuum chamber of fast pulsed magnets of Indus. This process technology is required for future low emittance storage rings for passage of image current. This development has established import substitute and self-reliance for this critical item. This process will be used for Ti coating of alumina ceramic chamber of upcoming pinger magnets in Indus-2. The coating has been characterized for vertical pinger magnet chamber.



Coating setup

Digital control card

A power converter rated for 300 A, 90 V output with output current stability better than ±10 ppm has been developed as a part of a project: Technology Development for Low Emittance Storage Ring. The power part of magnet power converter rated for 300 A, 90 V output has been designed by RRCAT and developed with industry support (M/s ECIL, Hyderabad). The necessary customized electronic cards and control rack were also developed and provided to ECIL for integration. The equipment and the set-up to carry out high-stability measurements were established, and precision current sensors were

procured. With this development, it is thus demonstrated that the power converters for electromagnets, a highly specialized system which is not readily available in the Indian market, can be developed with the participation of industry within the country. Industry participation and capability building essentially is the backbone of future mega science projects.

A high voltage DC power supply of -30 kV /300 μA with a short term stability better than ± 10 ppm and ripple better than 10 ppm, and a current controlled filament power supply (8 V/4 A) have been designed and developed. This power supply is required for the Scanning Electron Microscope (SEM) being developed at BARC for high resolution imaging. The power supply will be integrated with the developed SEM at BARC by March 2020.

A view of in-house developed HV power supply unit for SEM

Based on the design and prototype developed at RRCAT, all 73 power converters have been manufactured at ECIL, Hyderabad and delivered to FAIR, Germany in Sept 2019. This also happens to be India's first in-kind contribution to the FAIR project. These power converters are rated for 300 A maximum output current, and operate in two and four-quadrant modes. Similarly, 48 more four-quadrant power converters of 100 A output current rating are in the advanced stage of production and testing at ECIL. These units are also based on the design and pre-prototype development carried out at RRCAT.

The series production batch of power converters delivered to FAIR

Indus -1 and Indus-2 are national facilities with 14 beamlines in Indus-2 and 6 beamlines in Indus-1, which are available to users. Users from different universities, national labs and institutes are regularly engaging these Indus beamlines for experiments. About 900 user experiments were carried out in the calendar year 2019 leading to more than 170 research publications in peer reviewed international journals. Along with the above utilisation, there has been a continuous effort in improving the facilities at the beamlines and other related aspects. These beamlines have been used for several work related to materials science, chemistry, health and medicines. A set of experiments have also been performed by scientists from ministry of AYUSH, Govt. of India on a few ayurvedic medicines. There has been in increase in the number of users from industries, who have used the x-ray diffraction. X-ray absorption and small angle x-ray scattering beamlines for their product and process development.

The engineering applications beamline BL-02 has been commissioned in Indus-2. This beamline operates in the energy range of 5 keV to 25 keV. The beamline is designed to operate both in the energy dispersive and the angle dispersive modes for carrying out diffraction based measurements of stress in worked samples, welded joints, industrial components etc. For the angle dispersive measurements, the beamline has a goniometer that has capacity for mounting samples upto a length of 500 mm and weight of 10 kgs. The beamline is in regular use and has been recently used for the determination of strain at the SS-Zircaloy cold welded joints in samples from Reactor Engg. Divn, BARC and several other samples from Materials Group, BARC.

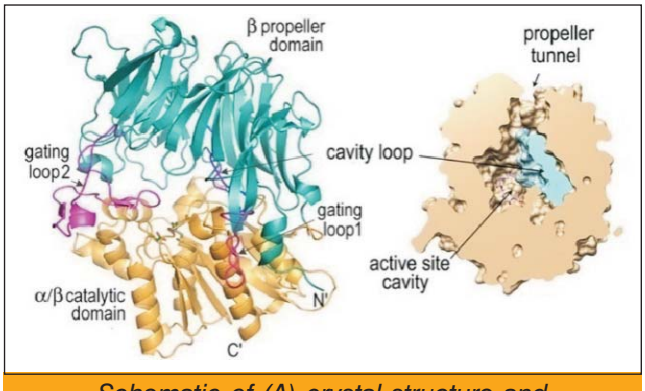
Cr/Ti multilayers designed with bi-layer spacing of 4.0 nm and Cr to bi-layer thickness ratio of 0.40, were fabricated in a Dual Ion Beam Sputtering system.

Multilayers were deposited and studied with and without C barrier layer. Cr-on-Ti interfaces are significantly sharper on introducing a 0.3 nm C barrier. Reflectivity is significantly enhanced in multilayers (with 75 bilayers) prepared with C-barrier. The measurements have been carried out at BL-03 soft X-ray beamline at Indus-2 Synchrotron Radiation Source (SRS), RRCAT.

An easy to assemble and re-usable electrochemical battery cell was developed at the BL-9 beamline at Indus-2 for in-situ XAFS measurements. The galvanostatic charge/discharge cycles were performed at current density corresponding to C/3 within the cell voltage range of 3.0–4.5 V. The measurement has revealed that manganese in $LiMn_2O_4$ exhibits two distinct valencies, Mn^{+3} and Mn^{+4} with two kinds of MnO_6 octahedra. The large-scale rearrangement of the local structure, during charging-discharging process, is identified to cause severe capacity-fading of $LiMn_2O_4$ with cycling.

Photo-physics beamline at Indus-1 SRS was upgraded for carrying out gas phase (UV and VUV) spectroscopy on molecules with applications in diverse areas such as Astrophysics, Astrochemistry, plasma physics, environmental science, catalysis, etc.

Protein crystallography beamline BL-21 at Indus-2 was used by various research groups in India, resulting in more than 100 structural entries into Protein Data Bank (PDB). In a significant result, BARC determined crystal structures of prolyl oligopeptidase peptidase from Deinococcusradiodurans, which revealed novel enzymatic activity and substrate screening mechanism (PDB entries: 5YZM, 5YZN, 5YZO; JBC, 294(1), 2019). This study has implications in designing new therapeutics in diabetes and neurological diseases.

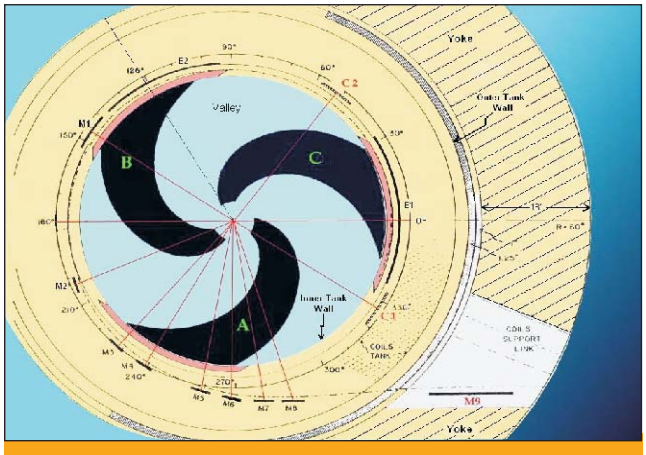


Schematic of (A) crystal structure and (B) its slice through of the enzyme

CYCLOTRONS & THEIR UTILISATION

Successful Beam Extraction from K500 Superconducting Cyclotron

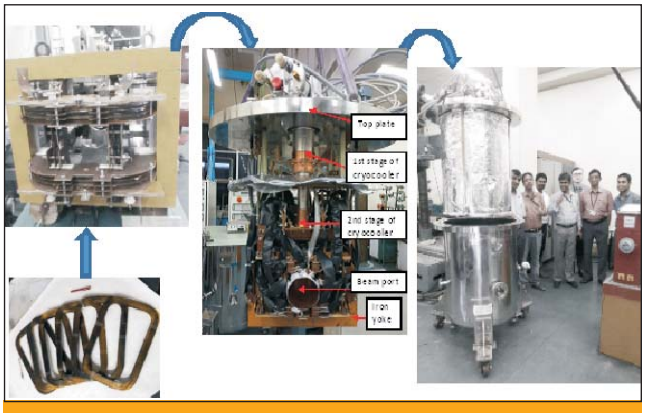
Beam extraction from K500 Superconducting Cyclotron could not be done earlier due to unacceptably large first harmonic imperfection in the magnetic field (50 G). In order to keep the first harmonic field at the extraction region below the tolerance limit of ~10 Gauss, the coil and coil-tank were required to be repositioned with an accuracy of 200 μm with respect to three-fold symmetric magnetic field. A new mechanism was used for precise radial positioning of the cryostat. Three radial screws were used to move the cryostat with respect to the central plug. Dial gauges at the outer radius of the cryostat were used to estimate the movement of the cryostat. Final measurement of the cryostat position was taken with portable CMM machine. Extensive field mapping at different excitations of main coils and at the extraction zone beyond 26 inches was carried out with search-coil-NMR system. The gross reduction of first harmonic at extraction radius is obtained following shifting of cryostat as a whole. Further, regular measurement was carried out over the operating zone of the machine. In the last week of November 2019, N2+ beam has been extracted through the deflectors up to the magnetic channel #3 and then in the 1st week of December 2019, about 100 pA beam has been extracted out of the machine and measured on the Faraday cup (FC#01) in the external beam line. Now around 2 nA beam is available on FC-01. Further optimization is in progress.



Extraction System Layout

Indigenously developed HTS steering magnet for K500 cyclotron beam line

A High Temperature Superconductor (HTS) based cryocooler assisted steering magnet operating at 20 K temperature has been developed at Variable Energy Cyclotron Centre (VECC) for the extraction beam line of K500 cyclotron. The magnet is specified for beam steering of ± 3 degree in horizontal plane and ± 1.5 degree of vertical in vertical plane for maximum rigidity of 3.3 T-m. The magnet is composed of two sets of double pancake racetrack coil, one set for vertical field (By) and other for horizontal field (Bx) inside the return iron yoke. Both sets of double pancake coils are fabricated in-house with commercially available HTS tapes (BSCCO-2223) by wet winding technique using cryogenic grade epoxy. The coil assembly along with stainless steel vacuum vessel has been integrated with cryo-coolers and instrumentation. The technical know-how will be useful for developing high field liquid helium-free magnet system for accelerators as well as other varieties of applications.



Indigenously developed HTS steering magnet for K500 cyclotron beam line

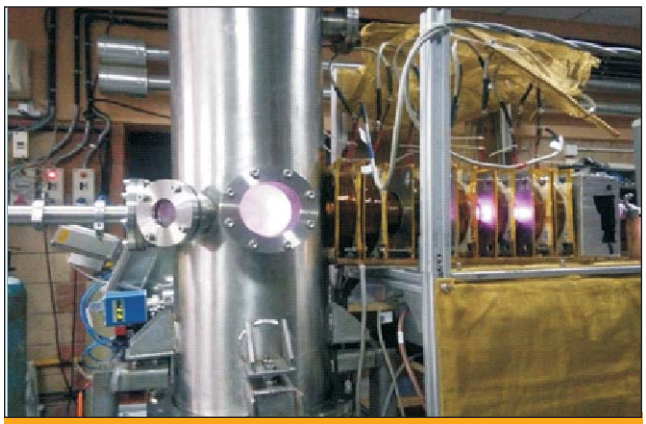
Room Temperature Cyclotron (RTC) Utilisation

The room temperature cyclotron (RTC) has been operating in round the clock shift basis and delivering ion beams to various experimental research programs. The internal penning ion gauge ion source (PIGIS) is presently being used for producing light ions. Alpha with energy range 26-55 MeV and Proton with energy range 7-15 MeV ion beams have been developed in cyclotron and delivered for experiments. Alpha and proton beams of energy ranges mentioned above are regularly being used to produce radio-isotopes, irradiation, radiation damage studies and nuclear physics experiments etc. The facility has been utilised by the experimentalists of VECC, SINP, Materials Division/BARC, ACD/BARC/VECC, RPD/BARC, RCD/BARC, HPU/BARC/VECC etc. The cyclotron is regularly fulfilling its target for beam availability and this year also the beam availability has been 3140 hours till December 15, 2019.

PLASMA & FUSION TECHNOLOGIES

Helicon Plasma Thruster

A prototype Helicon plasma thruster system has been designed, fabricated and operated at IPR. An RF plasma source drives the Argon gas based thruster. A thrust of 10 mN has been achieved with 1500 W rf power operation, using electromagnets as well as permanent magnets.

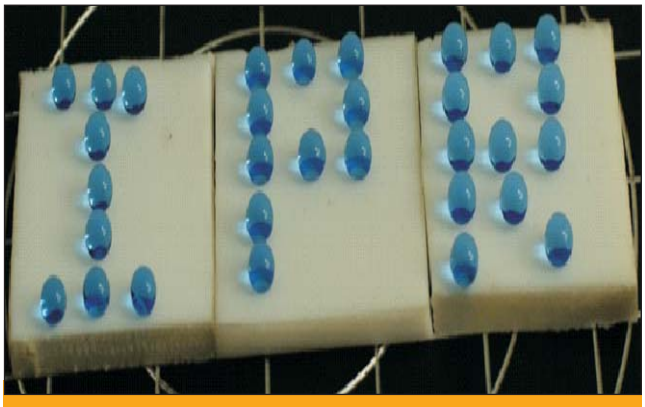


Helicon Plasma Thruster

Water Repellent Super-hydrophobic Polytetrafluoroethylene (PTFE) Surface Produced by Low Energy Ion Beam Irradiation

Super hydrophobic surfaces are of great interest due to their superior water-repellent applications, such as self-cleaning, anti-scratch, anti-icing, anti-corrosion and fog harvesting. Super hydrophobicity is achieved by having a large contact angle (è > 150°) with low surface energy. Surface properties are modified either by surface structuring or by changing surface chemistry. Teflon and Teflon-like coatings have several

applications in automobiles, non-stick cookware, and medical applications due to high heat resistance, excellent electrical insulation and biocompatibility. As PTFE is hydrophobic in nature, many investigations have been carried out to alter its wettability by modifying the surface structures. In our recently published study in Nature Scientific Report, we have found remarkable changes in wettability (increase in hydrophobicity) of PTFE after just a few seconds of Ar+ ion beam irradiation at energies as low as 300 eV. We have also found that PTFE surface become super-hydrophobic under lower energy (300 eV-800 eV) Ar+ ion beam irradiation. Also, with the help of oblique incidence irradiation, the surface can become super-hydrophobic at much lower fluencies and energies without any additional gas and high energy ion beams. From a technological view point, this technique would be helpful for developing super-hydrophobic bulk PTFE sheets in with small duration irradiation; also, parts of the surface can be make super-hydrophobic by using masking or ion beam writing.



Water Repellent Super-hydrophobic Polytetrafluoroethylene (PTFE) Surface

In-vitro and In-vivo studies using Plasma Jet for oral cancer cells

IPR is collaborating with ACTREC to study the interaction of plasma jet with oral cancer cells. Initially, the plasma jet parameters were optimized for in-vitro condition in terms of voltage and duration of treatments. In this study, plasma jet treatment was done on oral cancer, breast cancer and HEK293 cell lines using biological assays. On the basis of the in-vitro findings, preliminary in-vivo studies were initiated on tumours generated in Hamster Buccal Pouch (HBP) model. Further studies to understand the mechanism of interaction are in progress.

Development of multilayer (TiN, TiAlN) coating on zirconium alloy tube

Zirconium based alloy tubes which are used in nuclear power reactors undergo waterside corrosion by the coolant water under normal operating condition. Also, in the case of loss of coolant situation, the temperature may increase which can lead to acceleration of corrosion reactions and corresponding hydrogen generation. Multilayer coatings of TiN and TiAlN have been widely studied to mitigate this problem because they have better corrosion resistance at higher temperatures. To explore the possibility for development of such coatings discussions meetings have been held and decided to do such coatings by using cylindrical magnetron sputtering. Accordingly, the existing cylindrical magnetron sputtering system was modified. The water cooled Titanium (Ti) and Aluminium (Al) cylindrical targets along with substrate rotation assembly were incorporated in the vacuum system. Preliminary experiments for the deposition of TiN and TiAlN as individual and multilayers were carried out. The process has been optimized for the deposition of TiN and TiAlN on the outer side of cylindrical Stainless Steel tube. Similar coatings on the zirconium alloy tube will be developed and the corrosion studies will be done in future.

Aditya-Upgrade Tokamak Operation

The Aditya – Upgrade tokamak is being operated with more than 600 discharges till December continuing with many experiments. A new experiment related to disruption mitigation is being done. The disruptions in big tokamaks can leave irreversible damages to the first wall and other plasma facing components inside the machine. Hence the mitigation of such disruptions are of great importance. In this regard, in Aditya-Upgrade tokamak, pellet injections using an electro-magnetic injector are being experimented for the first time. These injected particles are expected to take away the energy from the hot disrupting plasma and radiate them heavily. Hence the effect of the disrupting flux on the plasma facing components are reduced drastically and the irreversible damages are reduced. In Adtiya-Upgrade, Lithium Titanate and Lithium Carbonate particles were injected using the electromagnetic pellet injector. The injected particles of size 50 micron and velocity 200 m/sec reaching the core of the tokamak plasma in 1.5 ms causes fast disruption of plasma current. The density and temperature of disrupted plasma were observed

to decrease very rapidly due to increased plasma radiation after the injection, thus helping to achieve the expected result.

Aditya-Upgrade Tokamak Operation

Steady-State Superconducting (SST-1) Tokamak Operation

The SST-1 tokamak was operated for plasma pulse durations upto 650 milliseconds, 33% higher than the best ever achieved before. This became possible due to improvement of the initial magnetic field null inside the vacuum vessel, permitting higher gas fill pressures, in turn allowing plasma creation with a limited pulse of electron cyclotron heating at 42 GHz. The improved plasma density also permitted long-duration current drive using injected power at 3.7 GHz, which was not hitherto possible due to a low-quality plasma near the wave launcher. Also for the first time in SST-1, the three frequency ranges used for plasma heating (tens of MHz, few GHz, tens of GHz) were applied simultaneously. Furthermore, improved cryo-insulation has permitted production of liquid Helium from the cryo-plant in addition to coil cooling, which will now allow cooling of current leads. There were a record 15 days of plasma operation in the 25^{th} experimental campaign of the SST-1 tokamak, yielding 300 plasma shots. The campaign was focused on defining the useful operation space of ohmically-driven operation. Good reproducibility was achieved. Plasma pulse duration with only ohmic current drive was extended to 650 millisec, substantially higher than the 450 millisecond limit obtained in the 24th campaign.

Optimization of cryoplant operation for SST-1

Optimal utilisation of the SST-1 cryogenic plant has resulted in the following achievements (i) A flat-top toroidal field current lasting for ~20,000 seconds was demonstrated using vapor-cooled current leads. This allowed a more than two-week long "window" for plasma experiments in SST-1; (ii) Simultaneous cool down of the TF coils, PF coils and Case have been successfully demonstrated at temperatures of 15-16 K; (iii) For more than 24 hours, the PF-3 coil pair were kept at 7-8 deg-K temperature, simultaneously with keeping TF coils in the superconducting state.

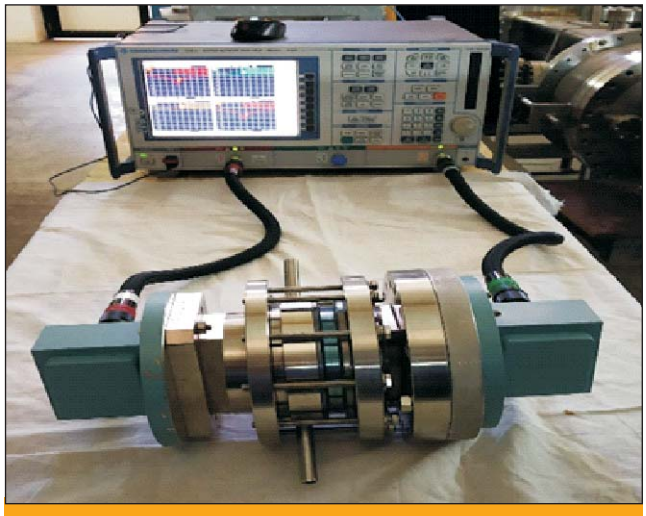
In-house development of neutron resisted insulation material for Superconducting magnets

An indigenous insulation material (GFRP) Glass Fiber Reinforced Plastics (GFRP, G-10, CR grade) composite based material applicable for future fusion superconducting machines used in the superconducting magnets coil, Electrical insulation breaks, structural material, laminate form for electrical isolation purpose. The material consists of S-glass and in house developed cryogenic epoxy resin system. Prepared samples have been experimentally validated in Fast Breeder Test Reactor, IGCAR, Kalpakkam. The insulation samples have achieved neutron fluence of 1.02×10^{21} n/m^2 and passed the acceptable radiation tolerance limit of GFRP insulation material of neutron fluence of 10^{20} to 10^{22} n/m^2. The insulation material undergone for mechanical and electrical performance test, namely, as tensile strength, shear strength and break down strength at ERDA (Electrical Research and Development Association, NABL Lab, Vadodara and the test results show no significant degradation is observed in properties.

Indigenous development of high-power vacuum window for GHz range

Nuclear fusion reactors require coupling of high levels of microwave power (few GHz, hundreds of kilowatts) into a plasma in an Ultra-High Vacuum (UHV) system. This requires a "window" that is compatible with an UHV environment on one side and 3 bar pressure on the other. Such windows have hitherto been imported. An RF Pill Box type vacuum window has been indigenously designed & developed to operate at 3.7 GHz for 125 kW for a duration of 1 second. The major challenge was to establish & optimize the vacuum brazing of metal (copper) to ceramic (alumina), including the brazing set-up, its fixtures, precision machining & brazing cycle. It also required vacuum brazing of three dissimilar materials

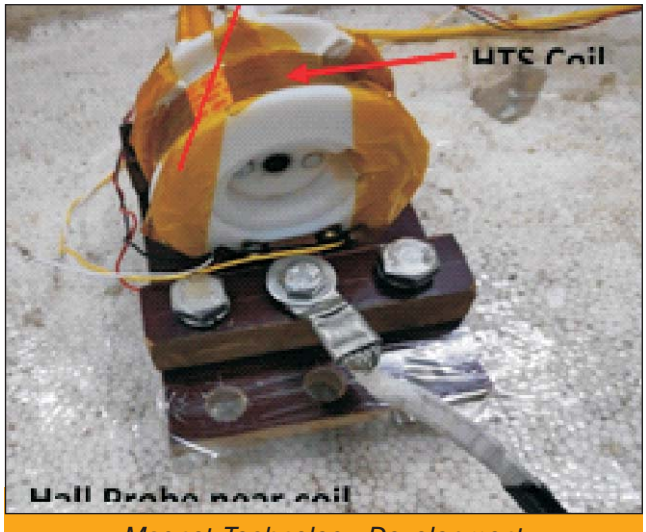
(copper, SS and alumina) in a single vacuum brazing cycle at high temperature.



Indigenous development of high-power vacuum window for GHz range

Magnet Technology development

High Temperature Superconductors (HTS) are promising candidates for next generation high field compact magnets. Coil winding, inter-pancake and terminal joints are challenging technology for the fabrication of HTS tape based high-field magnets. A small bore (50 mm) double pancake, liquid nitrogen bath-cooled, HTS solenoid coil has been fabricated with 24 turns and a height of 21 mm. This has produced a pulsed magnetic field of 1.1 Tesla with a current pulse of duration 0.72 millisec, and a DC magnetic field of 0.06 Tesla at 110 A current. The next step will be to develop higher-field and larger bore HTS coils for practical applications.



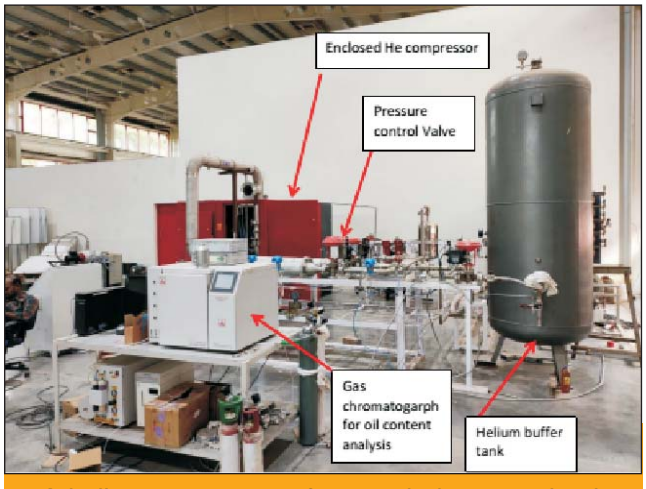
Magnet Technology Development

Fabrication and testing of Hybrid Nb3Sn and NbTi CICC joint

A hybrid kind of Nb_3Sn and NbTi CICC overlap joint of length 120 mm has been fabricated by the Magnet System Division of IPR. This joint has been tested at 4.5 K at the operating current of 480 A, self-field. The joint resistance of around 2.2 n&! measured at 4.2 K, self-field. The thermal and electrical stability of this joint have also been tested at 4.2 K with external heat load of 22.5 W at the operating current of 480 A. The average rise in temperature was around 1 K at 4.5 K due to externally applied heat load. In actual operating current of 10 kA, the expected joule heating in this kind of joint is around 0.22 W at 4.2 K, self-field, while the applied heat load is hundred times higher. Hence, this is a thermally stable joint at operating temperature of 4.5 K. This type of joint are very useful for the large Nb_3Sn superconducting magnets bus-bars, where the length and the bending of heat treated Nb_3Sn CICC are very much critical due to strain limitation.

A helium compressor from an industry scale air compressor

An Industry-scale air compressor has been successfully converted to a helium compressor. This industry scale converted compressor has been operated successfully in closed loop non-stop for 24 hrs. The main features of this compressor are Helium flow rate-60 g/s, compressed helium available for application-14.5 bar, oil content in compressed helium gas < 100 PPB (parts per billion), Electrical power consumption- 170 kW, oil-injected single stage screw



A helium compressor from an industry scale air compressor

compressor and fully air-cooled (no water cooling) type, local helium leak rates are in the order of 10^{-5} mbar.ltr/sec. This will pave the way to develop indigenous helium compressor.

High Heat Flux testing of Back Plate of NBI PINI ion source

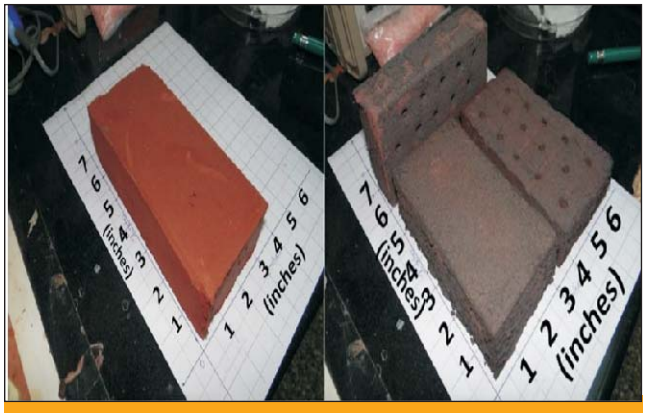
High Heat Flux testing of Back Plate of NBI PINI ion source

This plate is one of the critical components of PINI ion source which holds the filaments and permanent magnets for the production and confinement of ion source plasma. This back plate will also be functioning as heat removal component of ion source chamber. The manufacturing of this plate has many criticalities like large area vacuum brazing and machining grooves for magnets and filament feedthroughs. This has been manufactured in the country with low cost. This back plate was tested for the required heat flux in the High Heat Flux Test Facility at the institute. It was tested with an incident heat load of 205kW by electron beam (energy 45 eV) heating for about 458 seconds and the back plate was found to sustain a heat flux of 2.62 MW with stable bulk water temperature rise of 31°.

MATERIAL SCIENCE

R & D activities for nuclear safety and materials relevant for nuclear fuel cycle

In order to develop reactor core catcher materials to manage molten corium formed under severe reactor accident, model bricks made of red-mud in different sizes were made by BARC using appropriate additives and stepwise heating procedures. The bricks melt at around 1600 °C and do not ablate upto 1800 °C.



Calcined red-mud bricks (Left) and Sintered red-mud bricks (Right)

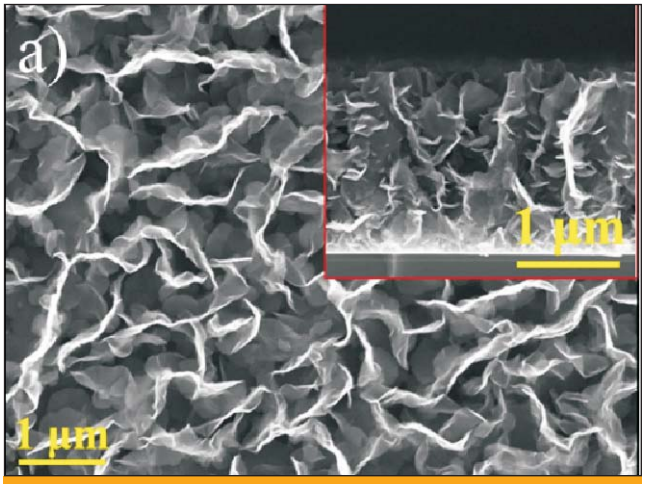
Thermal expansion of energetic material TEX obtained from X-ray diffraction and first principles calculations

One of the thrust areas in basic research in IGCAR is phase transformations in materials as a function of pressure and temperature. Many different materials have been investigated by IGCAR in the past using Raman spectroscopy and/or X-ray diffraction, including ceramic oxides that exhibit negative thermal expansion, uranates, alkali sulphates and rare earth oxides. As a part of collaboration with DRDO, temperature and pressure induced phase transformation studies on some secondary explosives were taken up recently. New high pressure phases of the insensitive high explosive TEX ($C_6H_6N_4O_8$) were reported by us, and this has been followed this year by the first ever report of the thermal expansion coefficient of TEX, using temperature dependent X-ray diffraction and first principles calculations. A major problem in the fabrication, use and storage of explosive components is their anisotropic thermal expansion; leading to anisotropic and irreversible shape change of the explosive material. Anisotropic thermal expansion causes internal stress and when the effect of this stress is larger than the cohesive energy, micro cracks will appear in the crystal. These internal micro voids can induce hotspots and increase the sensitivity of the explosives, rendering them unsafe to handle or store. Our measurements show that the thermal expansion of TEX in different crystallographic directions is different. The volume thermal expansion

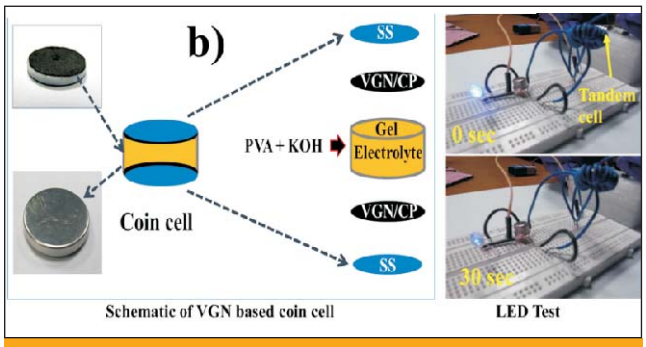
coefficient of TEX is $a=17.4x10^{-5}K^{-1}$, comparable to that of a related material, CL-20 ($a=13.5x10^{-5}K^{-1}$). These results are expected to be useful in applications like modeling the response of energetic material to external stimuli.

Vertical Graphene Nanosheets an emerging material for electrochemical energy storage

Supercapacitors, also called electrochemical capacitors, store energy using either ion adsorption (electrochemical double layer capacitors) or fast surface redox reactions (pseudo-capacitors) and can complement or replace batteries. Usage of carbon electrodes with sub-nanometre pores opened the doors for designing high-energy density devices using a variety of electrolytes. Vertical Graphene Nanosheets (VGN), a novel carbon nanostructure, is an ensemble of interconnected network of 3D vertically standing few layer graphene sheets with superior electrical conductivity, chemical inertness and mechanical stability. VGN has emerged as an ideal choice of electrode material for supercapacitors, fuel cells and Li-batteries. Its unique geometry bestows a large surface area with high density of sharp edges; offering an easy access for the electrolyte ions to its surfaces, which is a big boon for its utilization as an electrode material. At IGCAR, we have established a PECVD technique to grow VGN on a variety of substrate materials. SEM image of the 3D-interconnected network of VGN along with cross-sectional view is illustrated as under. Further, the potential utilization of VGN electrodes is tested by fabricating a symmetric coin cell device and light the LED as shown in figure.



FESEM morphology of VGN network, inset shows the cross-sectional view



Symmetric super capacitor coin cell device using VGN electrode and LED test

First-principles study of interaction energies of atomic defects in bcc ferromagnetic iron

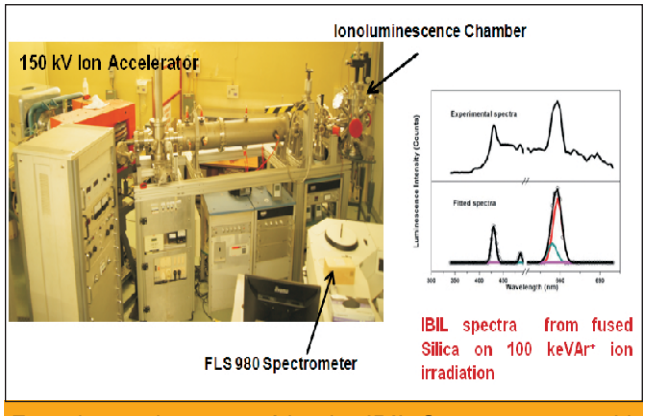
Energetics of atomic defects such as vacancy, solute formation energies, vacancy-solute and solute-solute binding energies are important parameters controlling the diffusion of solute atoms and hence the nucleation, growth, and coarsening of precipitates. A large database of solute formation energies, vacancy-solute, and solute-solute binding energies in bcc iron have been generated using DFT total energy calculations with super cell method.

This work reveals several trends in the formation and binding energies of atomic defects in iron. Formation energies of solutes from 4th and 5th periods vary with their atomic numbers such that they reach a maximum near the ends of the period and minimum in between, with a local hump near Cu/Ag. Solutes from the 2nd and 3rd periods show similar trends like the elements near the ends of the 4th and 5th periods. The common solute additions to Fe possess moderate formation energies. Large endothermic formation energies are obtained for solutes that lack solubility in Fe. Solubility estimated from formation energies agree with phase diagram database. The size factors of the solutes show similar variation as formation energies. The vacancy-solute and solute-solute binding energies vary with the atomic numbers of the solutes in a manner inverse to the formation energies and size factors. Vacancy-solute binding energies correlate with the diffusion coefficients of the solutes.

In-Situ Ion-Beam Induced Luminescence and Optical Spectroscopy

Studies of defects and structural changes caused by ion irradiations in various insulating materials and

semiconductors are of great interest, and important for basic understanding of mechanisms of point defects generation and characterizations of ion-beam induced phenomena in real time (i.e. without interruption of the ion irradiation). In addition, detailed knowledge of radiation induced modifications, mechanical *vis-a-vis* radiation stability of materials exposed to high levels of radiation are important for different nuclear applications. Effects of ion irradiation in semiconductor and insulator materials are usually characterized by different ex-situ techniques. Compared to these techniques, an in-situ method known as Ion Beam Induced Luminescence (IBIL) spectroscopy, is a more sensitive technique to elucidate the origin of luminescence in these materials combining with point defects or impurities. Photograph shows the IBIL set-up at IGCAR coupled to the ion accelerator. Preliminary result in terms of IBIL spectrum as obtained in low energy Ar+ ion irradiated a-SiO_2 is also shown in the Photograph.



Experimental set up of in-situ IBIL Spectroscopy with the 150 kV accelerator at IGCAR

Tip Enhanced Raman Spectroscopy (TERS) of smallest Si nanowires in the sub-diffraction limit

Spectroscopic study of single semiconductor nanostructure is important for understanding the physical properties to differentiate from bulk as well as ensemble characteristics. A Tip-Enhanced Raman Spectroscopy (TERS) facility has been established in IGCAR, for the first time in the country, to characterize nanostructure in the sub-diffraction limit using localized surface plasmon of Au nanoparticle attached to an Atomic Force Microscopic (AFM) tip coupled with a Raman spectrometer. The Raman spectroscopy of optical phonons in Si Nano Wire (NW), as small as 25 nm, were studied for the first time. Localized Raman measurements on single NW by near-field TERS demonstrate the decoupling of multiple origins responsible for the peak shift which is accompanied by asymmetric broadening of the phonon mode of Si. A model based on the localized phonon population induced by NW size dependent charge depletion, is proposed to explain the observed dependence of phonon characteristics on NW size.

Exploration of low temperature magneto-caloric properties of EuSe system

The Magneto Caloric Effect (MCE) is a phenomenon in which the temperature of a magnetic material changes by changing the externally applied magnetic field. Magneto Caloric Materials (MCM) find their applications in magnetic refrigeration technology, which is considered to be energetically efficient and more environment friendly than the conventional gas/vapour compressor-based refrigeration technologies. MCM based magnetic refrigerators have application potential in the near room temperature cooling systems such as air conditioners, refrigerators, cold storage units and in the low temperature regimes like Liquid Nitrogen (LN_2), Liquid Hydrogen (LH) and natural gas liquefaction industries. Therefore, exploration of novel magnetic materials which exhibits good magnetocaloric properties at different temperature regimes is essential. With an objective to search MCE in sparsely investigated rare earth selenides, we have performed detailed thermo-magnetic characterizations of the EuSe system via isothermal magnetization measurements and evaluated the role of thermo-magnetic hysteresis on its magneto-caloric properties. Our study reveals that the EuSe system yields highest isothermal entropy change ($|\Delta S_M^{Max}|$) of 33J/(kg K) around 5 K. The value of relative cooling power (RCP) is found to be 600 J /kg; which is one of the highest reported value. Based on the high $|\Delta S_M^{Max}|$ and RCP values and the negligible effect of thermo-magnetic history dependence on these parameters, present study suggests that EuSe can be potential candidate for low temperature magneto-caloric applications.

Microstructural evolution of proton irradiated Fe-2.25Cr-1Mo characterized using synchrotron XRD (SXRD)

Synchrotron X-ray Diffraction Data (SXRD) has been used to characterize the microstructural changes in 3.5 MeV proton irradiated 2.25Cr-1Mo (T22) steel samples as a function of dose through different techniques of X-ray Diffraction Line Profile Analysis (XRDLPA).Williamson-Hall method, modified Rietveld method and convolutional multiple whole profile fitting technique have been used to evaluate the coherent domain size, r.m.s microstrain, dislocation density and dislocation character from SXRD data. It is demonstrated that XRDLPA is a powerful tool for extracting the microstructural parameters of irradiated samples. Vicker's micro hardness measurement has also been carried out to get information on the mechanical property changes with dose.

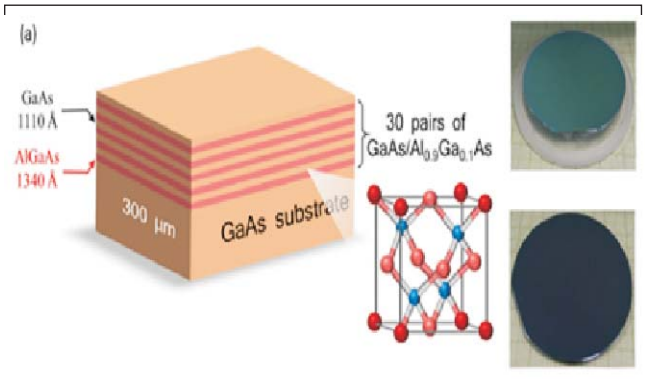
Synchrotron GIXRD and slow positron beam characterization of Ar ion irradiated pure V and V-4Cr-4Ti alloy

Candidate structural material for Fusion reactor application: Pure V and V-4Cr-4Ti has been irradiated with Ar9+ ion at 0.4, 2.3, 8.4 and 23 dpa. GIXRD was carried at two different incident angles i.e. at 0.2 and 0.45 degree using Synchrotron radiation. The XRD data were analyzed to determine the variation of microstructural parameters like domain size and microstrain as a function of dose by Modified Rietveld Technique. Slow positron annihilation spectroscopy has been used to characterize the irradiation induced depth dependent changes in the microstructure with dose. The study confirms the creation of vacancy type open volume defects in the damaged region of the ion-irradiated samples. It was observed that there is no appreciable change in open volume defect density and type of defects up to 8.4 dpa for pure V except at the highest dose. However, in contrary to pure V, the increase in S-parameter at highest dpa clearly indicates that the type of defects at highest dose is significantly different from the other samples.

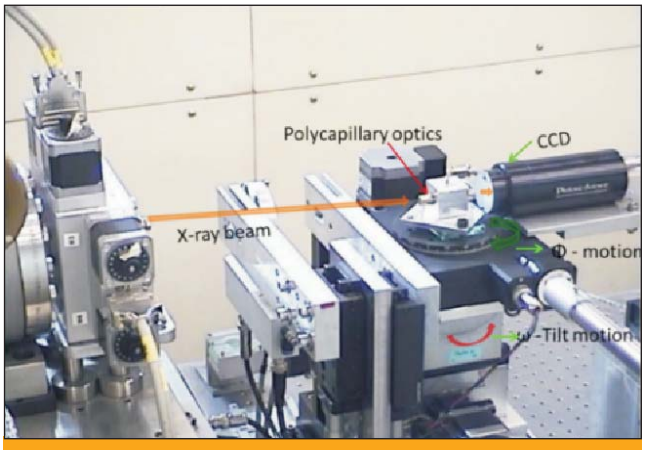
Characterization of ion induced damage as a function of depth in proton irradiated pure Ti and Ti-6Al-4V

The inhomogeneous damage caused by ion irradiation (proton) as a function of depth has been characterized on pure Ti and Ti-6Al-4V at different doses. X-ray line profile analysis was used to evaluate the microstructural parameters such as domain size and microstrain within the domain. Although a systematic decrease in domain size as a function of depth is observed in both the materials, but the changes are less prominent in Ti-6Al-4V than in pure Ti. The increase in the value of S-parameters measured from Doppler Broadening Spectroscopy of Positron annihilation technique reveals higher concentration of open volume defects near Bragg peak (maximum damage region). Micro-hardness is also measured as a function of depth for both irradiated and unirradiated samples. The results obtained from microhardness measurements are found to corroborate with the findings from PAS and XRDLPA. Radiation induced segregation (RIS) which was observed in the Ti-6Al-4V at the highest dose 5E17p/cm2 is found to be limited near to the surface. Detailed X-ray analysis using Convolutional Multiple Whole Profile fitting of the XRD data from the surface of the irradiated Ti-6Al-4V samples could reveal the nature of the dislocations (ie. <a> or <c> type).

"Monocrystalline grown reflectors", as an end mirrors in a Fabry-Parot cavity, are the state of art design for achieving extremely high reflectivity with a tenfold reduction of Brownian noise at room temperature when compared to e-beam/sputtered mirrors. At RRCAT, single crystalline distributed Bragg reflector mirrors with reflectivity exceeding 99% at 1064 nm and 1550 nm are designed and grown using metal organic vapour phase epitaxy. Subsequently, the high Q resonator with Q factor of 1100 are developed by using two sets of DBR. This will be useful for LIGO application as low thermal noise mirrors.



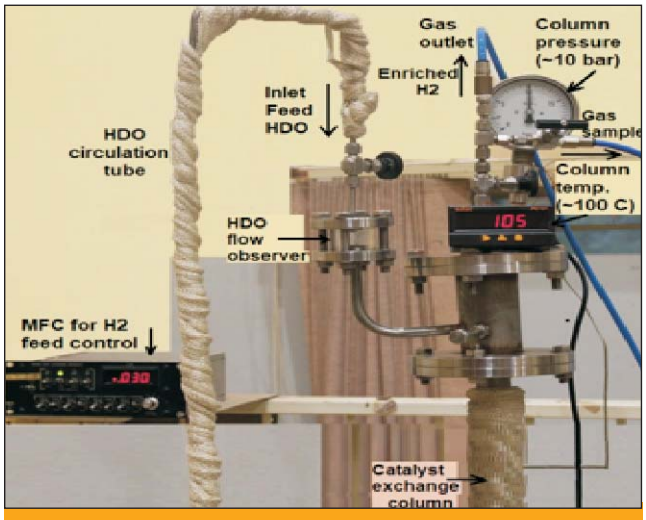
Schematic layer structures and photographs of the developed distributed Bragg reflector mirrors



The experimental setup used for aligning and commissioning of the polycapillary optics at BL-16 Indus-2

Polycapillary optics is one of the most cost effective and simple techniques for focusing X-rays to spot sizes within a few 10s of microns. The facility for using polycapillary optics to focus x-rays has been developed at X-ray fluorescence microprobe beamline (BL-16) in Indus-2 and is now available for users. At an incident energy of 8 keV, the minimum spot size (focal spot) obtained is 50 μm at a distance of 10.5 mm from the polycapillary exit. In comparison with the commonly used focusing mirrors, the polycapillary optics provides 10 times better tight focused beam, with a photon flux gain is one order less than an X-ray mirror. On other hand price ratio of focusing x-ray mirror to polycapillary optics is 25:1.

Accelerated testing of Pt-CA coated Dixon ring catalyst being developed for hydrogen isotope exchange based CECE application was performed by subjecting the catalyst to cyclic pressure & temperature loading at much above the routine operating conditions and KOH exposure to ascertain stability towards electrolyser. Accelerated testing of the Pt doped carbon aerogel coated Dixon ring catalyst was carried out for cyclic pressure & temperature loading at 10 bar and 100 ºC, much above the routine isotopic exchange conditions of 1 bar & 50 ºC. The catalyst evaluated after the above conditions showed no degradation in performance, adhesion and hydrophobicity showing its resilience for long term stability. This activity will be pursued to supply the large quantity of coated Dixon rings to BARC.



Catalyst test column operated at 10 bar pressure & 100 ºC

IR-THz frequency domain spectrometer set up for the utilization of FEL radiation

A setup for IR-THz frequency domain spectroscopy, with provision for experiments in low temperature (up to 5 K) and high magnetic field environment (up to 5 T), has been successfully commissioned. This will be used for experiments using the radiation from the IR-FEL to study materials of technological importance.

Intergranular corrosion (IGC) accounts for failure of many austenitic stainless steel (SS) components operating in chemical and process industries. In most of the industrial applications, IGC damage is encountered on the inside surface of SS tubular components. A laser based beam maneuvering system has been designed to carry out in-situ laser surface treatment on the internal surface of tubular components with inner diameter in the range of 50 - 500 mm and length of up to 1 m. The technique is

highly useful for life extension of IGC-damaged in-service austenitic stainless steel components.

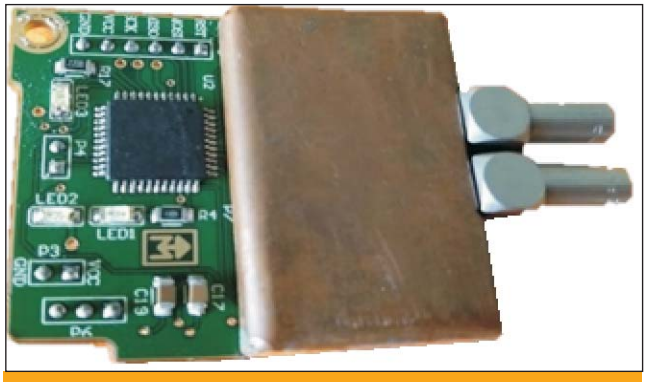
Effect of temporal pulse shape of intense ultra-short pulses on the momentum distribution of e^+ - e^- pairs has been studied by considering two closely resembling temporal envelopes namely, the Gaussian and Sauter pulses. The momentum spectrum of the pairs created by the two pulses are found to differ significantly in all the temporal regimes. The relevance of this theory is for the future experiments to be carried out using ultra high intense laser viz, Petta Watt laser.

At TIFR, 'Exotic' magnetism was reported in a distorted kagome lattice, based on metals, viz., $Tb_3Ru_4Al_{12}$. This compound exhibits anisotropic spin-glass features, which emphasizes the need to revive theories proposing spin-glass ground state due to geometrical frustration. Particle size study was reported for the first time for a Eu-based mixed valent compound. A facile synthesis technique was developed for WS2 nanotubes by sulfurization of tungsten thin films and their formation mechanism, structural and optical properties were studied. Tunable graphene superlattice was fabricated and studied. InAs nanowires were studied to probe their electrical, mechanical and thermal properties. An optical tweezer based technique was developed to understand weakly adhering systems. Multiferroic (magnetic and ferroelectric) ordering was discovered in elemental Selenium. THz metamaterials were demonstrated to mimic classical analogues of quantum optical phenomena including EIT and Fano resonances as well as high Q, actively tunable resonances were demonstrated.

INTERDISCIPLINARY AREAS

Development of Mini Pico-Ammeter for in-situ-measurement of Ultralow Current

In several experiments, in-situ ultralow current measurement becomes a necessity due to experimental setup limitations. To facilitate such experiments, a miniature version of dual channel digital Pico-Ammeter has been developed by VECC & tested in field successfully. The size of the module is only 5x4x1 cm^3. It is capable of measuring current from 1pA to 1.8μA which may be monitored by a local LCD or in PC based GUI application software. The module has eight different ranges which can be set manually from PC or it supports auto ranging facility to measure current with maximum precision.



Mini Digital Pico-Ammeter Module

At the Centre for Interdisciplinary Sciences, Hyderabad, an interdisciplinary team of researchers from TIFR, India and America have developed a nanotool that shows potential in precise imaging and treatment of tumours. Preliminary results on diseased animals indicate that the probe is useful as an in-situ guiding tool during surgery. The crux of the research lies in the novel design of a multi-layered nanoprobe derived from a conventionally used gold nanoprobe that carries the fluorophore. In another study, an atomic/molecular beam surface scattering apparatus was designed and built where one can study the spatial distributions of the scattered flux. From the information available in the spatial distributions, one can obtain a topography 'image' of the surface from which the atoms have scattered, thereby leading to an image of the surface itself. At present, a computer controlled data acquisition system which can control the motion of the sample stages, mass spectrometer detector to generate an image is being built and tested. In NMR Spectroscopy, strategies were introduced to speed up multidimensional data acquisition in magic-angle spinning solid-state NMR. They rely chiefly on exploiting unused coherence/ magnetisation pathways and combining them all in an appropriate way to build up the necessary connectivity that may be useful in the assignment of spectra and elucidation of structural constraints. The methods have been shown to work for model compounds and currently steps are underway to implement them in bigger size proteins.

INTERNATIONAL RESEARCH COLLABORATION

The TIFR scientists participated in all aspects of the CMS experiment: data collection, monitoring, analysis, detector hardware construction and grid computing. The TIFR grid computing facility has played a major role in processing both collision and Monte Carlo data sets. The harvesting of pristine e+e- collision data recorded by the Belle experiment at the KEK B-factory continued with leading contributions from TIFR. The group has also played a key role in the acquisition, filtering and reconstruction of collision data delivered by the SuperKEKB accelerator. The Crab nebula was observed to assess the performance of HAGAR telescopes since its inception in year 2008. The consolidated results spanning nine years of observations showed long term consistency in the performance of HAGAR.

At TIFR's International Centre for Theoretical Sciences, Bengaluru, in String Theory, the extent to which holography follows just by putting together the known low-energy physics of general relativity with the principles of canonical quantization was explored. This work has several implications — it shows why holography works best in asymptotically anti-de Sitter spaces; it shows why holography only works for theories of gravity and not for any other theory; and it shows why holography is a quantum phenomenon with no classical analogue. In Fluid Dynamics, turbulence in the Bay of Bengal has been measured, most likely for the first time in a collaboration between various institutions in India and the USA. Using this data, researchers showed that, during mid-monsoon, soon after fresh water from river efflux arrives at a particular mooring, turbulence in the Bay at depths of several tens of meters is dramatically suppressed. This is particularly surprising because winds are strong at this time.

Two large size mini muon chamber modules (mMUCH), based on Gas Electron Multiplier (GEM) technology having about 2000 readout channels, were fabricated at VECC and commissioned in the mini Compact Baryonic Matter (mCBM) experiment at GSI as part of FAIR phase 0 program. One 30 cm X 30 cm Bakelite based Resistive Plate Chamber (RPC) module having resistivity 3.9X1010 ohm-cm has been tested at lower gain at VECC using free streaming DAQ. The optimized operating conditions of the RPC will be used for testing at mCBM experiment in the year 2020. Radiation hard Low voltage power supply (LVPS) has been upgraded to 15 output channels each having dedicated DC-DC converter with over current sense and trip circuitry. Major accomplishment of this work lies in indigenous design of radiation hard power supply and its error resilient control firmware with low cost readily available industrial grade components. This design had been validated and tested in the conformity with CBM standards Two LVPS boards with fault tolerant firmware are running successfully with control software in mCBM experiment. Detailed simulation has been performed to finalize the realistic design of the first absorber of muon detector system in CBM experiment. Two parallel test-benches for Common Readout Unit (CRU), a key component of ALICE- DAQ upgrade, has been set up at VECC. A prototype for Muon Tomography (MT) system using Bakelite based RPC is being developed.

High Energy Nuclear and Particle Physics group of SINP is linked with the ALICE and CMS collaborative work at the Large Hadron Collider (LHC) of CERN. The main thrust is to understand the matter and its interaction during the first micro-second of the creation, which is believed to the Big Bang. These extreme conditions of temperature are achieved by colliding ultra-relativistic beams of protons or lead (Pb) nuclei using the LHC. The particles coming out of these collisions are tracked in the gigantic detectors, ALICE and CMS. The group has built indigenously Second Muon Tracking Station of ALICE and is responsible for its maintenance and upgrade. The readout upgrade of HGCAL of CMS detector has also been carried out by the group. The faculties and students participate in the data taking and the physics analysis.

The ALICE group is involved in characterising the microscopic properties of the matter (Quark Gluon Plasma) created in Pb-Pb collisions. The Universe was believed to be in this plasma state after a microsecond of its creation.

The CMS group on the other hand aims to discover new particles, which are still unknown to us but can be created at these collisions at extreme energies. The other interest is to find new physics beyond the Standard Model, which successfully describes the interactions between the fundamental particles (quarks and leptons).

International Thermonuclear Experimental Reactor (ITER)

Institute of Plasma Research (IPR), Bhabha Atomic Research Centre (BARC) and Indira Gandhi Centre for Atomic Research (IGCAR) are involved in the design, material development, thermo fluid MHD analysis and various aspects of Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) for ITER.

Handover of ITER Cryostat sub-assembly

The sub-assembly of the ITER Cryostat Base Section, weighing 1250 tons, is the heaviest single component in ITER and will be the first component to be installed in the tokamak pit. This sub-assembly was successfully completed and handed over to ITER Organization. A ceremony was held on 23 July 2019, where India was represented by Dr. Anil Kakodkar and the Indian ambassador in France. This involved fabrication meeting strict tolerances, a first at this scale and magnitude.

An important milestone for the cryoline project

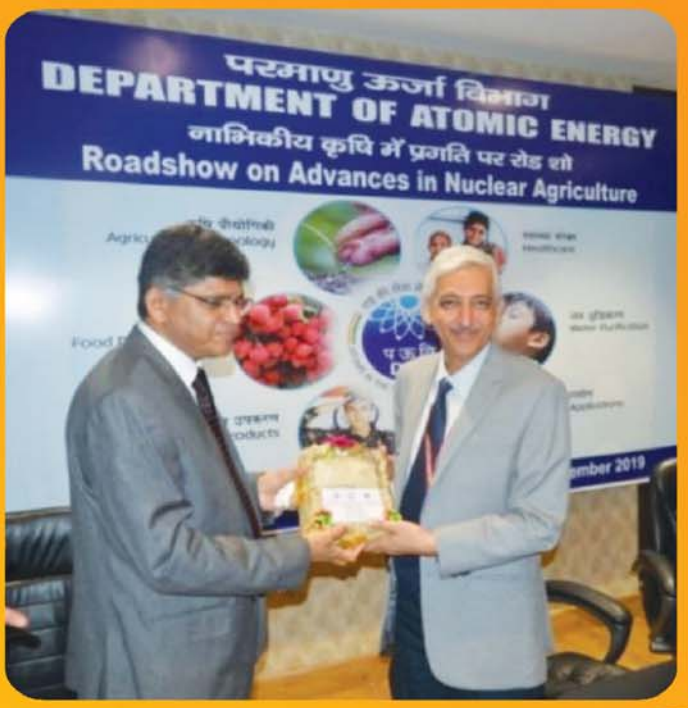
The first element of quench cryoline SQL (Group-Y) has been lifted and successfully positioned inside the tokamak building at B2 level supplied by M/s. INOXCVA which marks an important milestone in cryoline project. The cryoline is assembled by the contribution from skilled Indian workforce duly qualified to work in accordance with French norms and standards. The Indian workforce comprises of six site staff/supervisors and four technicians/welders who are qualified to work. The function of the cryoline is to depressurize and recover the cold helium at 4 kelvin from superconducting magnets to quench tank in case of magnet quench event. The cryoline has to satisfy the stringent criteria as a SIC-2 cryoline (Safety Important Component).

Other developments

- The SPIDER test facility in Padua, Italy, produced the first SPIDER hydrogen beam. The 96 kV, 75 kA Acceleration Grid Power Supply (AGPS) for this facility is an Indian-developed in-kind contribution to ITER. The performance of the AGPS was acclaimed in the global scientific community, as quoted in the ITER Newsline issue no. 525 dated 17 June 2019 “The acceleration of the beam, in particular, confirms the perfect integration of the high voltage power supplies, delivered by ITER-India, within the complex and state-of-the-art electrical system of SPIDER, an authentic masterpiece of electrical engineering”.
- The Site Services Building, with equipment installed at ITER site, has been successfully commissioned at ITER site. The major part of the cooling water piping network and equipment (chillers, pumps, electrical panels etc.) has been delivered by ITER-India. Key ITER auxiliary systems (cryogenic plants, power converters, etc.) receive cooling water from this system.
- An indigenously-developed Nuclear Activation Code (ACTYS) for fusion activation calculations in ITER was developed and tested.
- A new type of wideband Hybrid Megawatt (MW) Level Continuous Wave (cw) Radio Frequency Combiner/Splitter has been designed and developed and successfully tested at 1.5 MW for the frequency band 35-60 MHz. A MW level cw Single-Pole-Double-Throw (SPDT) Coaxial Radio Frequency Switch has also been designed & developed, and the same tested at 1.5 MW for long pulse operation. Patents have been filed for both these developments.

A new type of wideband Hybrid Megawatt (MW) Level Continuous Wave (cw) Radio Frequency Combiner/Splitter has been designed and developed

CHAPTER 6



Vice Chancellor, Indira Gandhi Krashi Vishwavidyalaya (IGKV) presenting samples of rice mutant Safri-17-2 Mutant to Dr. K. N. Vyas, Chairman, AEC on 29th November 2019

RESEARCH EDUCATION LINKAGES

Dr. A. K. Mohanty, Director, BARC monitoring the Rice Mutation breeding Field

The Department of Atomic Energy supports the research education linkages mainly through grants-in-aid to institutes of national eminence, funding of extra-mural research, DAE-UGC consortium for scientific research and others.

The human resource and knowledge management is developed through Homi Bhabha National Institute (HBNI), BARC Training School and the Administrative Training Institute (ATI).

The Board of Research in Nuclear Sciences (BRNS) an advisory body of the Department of Atomic Energy (DAE) provides financial assistance to universities, academic institutions and national laboratories for encouraging and promoting scientific research in the areas of relevance to the mandate of DAE.

The National Board for Higher Mathematics (NBHM) established under the aegis of DAE promotes excellence in higher Mathematics education and research in the country. The Board also provides grants for promotion of activities in pure and applied Mathematics under several schemes including support to research projects, travel grants for participation in workshops, conferences and undertaking collaborative research funds for organizing conferences etc.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a Deemed to be University, is a grant-in-aid institute of the Department of Atomic Energy (DAE). It has completed a successful 14 years. During this period, it has established itself as one of the best research universities in the country, encouraging research in various facets of nuclear science and technology including mathematics. In the recently published result of 2019 Nature Index database, HBNI was placed at 16th position among Young Universities (less than 50 years old) in respect of publications in all science disciplines, whereas with respect to physical sciences, HBNI was placed at the tenth position, on a global level.

The academic programs of HBNI are leading to Human resource development not only in core areas of nuclear sciences and engineering but also in several other areas of societal importance such as medical and health sciences. In the academic year 2019-2020, four new programs in medical and health sciences, M.Sc.(Nuclear Medicine and Molecular Imaging Technology), M.Sc.(Hospital Radiopharmacy), M.Sc.(Occupational Therapy in Oncology), M.Sc.(Public Health in Epidemiology), have been introduced.

During the year, HBNI also organised two important value addition courses. As part of a MoU entered into with INSTN, France, a joint course was organized on Severe Accident Phenomenology (SAP), from 9^{th} – 14^{th} September 2019 at CEA-Cadarache, France and HBNI, Mumbai. HBNI also organized a certificate course on Nuclear Law for middle-level professionals in various units of DAE such as BARC, AERB, NPCIL, IGCAR, NFC and BRIT, forty-four officers attended the course. The course consisted of 44 lectures and covered overview of various international treaties, Indian laws covering various aspects such as liability and Insurance, nuclear security, and some aspects of nuclear safety.

Till December 2019, HBNI has awarded 1549 PhD degrees in a variety of disciplines. The total enrolment in the academic programs of HBNI in the academic year 2019-2020 is 879, which includes 320 for PhD,78 for MD, 27 for DM and 34 for MCh programme. HBNI continued to make sustained efforts to enhance interactions between students of various Constituent Institutes (CIs) and Off Campus Centre (OCC), and make the students aware of the details of the academic Governance system. Several other student-friendly measures have also been introduced such as online enrolment.

HBNI also introduced, for the first time, a formal induction program for the faculty, to familiarise them with the academic processes of HBNI. The first induction program, held in December 2019, was attended by 78 newly recognized faculty members.

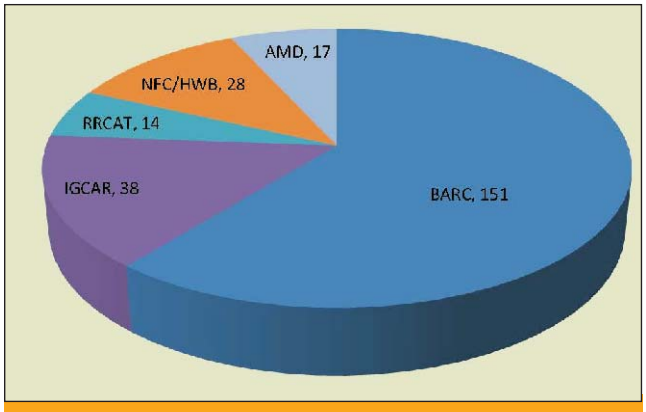
The Foundation Day of Homi Bhabha National Institute was celebrated at the DAE Convention Center, Anushaktinagar, Mumbai, on June 3, 2019. Chairman, AICTE, Prof. Anil Sahasrabudhe was the Chief Guest for the occasion. Prof. Anil Sahasrabuddhe distributed degree certificates and also presented awards to the outstanding students. Dr Anil Kakodkar delivered the J. B. Joshi Research Foundation Endowment Lecture on the topic "Reshaping research culture – Genesis of Homi Bhabha National Institute". HBNI brought out its first Newsletter on this occasion. This bi-annual newsletter brings out highlights of various activities at HBNI and its Constituent Institutes and Off-Campus Centre, and the achievements of faculty members and students.

In association with BARC and the Atomic Energy Education Society, HBNI organized a half-day theme meeting commemorating the International Year of the Periodic Table on November 27, 2019. Prof. C.N.R. Rao gave the keynote address. The programme was attended by more than 400 students from Atomic Energy School and 250 delegates from DAE and various colleges in Mumbai.

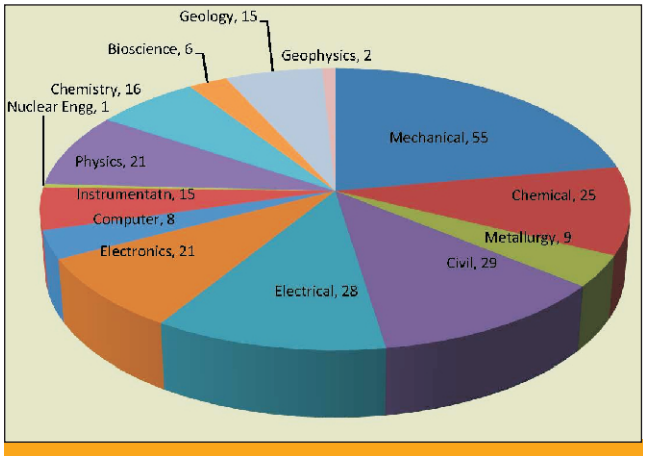
Training School

BARC Training Schools, at Mumbai; RRCAT, Indore; IGCAR, Kalpakkam; NFC, Hyderabad; and AMD, Hyderabad are providing skilled human resources to DAE through the one year Orientation Course for Engineering graduates and Science postgraduates (OCES) programme and DAE Graduate Fellowship Scheme (DGFS). The linkage of these programmes with Homi Bhabha National Institute (HBNI) ensures continuous availability of professionally qualified manpower to fulfill DAE mandate to enhance share of nuclear power in the country and to contribute to national security. BARC also recruits students for HBNI PhD programmes in BARC, IPR, IGCAR and VECC through nationwide on-line / off-line test followed by an interview.

While the academic programme of the 62nd batch was underway, screening examination for 1,40,622 OCES/DGFS applicants (1,49,687 last year) in 9 engineering and 5 science disciplines was organized at 89 venues in 43 cities. About 2,426 candidates were shortlisted for the interview. Recruitment data are displayed below in the form of PIE diagrams and bar charts. A total of 248 candidates were selected for OCES/DGFS-2019 compared to 229 last year.



Number of selected OCES/DGFS-2019 Candidates for various BARC Training Schools



Discipline wise total selection of candidates for OCES/DGFS 2019

A total of 74 trainee officers (53 Engineering+ 3 Physics + 4 Chemistry + 5 Biosciences + 9 RSE) have successfully completed the training and they have been placed in various DAE units. There were 9 Trainee Defence Officers (TDO) who passed out from this batch have been assigned to different Divisions/ Units for pursuing M. Tech projects. About 4 fellows of OCDF 2018 (DGFS-2016-18) scheme have successfully completed training and have returned to their respective Divisions in BARC.

The Human Resource Development Division (HRDD), BARC imparted training to 'Executive Trainees' from NPCIL (civil engineering) for 2nd year in a row with a committee of coordinators from HRDD,

NPCIL and AERB. They were absorbed by NPCIL. Four trainees recruited by ECIL through OCES selection process are being trained at HRDD. Eight PhD students in Science disciplines and ten DGFS PhD students in Engineering disciplines are doing their coursework in BARC Training School. QUEST Programme under DAE Continuing Education Programme offers advanced courses approved by HBNI for PhD students and DAE employees to upgrade their knowledge. HRDD issues certificates to those candidates who score more than 50 percent.

HRDD celebrated 5th International Yoga Day on 21st June 2019 with the participation of 62nd batch TSOs and HBNI PhD students.

HRDD coordinates 1 to 2 months practical training and offers 3 to 12 months academic projects in BARC for students of BE, B.Tech, M.Tech, ME, MSc, MCA, JRF, SRF from all over the country. During January –December, 2019, 1387 students from different institutes visited BARC for project work.

Under a Memorandum of Understanding (MoU) with the Central Ground Water Board (CGWB), Health Physics Division (HPD), BARC is likely to organise training programmes for chemists of CGWB for determination of ultra-trace levels of uranium in groundwater. The programmes is expected to cover theoretical aspects of uranium determination and hands-on experience for the participants from CGWB. The first training programme is scheduled in BARC, Mumbai.

Dhruva continued to be a major facility for neutron beam research. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

Radiation Medicine Centre (RMC) offers several degree and diploma programmes under Homi Bhabha National Institute, such as 3-year MD programme in Nuclear Medicine for six medical graduates annually. RMC also conducts 1-year Diploma in Medical Radio Isotope Techniques (DMRIT) for science graduates. RMC has started 2-year M.Sc. in Nuclear Medicine and Molecular Imaging Technology (NMMIT) and M.Sc in Hospital Radiopharmacy in 2019.

NPCIL has strong and dedicated workforce of 11134 employees as on 30.11.2019 consisting of Engineers, Technicians and Supervisors, Non-Technical Executives, Staff and Auxiliary support staff who spearhead the activities of the organization. During the year 2019, 192 young talents were recruited in Group A, B & C and 17 young talents were recruited under Persons with Benchmark Disabilities Category. NPCIL's HR initiatives are directed towards fulfilling the NPCIL's mission and vision by attracting, motivating and retaining the right talent and intellect. While developing the strategic and incremental packages for employees, the individual goals and aspirations are encouraged by way of training, culminating in achievement of goals of NPCIL. NPCIL being a Company carrying out special nature of business, the strategic dimensions of its business and the operational flexibility needs to be maintained in every aspect. The trained and skilled Human Resource is an asset of NPCIL. Hence, optimization of manpower is an important strategy towards best utilization of human resource. Accurate and comprehensive manpower optimization models for Construction Projects, Operating Stations, Design & Engineering, including Multi-Unit Sites are developed separately in NPCIL. Staffing is done strictly in accordance with these models in NPCIL.

During the year 2019, Harmonious Employee Relations prevailed in all the Stations, Projects and Headquarters. Structured/regular meetings were held with the recognized Unions at Station/Project levels and with the Joint Consultative Council at the apex level to discuss and resolve the various employees' related issues. The positive employee relations achieved are based on sound and constructive participation of workers' representatives in decision making in matters affecting the general welfare and service conditions, conflict resolution based on a mutual understanding and emphasis on increased production and productivity and individual grievance resolutions through online Grievance Redressal and Monitoring System. The NPCIL (High Performers Annual Award) Scheme goes a long way in encouraging employees to push, envelope and work towards achievement of organizational goals in efficient and effective manner. 562 High Performers were felicitated under NPCIL (High Performers Annual Award) Scheme for the year 2018. Special Reward for

longest continuous operation of NPCIL Units beyond 300 days and above was paid during the year to the employees of RAPS-5&6 and KGS-1&2.

Being a Central Public Sector Enterprise, NPCIL is committed to implement the Presidential Directives and all the Govt. of India orders on reservation, relaxation and concession for SC/ST/OBC/EWS and Persons with Benchmark Disabilities in recruitment and for SC and ST in promotion, wherever applicable. A structured mechanism exists for redressal of grievances which is sensitive and attentive to employees' grievances at all levels. The grievances are now being heard and resolved through online Grievance Redressal and Monitoring System (GRAMS). The Orders issued by Government of India duly endorsed by DAE on Prevention, Prohibition and Redressal of Sexual Harassment of Women at Workplace are being implemented in NPCIL. Four workshops have been conducted in the year to sensitize the employees.

Twenty-three Trainee Scientific Officers of the 13th batch of BARC Training School at IGCAR have completed training in five disciplines and were placed in various DAE units. In the present academic year, twenty-one Trainee Scientific Officers are undergoing training at the Training School in six disciplines, including an additional discipline, (viz.) Fast Reactor Technology (Electrical and Electronics), which has been introduced from this year. Along with the current batch of Trainee Scientific Officers, 25 Research Scholars and 35 Employees, pursuing higher studies under the aegis of Homi Bhabha National Institute, continued to do their coursework at the Training School.

Human Resources Development activities at RRCAT revolve around imparting training to Ph.D. Scholars and M.Tech. students from various Indian institutes. The stipendiary programme for CAT-I and CAT-II is conducted for the Scientific Assistants and Technicians. RRCAT has initiated "Trade Apprenticeship Scheme at RRCAT" abbreviated as TASAR from 15th October, 2018 to impart practical training to, ITI trained boys and girls to expose them to modern technologies and improve their proficiency, skill and employability. Thirty apprentices have been trained in first batch and 85 are being trained in current batches.

A fitter apprentice learning drilling & tapping

A draftsman apprentice making drawing

BARC Training School AMD Campus, Hyderabad continued its activity wherein 17 Trainee Scientific Officers (TSO) of the ninth batch (OCES-2018) completed induction training on 31-07-2019. 12 TSOs of the tenth batch (OCES-2019) are undergoing induction training.

TMC continued to be a recognized training center in cancer education and research by several national and international organizations, including the World Health Organization (WHO), the International Atomic Energy Agency (IAEA) and the International Network for Cancer Treatment and Research (INCTR).

The only standardized academic program in the country Kevat, the one-year patient navigation course entered its second year. The first batch (2018) of 30 students passed out in August 2019. Of them, 15 were chosen for a one-year fellowship.

TMC initiated training of African, Sub-Saharan country doctors and nurses under the Indo-African

Forum Summit III entered its second year. The annual fellowship and exchange programs for cancer research and education continued between King's College, London and TMC.

The 17th conference on "Evidence Based Management of Cancers in India - EBM 2019" was held from 28th February to 3rd March 2019. The Hospital Day Oration was delivered by Prof. Helmut Friess on: Curing Pancreas Cancer in the 21st Century on 2nd March 2019.

Administrative Training Institute

Administrative Training Institute (ATI) started functioning on 2nd July, 2007 with the motto "Prashikshaneshu Dakshaprayate – Training Empowers". ATI has been able to organize over 1000 programmes for over 29,0000 participants till date. This could be achieved because of the robust Training Management Information System (TMIS) in place. This takes care of major training activities right from drawing the Training calendar, preparing schedules, nomination data, confirmation, faculty database, feedback, budget and expenditure management, etc. Another major achievement of ATI is "Training at Doorstep" of different units.

ATI offered wide range of programmes starting from induction to post retirement and periodic in-service programmes and subject specific workshops ensuring depth and range.

The programmes conducted during the year included Gender Sensitization & Equal opportunities in Govt. service, Three Mandatory Induction Programmes for Work Assistants, Four refresher programmes for JPA/JSK, one Mandatory Induction Programme for Administrative Staff and Three Computer programmes in MS Excel, MS Office, MS Access, etc.

Some of the major highlights of the ATI training programmes included a programme on GeM for Head of Divisions of BARC, Four programmes on Retirement Benefits and Life Management post retirement; One programme on Heart of Effective Leadership and three programmes on Effective Living & Leadership at Initiatives of Change, Panchgani. All the programmes were well received. Under the Management Development Programme, a one week programme for Group-A & B Officers is planned to be conducted at Jamnalal Bajaj Institute of Management Studies, Mumbai.

The Participants of ATI Training Programme with Smt. Saroja Gopal, Director, ATI

The ever changing work environment requires a training environment providing in depth knowledge. In order to bring in more understanding/insight in the subjects dealt with in day to day administrative work, Workshops on Leave, LTC/TA, Pay fixation, etc. were also introduced. A refresher programme for the Divyangjan (Hearing impaired) was also conducted for the first time in ATI which was very well appreciated. This was an effort to make training more inclusive.

ATI has collaborated with International Institute of Population Sciences (IIPS) for meeting training needs of their staff on a specific requirement from Director, IIPS. This is the first time in the history of ATI, such a collaboration has been entered into.

Professional liaison and coordination by ATI have helped in strengthening network with the premier training institutes and faculty members. This helps in ensuring qualify, variety and freshness in the programmes.

It has been the endeavour of ATI to innovate and adopt the best practices in training with an aim to make it a robust Institute thereby creating a strong, informed and skilled human capital.

SPONSORED RESEARCH

Board of Research in Nuclear Sciences (BRNS)

Board of Research in Nuclear Sciences (BRNS) has been funding national research institutes and universities for various research projects and scientific events which are relevant to DAE programmes. Proposals for research projects are invited, scrutinized by expert committees and selected through a critical review process for financial and technical support. In most cases, project collaborators are identified from scientists and research groups from one of the DAE research centres, who maintains the link with the Principal Investigators (PIs) from implementing institutions. The progress of the projects are monitored and mid-course corrections are often introduced. Over the years, sponsoring such projects has not only promoted research activities in various academic and research institutes in the country but also provided important scientific inputs to the DAE programmes.

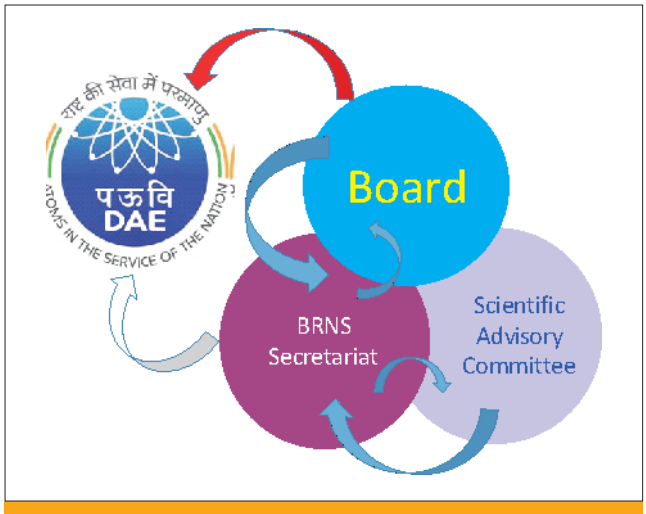


Illustration of basic functional structure of BRNS

Recently, the BRNS Board has been reconstituted with experts from different domains and the new BRNS Board is supported by nine BRNS Committees, each dealing with a focussed activity as listed in the DAE vision document, namely, Nuclear Power Programme (NPP), Uranium and Rare Metals Exploration, Mining and Processing (URM), Fast Reactor and Back End Fuel Cycle (FRR), Health Care (HLC), Food Security (FOS), Water & Waste Management (WWM), Mega Science Schemes (MSS), Basic Research & Science Education (BRE) and Directed Research (DIR).

During the calendar year, 74 new research projects with corresponding total grants amounting to ₹ 2044 Lakhs were sanctioned. Most of the projects have implementation periods of 2 to 3 years, during which the grant is utilised. The total grant of ₹ 3816 Lakhs has been released during this year for pursuing new and on-going research projects, supporting scientific events /workshops and financing the Olympiad Programme of training the Indian students contingent by Homi Bhabha Centre for Science Education (HBCSE).

Besides funding research projects, BRNS also provides financial assistance for organising symposia/ conferences/ workshops on topics relevant to the programmes of DAE. Financial support to the tune of ₹ 189 Lakhs was extended for conducting 89 scientific events. Out of these, sixteen fully funded symposia were organised by the DAE fraternity.

BRNS has also been providing financial support to educational activities of Homi Bhabha National Institute. Funding from BRNS also supports Dr. K. S. Krishnan Research Associateship and the DAE Doctoral Fellowship Scheme (DDFS) Programme. During the current year, 21 new students were inducted under DDFS Programme, bringing the total number of Ph.D. students enrolled under this scheme to 173. A total of 66 DDFS students have completed their Ph.D., since the inception of this scheme. Out of these, 11 students have been awarded Ph.D degree by HBNI this year.

The International Science Olympiad Programme is fully funded by the Government of India through the Board of Research in Nuclear Science, Department of Atomic Energy (BRNS, DAE), Department of Science and Technology (DST), Ministry of Human Resource Development (MHRD) and the Indian Space Research Organisation, Department of Space (ISRO, DoS). The national Olympiads are overseen by a National Steering Committee (NSC), constituted by DAE, comprising members of each funding agency as well as eminent experts in each subject. The national Olympiad programme follows a five stage process,

starting with an examination held at nearly 1400 schools across the country, selection process at multiple levels, extensive preparatory training of the finalists in Homi Bhabha Centre for Science Education (HBCSE) and finally, deputing the Indian contingent, including the student participants and a few leading teachers to yearly Science Olympiads in different subjects such as Physics, Chemistry, Biology, Earth Sciences and Mathematics. During the year 2019-20, BRNS has provided ₹143.16 lakh financial support to Olympiads in different subject areas.

Relatively higher scale grants are provided by BRNS by entering into MoUs with Research Institutes and Universities. Notable events and achievements of MoUs during this year are as follows:

- A National Facility for Atom Probe Tomography has been setup at IIT Madras with financial support received from multiple funding agencies. BRNS contributed to this programme by entering into a tripartite MoU between BRNS, BARC and IIT Madras. This sophisticated facility which will be utilised for atomic scale characterisation of structure of materials has the provision for remote operation enabling DAE scientists to utilise this facility while working at their parent institute.
- With BRNS funded research project (MoU), Central Glass & Ceramic Research Institute (CGCRI) Kolkata in association with RRCAT, has developed ingots for Nd doped LASER glass discs. Work for larger size discs with edge cladding is in progress. Directed Research committee of BRNS reviewed the progress of the work and found it to be satisfactory.

BRNS funded: 15 L Induction furnace setup at CGCRI at Kolkata for RRCAT, DAE

For improvement of Traditional Farmers Varieties of Rice of Chhattisgarh through radiation induced Mutation Breeding, a new tripartite MoU among BRNS, BARC and Indira Gandhi Krashi Vishwavidyalaya (IGKV) has been signed and the work is in progress. As an initial outcome, Safri-17-2 Mutant (named as TCR Vikram) is being proposed for state release in 2020.

Dr. A. K. Mohanty, Director, BARC monitoring the Rice Mutation breeding Field on 09-11-2019 (left), and Vice Chancellor, IGKV presenting samples of rice mutant Safri-17-2 Mutant to Chairman, AEC on 29-Nov-2019 (right).

Promotion of Mathematics

The National Board of Higher Mathematics (NBHM) was set up by the Government of India under the Department of Atomic Energy (DAE), in the year 1983, to foster the development of higher mathematics in the country, to formulate policies for the development of mathematics, help in the establishment and development of mathematical centres and give financial assistance to research projects and to doctoral and postdoctoral scholars. NBHM functions essentially autonomously framing its own budget taking into account the funds made available by DAE on yearly basis.

Major activities of NBHM involves Financial Support to Mathematical Institutions; Travel Grant/ Conference Support/Research Project Grant; Mathematical Olympiad/Madhava Mathematics Competition (MMC); Mathematical Training and Talent Search Programme (MTTS); Undergraduate/ Postgraduate/PhD Scholarships, PD(F) Fellowship; Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes.

The headquarters of the NBHM are at Mumbai. The Board usually meets twice a year, to discuss its programmes and various proposals received from all

over the country. It has set up several committees to consider, throughout the year, proposals received, essentially for financial support for varied mathematical activities, from institutions and individuals. Decisions of the NBHM are based on the recommendations of these committees.

A typical NBHM Board Meeting in progress

Undergraduate Scholarship for B.A./B.Sc. and Postgraduate Scholarship for M.A/ M.Sc

The Board has instituted several scholarships for outstanding students with a pronounced aptitude for research, studying for the Masters Degree in Mathematics or Statistics. The selection for awarding these scholarships is done on the basis of written test / interview. In 2019, a total of 3023 candidates applied, of which 1912 appeared in the examinations, and 40 of them were benefitted from NBHM M.Sc. Scholarship. As far as BA/BSc scholarships are concerned, a budget of ₹11 lakh (same as last year) was approved and a budget estimate of ₹35 lakh is approved for MA/MSc scholarships for FY 2019-20.

Ph.D. Scholarship

Students possessing Master's degree in Mathematics, Physics or Statistics and wishing to take up research work in any branch of Mathematics (including Mathematical Statistics and Mathematical Physics) leading to a PhD degree are eligible to apply for the PhD scholarships awarded by NBHM. The selection of the scholars is based on academic records and the result of a Selection Test / Interview by a selection committee constituted by the NBHM. The budget for PhD fellowships for the Financial Year 2019-20 was ₹3 crore.

Post-Doctoral Fellowship

Every year, NBHM offers Post-Doctoral Fellowships (PDFs) to selected young Mathematicians who have completed their PhD degree in Mathematics. The committee received 55 applications in the 1st round (January 2019) and 125 in 2nd round (July 2019). Out of these 14 PDFs were approved in the 1st round and 22 in the 2nd round. Thus during the year 2019, 36 candidates were awarded NBHM PDFs.

Visiting Professorship

The NBHM provides funds to University departments and other Institutions for inviting eminent Mathematicians from within India or abroad for lectures, joint work and other academic activities. A total of 10 visiting professorships were awarded to such Mathematicians under this scheme during the year 2019.

Library Grant

NBHM operates a scheme to extend financial support to the libraries of various Universities and Institutions. There are eight regional centres and budget for each centre was ₹ 45 lakh. Total approved budgetary estimates for Library support was ₹ 6.65 crore for the FY 2019-20. The funds are meant for purchase of books and journals. The Board was happy to note that some of the grant-receiving institutes were having devoted corners for NBHM books. Some of the institutes do match the NBHM grants with their own grants in the form of providing Air Conditioners and other facilities.

Book Distribution Scheme

Under this scheme, NBHM supplies selected books to Mathematics/Statistics departments of Universities/ Institutes/ Postgraduate centres. Books sent under this scheme are meant for the Institutional / Departmental libraries and not for individual collections. If any Mathematics department of any University/ Institute wants to be included in the mailing list of the Complimentary Book Distribution Scheme, they (should) write a letter to the Coordinator of this scheme. DAE released a sum of ₹ 43,91,426/- for this purpose.

Research Project Grant-in-aid

NBHM provides assistance for selected research projects on the recommendations of the Committee of NBHM. The committee approved 10 proposals out of a total of 17 under Research Project (RP)-2019 category. Further, the committee shortlisted 27 of the 46 evaluated proposals under fresh RP2019 category. All 7 applications received for renewal were approved under the renewal RP in 2019 category.

Travel Grant

NBHM provides partial or full travel assistance to Mathematicians for attending Conferences, Symposia, Summer schools, etc. within the country or abroad. Out of a total of 48 applications (35 old + 13 new) received by NBHM for consideration of travel support, the Committee approved 13 applications. The outgo for them was about ₹ 16 lakh.

Conference Support

NBHM provides financial assistance for holding national and International Conferences/ Workshops / Seminars. Out of a total of 168 such applications received/ evaluated, about 40 were approved during the year 2019 by the committee.

Mathematical Olympiad & Madhava Mathematics Competition

The Mathematics Olympiad activity was undertaken by NBHM from 1986 onwards and is currently run in collaboration with the Homi Bhabha Centre for Science Education (HBCSE), Mumbai. Main purpose of this activity is to support Mathematical talent among high school students in the country. DAE released a sum of ₹ 1,24,20,504/- to HBCSE for organising Mathematical Olympiad and Madhava Mathematics Competition for the Financial Year 2019-20.

A total of 1.25 lakh candidates (of which 1/3rd were girls) appeared in the Pre-Regional Mathematical Olympiad (PRMO) examination held on 11th August 2019. Thereafter, Regional Mathematical Olympiad (RMO) was held on 10th October, 2019 and about 1500 candidates appeared in it. Similarly, EMO was conducted during December 2019 to January 2020. India won a gold medal in Iranian Geometry Olympiad (IGO).

Indian Women in Mathematics (IWM)

IWM is a collective of Mathematicians that has been in existence since 2009. Its objective over the years has been to encourage more women to pursue higher education in Mathematics, and to provide an exposure and environment that enables them to take up careers in Mathematics. In its pursuit to fulfil the objective, IWM organizes various Workshops and Conferences that focus on presentation of original research work and discussion about career opportunities in Mathematics.

NBHM supports Visitors programme, Conferences and Mini-workshops under this scheme. A sum of ₹ 9,98,000/- from the total of ₹ 27,32,160/- for the year 2019-20 was released to support 1st conference of IWM held at IIT Bombay during June 10-12, 2019. Subsequent to the above 1st installment, DAE released 2nd installment of ₹ 17,34,160/- in October, 2019.

Institutional Support is provided by NBHM to Chennai Mathematical Institute, Chennai; Kerala School of Mathematics, Kozhikode; National Centre for Mathematics, Mumbai; Bhaskaracharya Pratishthana, Pune and Institute of Mathematics and Application, Bhubaneswar.

Mathematics Training and Talent Search (MTTS), Hyderabad

During the summer vacation, active training programmes are also organized outside the regular educational framework at the undergraduate level, called Mathematics Training and Talent Search (MTTS). NBHM released a sum of ₹ 98,89,690/- (1st instalment of ₹ 78,89,690/- and 2nd of ₹ 20,00,000/-) to MTTS out of its approved financial support of ₹ 1 crore for the Fincnail Year 2019-20.

The International Conference on Industrial and Applied Mathematics (ICIAM-2019) is an event of unique significance to the Mathematical community around the world. It is held once every four years. NBHM approved funding requirement of 40 candidates from India to participate in the ICIAM 2019 held at Valencia (Spain) during 15-19th July, 2019. Out of these 32 availed the NBHM offer.

The selected applicants were from two categories i.e. Junior and Senior. Under Junior category were PDFs and Senior Research Students. Senior category comprised Senior Teaching Faculty from University and Colleges. There were no separate travel grants approved under this event.

GRANTS-IN-AID

Grants to Aided Institutions

The aided institutions of the Department of Atomic Energy are an integral part of the Department in as much as there is a growing synergy between these institutions and the Research and Development Units of the Department. Several joint projects have been undertaken between the Units and Aided Institutions and there is frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. The Department has eleven aided institutions fully funded in terms of their recurring and non-recurring expenditure and these institutions are growing at a faster pace in terms of the projects undertaken by them. They are Tata Institute of Fundamental Research (TIFR), Mumbai; Tata Memorial Centre (TMC), Mumbai; National Institute of Science, Education & Research (NISER), Bhubneshwar; Institute of Physics (IoP), Bhubneshwar; Saha Institute of Nuclear Physics (SINP), Kolkata; Harish-Chandra Research Institute (HRI), Allahabad; Institute of Mathematical Sciences (IMSc), Chennai; Institute of Plasma Research (IPR), Gandhinagar; Atomic Energy Education Society (AEES), Mumbai; Homi Bhabha National Institute (HBNI), Mumbai and University of Mumbai – Department of Atomic Energy – Centre for Excellence in Basic Sciences (UM-DAE-CBS).

Budget Provision of ₹ 2613.84 Crore has been made for aided institutes towards salaries, creation of assets etc.

Grants to Cancer Hospitals

The Department extends financial assistance to Cancer hospitals located in other parts of the country. The grant released for the year 2019-20 for such partial financial assistance is to the tune of ₹ 10 crores.

An increasing need was also felt to use the expertise available in the DAE funded Tata Memorial Hospital for creating a better network between cancer institutions all over the country. This would include research & development, training and preparation of protocols for treatment as well as incentives for indigenization of much of the radiation related equipment for cancer treatment. For this purpose, an Apex Committee was formed under the Chairpersonship of Director, TMC. The Apex Committee has deliberated on indigenous development and manufacturing of the equipment related to radiation oncology such as Cobalt 60 Teletherapy, Low Energy Linear Accelerator, High Energy Linear Accelerator, simulator development, Brachytherapy.

The initiatives taken to achieve the above stated objectives will lead to further gains in the DAE's outreach in the cancer care programme.

Olympiad Programme

The major highlight during this period was India's continued success at the International Olympiads. 24 Indian students at the International Olympiads (held during July–August 2019) returned with medals. The subject-wise distribution of medals are as follows: Mathematics (1 Gold, 4 Silver, 1 Honourable Mention); Astronomy and Astrophysics (1 Gold, 3 Silver, 1 Bronze); Biology (3 Silver, 1 Honourable Mention); Chemistry (2 Gold, 1 Silver, 1 Bronze) and Physics (2 Gold, 3 Silver). HBCSE was recognised as a Centre of Excellence in Science and Mathematics Education (CESME) under the Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching, by the MHRD, Government of India. Under Vigyan Pratibha project, a science talent nurture programme for students of Class 8-10 in Kendriya Vidyalayas, Jawahar Navodaya Vidyalayas and Atomic Energy Central Schools, about 25 Learning Units in Science and Mathematics developed in the previous two years have been revised and further developed based on trials with students and teachers from different schools. Team members visited several (about 25) schools to observe teachers conducting learning units and also conducted some of these units with the students. Two National Initiative on Undergraduate Science (NIUS) exposure cum enrichment camps were conducted —

Biology (41 students) and Physics (65 students). The camps consisted of both theoretical and experimental sessions.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

Development of e-Procurement Software for DPS

The Computer Division of IGCAR has developed an in-house E-Procurement Software to make the entire procurement workflow online with the implementation of digital signature. It is a full-fledged end-to-end e-Procurement system covering all the processes of indent management, committee approvals, tendering, purchase order recommendation, purchase order release, inventory management (stores), payments and accounts. The software is meant for use by DAE units, Purchase Units and Stores. The software has been deployed in Anunet and is being effectively used by IGCAR, GSO and DPS/MRPU.

Unified monitoring of critical network services

Various network services such as Email, Internet, DNS are provided to users of IGCAR on round the clock basis. These services need to be monitored regularly to ensure high availability. A unified monitoring web service has been developed using open source framework and implemented for all the critical network services. The system does real-time monitoring of services running on internet/intranet servers and generates alerts if any service reaches undesired state. The alert modules are configured to send e-mail to administrators of the respective systems and display alert on the dashboard.

Installation and commissioning of high performance computing cluster, Kshitij-5

High Performance Computing Cluster (HPCC) Kshitij-5 has been installed, commissioned and is released to the users for running Scientific and Engineering applications. Kshitij-5 is the latest addition to the centralized scientific computing facilities available in RRCAT. The sustained computing power delivered by Kshitij-5 HPCC is 190 Teraflops with 64 compute and 8 GPU nodes.

Deployment of parallel scientific computing applications on high performance computing clusters

As per requirement of users, various parallel applications such as MPP crystal, VASP, WEIN2k, EPOCH, parallel elegant, orbit MPI, and Amber have been successfully ported on Kshitij-5.

Intelligent agent for counting and detection of moving vehicles in videos

Intelligent agent has been developed for detection and counting of moving vehicles in videos using deep learning based algorithms. Convolutional Neural Network (CNN) and publically available COCO dataset is used to develop and train the agent. The agent is tested over variety of videos and produces 100% counting accuracy. This will be used for the categorization of types of vehicles entering in the technical area at guard house security post.

Development of statistics of usage of computing resources in graphical format for HPC clusters

Software packages for graphical representation of usage of individual user of HPC Clusters have been developed and deployed in RRCAT web-site. Usage can be view graphically for current month and last six months.

Commissioning of secure ARPFNet for ARPF site

ARPFNet is commissioned to provide secure network connectivity between RRCAT main campus and ARPF site near Sabji Mandi, Indore (10 km distant). A 12 port local area network has been commissioned for secure access of RRCATNet resources from ARPF site. ARPFNet is presently configured for monitoring of attendance of staff and for seamless access of RRCAT Infonet, Email and Internet facilities at ARPF site.

Design, development and deployment of centralized file sharing facility e-साझा

Centralized File Sharing facility, named e-साझा has been developed and released to users over RRCAT local network (RRCATNet). This facility can be used to share large files among RRCAT users authorized to access e-साझा facility in place of email where size restrictions are there. Each user is provided with 10 GB space for sharing large files. This facility is made available to members of Director's Advisory Committee (DAC), Scientific Committee of RRCAT (SCR) and all Group Board Members. This facility will help to reduce the usage of removable pen drives to a great extent.

Design, development and deployment of various Information Management Systems

Revamped RRCAT information portal - RRCATInfonet has been released on upgraded cluster based setup using multi-level load balancing to achieve enhanced scalability, availability, performance and reliability. Public Key Infrastructure (PKI) setup has been augmented by establishing Timestamp services to support assertion of proof for digitally signed documents after expiry of digital certificates.

Web based software for monitoring of PRIS-G targets has been developed and deployed on RRCATInfonet for keeping track of progress of targets by close monitoring. Various monitoring reports from this software will ensure availability of timely information to Director and Group Directors for effective decision making.

The significant developments in the last one year include software applications on RRCATInfonet to automate and streamline the process of GPF/CPF Advance/Withdrawal, quarter application, allotment and TA Settlement in paperless manner, while enhancing user convenience, saving time and improving efficiency. Workflow based software for online requisition and approval for liquid nitrogen and liquid helium has helped in managing the requirements and distribution of liquid nitrogen and helium to the users efficiently in paperless manner.

Software for submission of online applications for RRCAT conducts Young Scientist Research Programme (YSRP) has been developed and deployed over internet which has helped in efficient processing of applications in paperless manner. Dashboard has been developed and deployed on RRCAT website which facilitates presentation of real-time data for various key performance indicators like publications, human resource development and experiments performed on Indus beamlines of RRCAT.

Web based software has been developed and deployed on RRCATInfonet for logging Events and generating reminders via email (on RRCAT email account) and SMS (on registered mobile no.).

Publication management software has been developed and deployed on RRCATInfonet to keep track of publications. The software has provision for submission of requests to Head of Divisions/ Independent Sections for approval of uploaded manuscripts, plagiarism check reports and other documents related to the publications.

Revamping of telephone exchange of RRCAT colony area

Telephone exchange (EPBAX) of RRCAT colony area has been revamped. The number of services and telephone connections have increased multi-fold over a long period. The mesh of cables in the small room was causing trouble for telephone maintenance. Complete re-installation of EPBAX setup with re-routing and re-termination of all field cables was planned and executed successfully. All the services from this exchange were resumed in minimum possible down time.

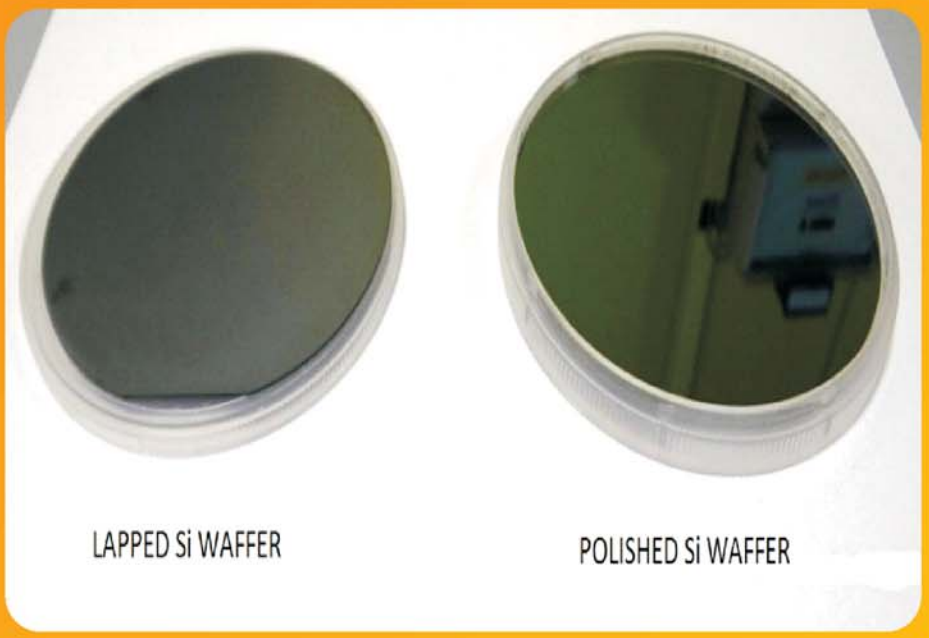
Upgradation of network security monitoring infrastructure

RRCATNet Security Information and Event Management (SIEM) infrastructure is enhanced with addition of Elasticsearch, Logstash and Kibana (ELK) stack (version 7.2) setup for real time network traffic and server logs monitoring and analysis. Various dashboards have been created to monitor malicious activities. This has allowed graphical visualization and statistical analysis of various network access activities related to RRCATNet over Internet.

CHAPTER 7

A compact, 13 kV/5 A, prototype Capacitor Charging Power Supply (CCPS) has been indigenously designed, developed and tested by RRCAT, Indore

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES



LAPPED Si WAFFER

POLISHED Si WAFFER

Mono crystalline silicon wafers - a Technology developed by BARC

The spin-off technologies generated out of the core programmes of the Research and Development organizations of DAE were developed and transferred to industries for commercial exploitation. Over a period of time, a number of technologies have been transferred to industries.

DAE organizations also entered into scientific collaborations with public and private sector organizations. This interaction has given beneficiary organizations a technological edge.

TECHNOLOGY TRANSFER

At BARC, a total of 33 technologies have been transferred to 44 parties. The 24 new technologies that have been introduced into public domain during the year are High-Efficiency Distillation Columns for Separation of Fluid Mixtures; Process for De-Bittering Fenugreek Seed Extracts; Cellulose based Water purifier for Arsenic removal; Setting up of a Gamma Radiation Processing Plant (RPP); Microplate based optical biosensor for detection of Methyl Parathion; Radio Frequency Directional Power Sensor; Multi Effect Distillation with Thermo Vapour Compression (MED-TVC) Desalination Technology; Biodegradable Films for Food Packaging Applications; Biosensor Kit (Biokit) For Detection of Organophosphate and Organocarbamate Pesticides; Super Cotton (super absorbent for removal of oily substance from aqueous media); Low-Carbon Ferro-Alloys (FeV, FeMo, FeNb, FeW, FeTi & FeC); Chlorine Dioxide releasing polymer for water disinfection (CLEAN); A Rapid, Reproducible and Sustainable Micropropagation Protocol for Turmeric (Curcuma longa L.); BLDC Motor Based 5 HP Solar Water, Pump; SP-FeDK: Smartphone based Iron Detection Kit for boiler coolant water; Mercury Visual Detection Kit for ground Water [MVDK]; Fast Current Transformer (FCT); Synthesis of NMC cathode for lithium ion battery; Liquid Helium (LHe) Dewar of 1000 L Nominal Capacity; 60 kW RF Broadband Dual Directional Coupler; Gluten Free - Multigrain premix; Hybrid Granular SBR for Wastewater Treatment (GST); Variable Collimated Hollow Laser Beam Generator and Minimally processed ready-to-eat (RTE) apple slices.

COLLABORATIVE PROGRAMMES

BARC and Indian Oil Corporation Ltd. signed a Memorandum of Understanding for development of Magnetic Flux Leakage – Ultrasonic combo Instrumented Pipeline Inspection Gauge (IPIG) with built-in speed control mechanism for 18-inch, 30-inch gas pipelines. The technology is envisaged to strengthen the integrity management of over 40,000 km of underground pipeline network for transportation of crude oil, natural gas and petroleum products.

SOCIETAL INITIATIVES

Government of Maharashtra signed AKRUTI (Advanced Knowledge & RUral Technology Implementation) Tech Pack agreement for development of a Project to demonstrate “Cillage Based Area Development”. Around 12 AKRUTI Tech Pack agreements and 39 technology licenses have been signed with 5 educational institutes, private firms, individuals and a woman entrepreneur. These agreements provide perpetual licenses for exclusive rural deployment of technologies such as Soil Organic Carbon Detection & Testing Kit, Rapid Biocomposting Process for dry leaves and garden waste technology, Nisargruna-Biogas plant based on biodegradable waste technology, Banana Tissue Culture, Vibrothermal disinfestor technology, Foldable solar dryer technology, Mass Multiplication Medium of Biofungicide “Trichoderma spp” technology, Micro-fine Neem Biopesticide, On-Line Domestic Water Filter based on UF Membrane and Nanocomposite Ultrafiltration Membrane Device for Purification of Arsenic, Iron and Microbial Contaminations in Domestic Drinking Water.

In order to promote technologies developed by BARC for rural populace, DAE Technology Display & Dissemination Facility (DTDDF) centres were proposed and two centres - at Manipur Science and Technology Council and at Utkal University in Bhubaneshwar were established during the year.

INTELLECTUAL PROPERTY RIGHTS

DAE-IPR Cell constituted by the Department, works as a nodal agency for all Intellectual Property Rights (IPR) related matters including filing of patents within India and abroad for all the Units including Public Sector Undertakings and Autonomous Institutions under DAE. During the financial year 2019-20, four DAE-IPR cell meetings were held, which reviewed fifteen new patent proposals. DAE filed ten new patent applications which includes; six in India, two in USA and one in Europe. One application was filed under the Patent Co-operation Treaty (PCT).

During this period, seven of the previously filed patents were granted to the Department. These includes; four in USA, two each in Europe and one in India. Following are the list of patents granted:

A Tri-vane Spiral Vacuum Booster Device for Pumping High Volumetric Fluid at Low Pressure - by BARC (in India): This invention relates to a spiral vacuum booster device for vacuum pumping system, for handling corrosive, condensable process gas at low pressure and at high purity level. The spiral vacuum booster device is equipped with Variable Frequency Drive (VFD) to operate at varied range of rpm to accommodate variable capacity backing pump as per different throughput requirement. This arrangement in turn leads to improved bearing & bellow life and reduced power consumptions. The booster device does not need any forced cooling arrangement favouring reduced overall power consumption.

Method of Manufacturing Actively Cooled Accelerator Grid with Full Penetration Weld Configuration – by IPR (in USA): This invention relates to a specialized joining configuration and process which can weld through the thickness resulting in a full penetration Electron Beam Weld (EBW) of SS pipe to Copper plate using an Inconel intermediary with full integrity of the joints. The invention finds application in neutral beam source accelerator grid segments, space and defense applications with different combination of materials.

A System, a Device and a Method for Passive Decay Heat Transport – by BARC (in USA & Europe): This invention is intended to remove the decay heat from the core directly to the atmospheric air using liquid metal coolant and heat dissipating fins. It comprises of liquid metal coolant (such as lead in multiple closed thermosiphons) which transports heat in fuel and multiple transition liquid metal thermosiphons dissipating heat to the atmospheric air. The entire cooling circuit remains in operation all the time (during reactor operation as well as after shut down). The proposed invention provides a passive decay heat removal system from water cooled reactors like; Advanced Boiling Water Reactor (ABWR), Advanced Pressurized Water Reactor (APWR), Advanced Heavy Water Reactor (AHWR), Boiling Water Reactor (BWR), Indian Pressurized Water Reactor (IPWR) and Reaktor Bolshoy Moshchnosty Kanalny (RBMK).

A method and device for tuning SCRF Cavity – by RRCAT (in USA): The invention relates to a method and device for tuning single-cell or multi-cell SCRF cavity for precise slow and fast tuning. The tuning device is the essential element of any SCRF cavities, which keeps the cavities in the correct resonating frequency with that of the source frequency at cryogenic temperature. The tuner uses an X-link mechanism, which is rugged, reliable, ease of manufacture & assembly, low hysteresis and reduced fabrication cost. The device could have wide applications in projects such as in International Linear Collider (ILC) and Indian Institutions-Fermilab Collaboration (IIFC) where a large number of SCRF cavities will be used.

A process for the removal of ^{99}Tc from liquid intermediate level waste of spent fuel reprocessing – by BARC (in USA & Europe): The invention relates to a process for removal of ^{99}Tc from liquid intermediate level waste of spent fuel reprocessing by using mild steel wool as a source of ferrihydrite. ^{99}Tc gets captured in the crystal lattice of the corrosion products goethite (FeOOH / Magnetite) which is then removed by filtration / settling. The supernatant solution, free of ^{99}Tc, is discharged while the goethite bearing the ^{99}Tc waste is subjected to vitrification and storage.

During the same period, the following 2 patented technology were licensed to 3 companies in India:

- Online domestic water purification based on polysulfone membrane (BARC)
- Foldable Solar Dryer (BARC)

Among the new patent applications that were filed, the following were published during the year:

1. **A System, a Device and a Method for Passive Decay Heat Transport** – by BARC (in Japan – App. No. 2017-521143 dated 13-Apr-2017).
2. **A process for the removal of ^{99}Tc from liquid intermediate level waste of spent fuel reprocessing** – by BARC (in USA – App. No. 16/076,523 dated 08-Aug-2018).
3. **A Method of Manufacturing Radio Frequency (RF) Coil Multi-Driven RF based Negative Ion Source** – by IPR (in USA- App. No. 16/058,195 dated 08-Aug-2018; Europe – App. No.. 18175976.2 dated 05-Jun-2018 & India – App. No. 201821014176 dated 13-Apr-2018).
4. **Human Neural Precursor Cells with Inducible STIM1 Knockdown** – by TIFR (in India – App. No. 201841014670 dated 18-Apr-2018).
5. **Method and electronic device for providing image-based CAPTCHA challenge** – by TIFR (in USA – App. No. 15/937,865 dated 28-Mar-2018).
6. **Process for Determination of parts per billion (ppb) levels of Total Iron in Boiler Coolant water** – by BARC (in India – App. 201921009009 dated 08-Mar-2019).
7. **A Beam Visualizer Device** – by RRCAT (in India – App. 201921009442 dated 11-Mar-2019).
8. **Metal-Carbon Aerogel Composite Electrode, Aerogel Supercapacitors, Process of the same and Application thereof** – by BRNS Project (BARC & CMET, in India – App. No. 201921012033 dated 27-Mar-2019).
9. **Method for Bio-beads Development for Normal and Saline Wastewater Treatment** – by BARC (in India – App. 201921015793 dated 21-Apr-2019).
10. **System and Method for Screening Chest X-Ray Image for Diagnosis** – by IPR (in India – App. 201921016615 dated 26-Apr-2019).

The above published documents can be accessed from the respective Patent Office websites:

Indian Patent Office
http://ipindiaservices.gov.in/PublicSearch/

US Patent Office
https://portal.uspto.gov/pair/PublicPair

European Patent Office
https://worldwide.espacenet.com/advancedSearch?locale=en_EP

During the year 2019-20, about 129 patent applications were referred to the Department by the Controller General of Patent, Intellectual Property (IP) India, to screen for the applicability of section 20 (1) of Atomic Energy Act, 1962, i.e., whether the application is related to or useful for atomic energy, and give its opinion. Directions of the Department were communicated to the Controller of Patents in India.

A one-day IPR awareness workshop was conducted for scientists and engineers at Electronics Corporation of Indian Limited (ECIL) Hyderabad and Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam.

Chapter 8

Office Building for AERB easter region at Kolkata

INFRASTRUCTURE

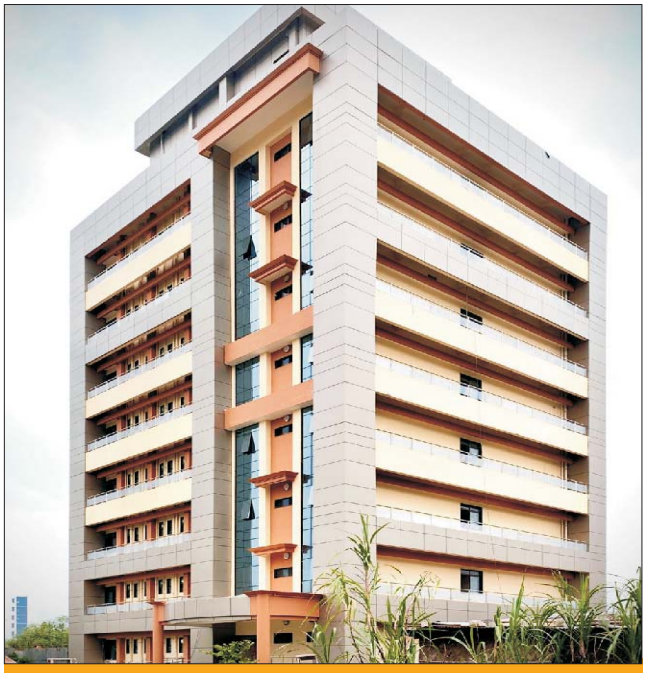
Construction of Extension of Vikram Bhavan at Anushaktinagar

CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible for providing infrastructure support to various Units of Department of Atomic Energy (DAE) including its aided institutions. DCSEM is involved in planning, designing & execution of various construction works for Housing, Schools and Hospitals, Laboratories, Institutional Buildings & infrastructural facilities to support the scientific & technological programmes of DAE. The Directorate is also responsible for operation and maintenance of various services, Estate Management and Security for the housing colonies of DAE at Mumbai.

During the year of report, the gist of major works completed by DCSEM include Construction of R & D Laboratory for AMD and Office Building for AERB eastern region at Kolkata; Construction of Type IIB DAE Housing 24 flats at RMP Mysuru, Karnataka; Renovation and upgradation of AERB Buildings A & B Block (Niyamak Bhavan) at Anushakthinagar, Mumbai; Infrastructure works for improvement of Security system is completed; Construction of Bio-Gas Plant in DAE Housing colony at Anushakthinagar, Mumbai (Under Swatchhta Action Plan); Cleaning Activities of DAE premises at Anushakthinagar (Under Swatchhta Action Plan) and Laying of DI water supply line from UGT of Mandala to UGT of 312 Type VE flats at Anushakthinagar, Mumbai.

Construction of R & D Laboratory for AMD



Office Building for AERB eastern region at Kolkata

Construction of Type IIB DAE Housing 24 flats at RMP Mysuru, Karnataka

Construction of Bio-Gas Plant in DAE Housing colony at Anushakthinagar, Mumbai

Major works of DCSEM under progress are Restoration / Renovation of Old Houses more than 20 years old Phase-II; Up gradation of External Engineering services under 12th plan; Construction of 356 nos. residential quarters; Hostel for trainees of BARC/HBNI Phase- I&II; Construction of Extension to V.S. Bhavan; Construction of 312 flats of type V-E at Mandala, Anushaktinagar, Mumbai; Construction of Entry Portal & Boundary wall works at RMP Yelwal, Mysuru, Karnataka; Construction of 48 Flats Type I & II flats for SMF at Chellakare, Chitradurga, Karnataka; Construction of 100 Bedded Hospital building complex at Aganampudi, Visakhapatnam, Andhra Pradesh; Construction of Residential Quarters Type III, IV & V, Guest House B, Central Block and New School Building for GCNEP under Phase II at Bahadurgarh, Haryana; Pre Project Activities of LIGO (India) Project at Hingoli, Maharastra; Construction of Buildings for UGC-DAE-CSR, RMRC & Diamond Jubilee Guest House for VECC at Kolkata and Construction of Office Building for AERB (Niayamak Bhavan-C) at Anushakthinagar, Mumbai.

Construction of 356 nos. residential quarters at Anushaktinagar

100 Bedded Hospital Complex at Visakhapatnam Andhra Pradesh - Radio therapy block

Construction of Extension of Vikram Bhavan at Anushaktinagar

DCSEM continued to maintain the residential flats (10,169 nos.) and Institutional buildings viz. DAE Secretariat, Dispensaries, AEES Schools, Community Centres, Shops, DAE Guest House etc. in Anushaktinagar, Mandala & City area, including execution of upgradation works required for these buildings. It is also carried out the operation & maintenance and upgradation of electrical power distribution, water supply, sewer lines, sewage treatment plant, fire-fighting system, rain water harvesting system etc. for Anushaktinagar, Mumbai.

The Estate Management continued to look after the allotment & supervision of various public buildings like banks, post office, shopping centre, community centre, etc. within the residential colony.

PURCHASE & STORES

Directorate of Purchase & Stores (DPS), a service Organisation of DAE, carries out the Materials Management function of DAE since 1972. Procurement of the right material at the right price from the right source at the right time adopting the right procedure and receiving, storing, preserving, issuing the material and disposing Surplus & Scrap items has been its mandate. It also concludes various service contracts such as transportation contracts, import/export clearance contracts, Marine Insurance Contracts, etc.

The procedures for purchase and sale were continuously reviewed and simplified for improving efficiency. The e-tendering system used for procurement was upgraded and extended for sale tenders and DAE users located at remote corners were able to use the system. Tender documents were modified for implementation of Government procurement policies and for proper contract management.

Usage of Information Technology tools for materials management

Usage of Information Technology tools for materials management is being continuously increased using the technical competence of the constituent units of DAE. All major units are able to process their indents online. IGCAR has introduced new software for processing indents. Since, a large number of common user items are procured from GeM, the materials management software was modified by BARC to facilitate inclusion of requirements of procurement and updating status of procurement. DPS has trained its staff to utilise the new applications.

DPS processed about 14,000 indents, floated 13,139 tenders and entered into about 12,500 indigenous contracts and about 300 foreign contracts for supply of equipment and material worth about Rs. 2114 crores.

E-sale is presently being used at Central Stores Unit Mumbai, Stores Unit NRB Tarapur, Stores Unit IGCAR, Stores Unit AMDER Nagpur and Indore Regional Stores Unit. Users and vendors were trained for the new application. The process of transition to manual sale tender to e-sale tenders has been successful.

The complete inventory of all zonal stores at BARC, Mumbai comprising of over 70,000 items was codified in the new 11-digit material codification system. The staff and officers of DPS were trained for its usage. Stores Unit RMC, DAE, EBC Kharghar, Kalyan Stores, BRIT Vashi and DCSEM were codified using EMATMAN (Codification Programme). All Items at other Stores Unit were codified using the respective codification system available there.

Monitoring of contracts

In order to ensure speedy processing of purchase files as well as timely execution of contracts monitoring of High values cases carried out by officers of DPS at various levels. The review of files has resulted in considerable reduction in lead time and improved contract management.

User interaction

DPS has made considerable efforts in interaction with DAE users and its vendors as they need to be educated with the latest mode of procurement.

The vendor meets at Mumbai and Chennai were organized for manufacturers of Medicine, Medical equipment and associated accessories to create awareness about the requirements of hospitals of DAE and also to obtain their feedback. Vendor meets were also organized with MSME/NSIC Manufacturers, services providers etc., to create awareness of the requirement of DAE and also to educate the vendor community with regard to the latest changes introduced in E-tendering with revised tendering conditions of the Directorate. Training on E-procurement portal are arranged for the vendors.

In order to sort out the issues related to procurement, regular meetings were arranged for Departmental users. The issues as raised by the users in these meetings were addressed and monitored. In addition to these meetings issues raised are addressed through separate mail ID created for the purpose. Video Conference connectivity was established with DPS Mumbai and HWP Tuticorin, Baroda, Kota and Manuguru, VECC Kolkata, GCNEP etc.

Uranium fuel import

During the calendar year DPS has procured uranium from Canada and Kazakhstan. Discussions were also held with prospective uranium suppliers from Canada, Australia, Japan, Russia, Uzbekistan and Kazakhstan for negotiation of new contract. New contracts were signed with Russia and Uzbekistan.

Implementation of computerised solutions for Administration

APAR (Annual Performance Appraisal Report) of all employees working in units connected with ANUNET was submitted and evaluated online using a software developed by IGCAR. A new software module developed by Computer Division BARC was introduced for salary disbursement and leave management for employees at DPS Mumbai, Tarapur and Mysuru.

Automation of internal procurement process

At NPCIL, an initiative is taken for automation of internal procurement process to cover whole procurement cycle from user request to its payment and subsequent follow-ups. Modules for indent and tendering are already released for internal use. For improved vendor collaboration during Procurement, engineering and construction, vendor portal has been developed which can be used for exchange and approvals of drawings and documents with vendor participation, reducing the communication time and improving version control.

GENERAL SERVICES ORGANISATION

General Services Organization, Kalpakkam takes care of the common facilities such as Housing, Medical, Transport, Water Supply, Civil, Electrical, Telecommunication, Solid waste collection and disposal etc in the Atomic Energy Townships at Kalpakkam and Anupuram where employees of the DAE Units at Kalpakkam, viz – IGCAR, BARCF, MAPS and GSO reside. GSO provides infrastructural support to the Kendriya Vidyalayas, Atomic Energy Central Schools, Atomic Energy Higher Secondary School and accommodation for the CISF personnel. GSO liaises with State Government Departments for supply of water (to Plant site and Townships) & Cable TV network Connections with BSNL for telecommunication network to the Townships.

The activities of GSO are carried out by the Engineering Services Group and the Medical Group. The Engineering Services Group comprises of the Civil Engineering Division, the Engineering Services Division and the Planning & Computer Section. The Group is responsible for construction and maintenance of residential quarters, hostels and public buildings and providing essential services such as water supply, electricity, sewage treatment and solid waste collection and disposal. It's other major activities include maintenance of roads, operation and maintenance of electronic Telephone Exchange. Industrial safety, fire safety, air conditioning, transport, Autoshop activities and horticulture. The Autoshop takes care of maintenance of all department vehicles and Strategic Special Nuclear Material (SNM) Transport Vehicles which are visiting Kalpakkam from various BARC Units regularly. The Computer Section is responsible for all computerisation activities and providing hardware, software and networking support to offices and public buildings. The Planning Section is responsible for planning and budget monitoring of the Capital Projects.

The Medical Group comprising of Hospitals at the Kalpakkam and Anupuram Townships provides medical services to serving and retired employees of DAE Units at Kalpakkam. The DAE hospital at Kalpakkam also handles emergency medical cases from the neighbouring villages including accidents that occur on the East Coast Road.

All the activities of GSO are supported by Administration and Accounts who also look after Personnel Management, Estate Management and Recruitment.

Some of the significant works carried out this year includes the following:

- A check dam was constructed across the Palar River by the Tamilnadu State, PWD with full funding from GSO. GSO engineers co-ordinated

with the Tamilnadu State Water Resources Division and IIT Madras for finalisation of an innovative Design of the Dam. The Project was diligently monitored and completed in a record period of six months at one third the cost of a conventional check Dam.

- In-house Architectural & Structural engineering design of 0.15MLD and 1.5MLD Hybrid Biofilm Granular Sludge (HBGS) technology based Sewage Treatment Plants was completed.
- In-house Architectural & Structural engineering design of Type VE Tower Blocks was completed.
- Work orders for 93 works were placed at a total cost of Rs. 88.37 Crores. Some of the major work orders issued include Construction of Hospital (Phase-II), Balance works for 55 Nos. of type IVD quarters and 45 Nos. of type VE quarters (Tower 3 - G+12 storey), Balance works for 120 Nos. of type IIIC quarters (Tower 4 - G+15 storey) and Balance works of Guest house at the Anupuram Township, Construction of Kindergarten school, Extension of Dining and Kitchen for Multipurpose Hall and Construction of HP Lab expansion building at Kalpakkam.
- Construction of one Tower Block of Type – IIIC (120 apartments), one Tower Block of Type – IVD (120 apartments) and Additional Classes for Higher Secondary at AECS-II was completed. Construction of HBGS technology based Pilot plant at DAE Township, Kalpakkam is in progress.
- Rehabilitation works to aged Residential and Non-residential buildings was carried out to strengthen the structure and enhance the life period.
- 11 kV Additional VCB Panel boards were installed and commissioned at Substation MSS-2.
- A 380 kVA Diesel Generator Set was installed in Sub-station No. 5 at Kalpakkam Township, to distribute Class III Power supply to the Type IIB-tower blocks to cater to fire water and potable water pumping systems, one stretcher lift and common corridor lighting schemes, in case of a Class IV power failure or shutdown.
- Solar Water Heater system with storage tank facility was installed at the New Guest House at Anupuram.
- Video Conference System was installed at the GSO Annex Building in Kalpakkam Township and Meeting Room at Anupuram Township, to facilitate communication with other DAE Units and DAE headquarters.
- In phase-2 of e-surveillance of office buildings, CCTV camera network was installed at the offices and facilities such as the Water Treatment Plant, Sewage Treatment Plant, Pump houses and Guest Houses at the Anupuram Township.
- Fire Hydrant main for KV-2 and AECS-2 Schools was commissioned.
- A centralized Lubrication Oil Distribution System with single barrel storage system and associated piping system was installed. The new system ensures a leak free shop floor and accurate oil filling with enhanced productivity.
- The installation of the Security Isolation Fencing at both the townships was completed. A stringent system for operation of the Security Gates was introduced.
- OPD services like consulting rooms for General, Ophthalmology, Orthopedics & Dental cases, Pharmacy, laboratory, physiotherapy, Casualty department etc. started functioning at the new Hospital at Anupuram.
- As part of improvement of medical facilities under the Project “Enhancement of medical facilities at Anupuram and Kalpakkam Hospitals Plan Project”, action has been initiated for procurement of new equipment required both at Kalpakkam and Anupuram Hospitals.

CHAPTER 9

MACE Telescope at Hanle, Ladakh

PUBLIC SECTOR UNDERTAKINGS
(FINANCIAL PERFORMANCE)

X-ray Baggage Inspection System

Financial performance of DAE's public sector undertakings namely, the Nuclear Power Corporation of India Ltd., Uranium Corporation of India Ltd., Indian Rare Earths Ltd. and Electronics Corporation of India Ltd. are given below. (BHAVINI is yet to commence commercial operations). Operational highlights of these public sector undertakings, except ECIL, have been covered under the relevant major programme heads. Gist of the financial performance of these units along with detailed operational performance of ECIL is given here.

NUCLEAR POWER CORPORATION OF INDIA LTD.

The provisional profit (Total Comprehensive Income) up to December 31, 2019 in the current Financial Year 2019-20 is ₹ 3650 Cr. and the expected profit for the current financial year is around ₹ 4000 Cr. The profit (Total Comprehensive Income) for the last Financial Year 2018-19 was ₹ 2779 Cr.

URANIUM CORPORATION OF INDIA LTD.

The total income of the Company during the year 2018-19 was ₹ 2034.79 Cr. as against ₹ 1793.98 Cr. in the previous year. In terms of performance of the Company for the year 2018-19, UCIL is provisionally rated as "Excellent" by Department of Public Enterprises (DPE) as per Memorandum of Understanding (MoU) signed by the Company with Department of Atomic Energy. For the first time UCIL has achieved "Excellent" MoU rating for second year in a row.

INDIAN RARE EARTHS LTD.

During the period upto December 2019, the company registered growth in Sales Turnover by 33% as compared to corresponding period of previous year. Profit Before Tax (PBT) for the period upto December, 2019 is increased by 79% as compared to corresponding previous year.

ELECTRONICS CORPORATION OF INDIA LIMITED

Electronics Corporation of India Limited (ECIL) was established in 1967 as a Public Sector Enterprise under Department of Atomic Energy (DAE) to support the Control and Instrumentation (C&I) requirements of India's Nuclear Program. ECIL has pioneered a number of products and technologies and achieved significant results with prudently designed R&D programs and products ranging from miniature components to complex systems.

ECIL has world class infrastructure for design, manufacturing and testing of equipment to meet the functional performance, reliability and quality requirements of products required for Strategic sectors. The infrastructure includes facilities for CAD, CASE Tools, High Density Interconnect PCB facility, automatic SMD insertion machines, on-line PCB test equipment, EMI/EMC facility, calibration and characterization of radiation instruments, environmental testing and calibration and compact antenna test range facility.

ECIL has set up a Secured Manufacturing Facility as a trusted center for production of sensitive and strategic equipment with well-defined procedures and calibrated process flow.

Performance

The Company achieved a landmark turnover of [1] 2663 crores in FY 2018-19 because of its time bound supply of Electronic Voting Machines (EVMs), Voter Verifiable Paper Audit Trail (VVPATs) for General Elections 2019. The Company successfully manufactured 3.3 lakhs of latest model (M3 version) EVMs and 5.8 lakhs of VVPATs at the newly established Secure Manufacturing Facility (SMF) and supplied them for 2019 Loks Sabha Elections. ECIL also provided extensive support to Election Commission of India (ECI) for smooth conduct of Elections.

The Company has been set with a MoU Target of ₹ 1900 crores for 2019-20.

The sector-wise significant contributions during the year 2019-20 are as follows:

Atomic Energy

Major contribution in Nuclear sector is from Ultra Stable Power Converters, Passive Catalytic Recombiner Device for Nuclear Reactors, Nuclear Instrumentation Package, Radiation Detection Equipment.

Ultra Stable Power Converters for FAIR, Germany

Passive Catalytic Recombiner Device for Operating Nuclear Power Plants

Nuclear Instrumentation for 700 Mw PHWRs

RF Power Amplifiers for Fermi Lab, USA

Aerospace

Aerospace Segment comprises of sales from Antenna systems for various Space programmes, Antenna Platform Units, Strategic Communication Network and MACE Telescope.

Ka Band Antenna System for Broad band Communications

Antenna Platform Unit for LCA

MACE Telescope at Hanle, Ladakh

Defence

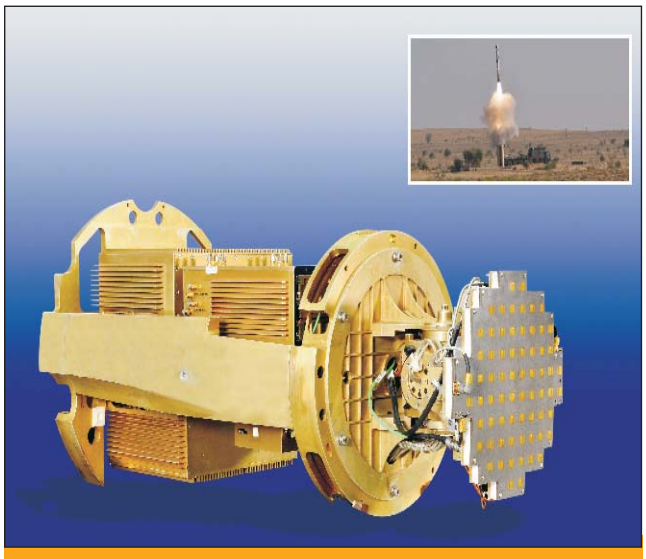
Major contributors in Defence Sector are Universal Electronic Fuzes, Seekers, Command and Control Systems for Missiles and various types of Military Radios.

V/UHF Military Radios

Universal Electronic Fuzes

Sensors

Actuator



Seekers for Missile program

Security

In Security Sector, major contribution is from Vehicle Mounted Jammers, Biometric Access Control Systems.

Vehicle Mounted Jammers

Biometric Access Controlled System

IT, e-Governance & Others

IT & e-Governance sector contribution largely coming from sales and services of EVMs and VVPATs.

EVM and VVPAT

R&D Program and New Products

The in-house R&D Programmes are guided and supported by the Technology Development Council (TDC) leading to several new products and enhancements being introduced into the market.

1. Solid State Pulsed Power Modulators for RF LINAC

Pulsed Power Modulators are used for driving Pulsed electron guns and high power microwave devices (Magnetrons and Klystrons) to power radio frequency cavities for Radio frequency Linear Accelerators (Linacs). These electron Linacs generate electron beams used for X-ray based cargo scanning applications, Industrial applications (food irradiation, medical products sterilization, crosslinking of polymers in cables and tyre industry, etc.).

Solid State Pulsed Power Modulators for RF LINAC

Explosive Detectors

Safe and Secure Programmable Logic Controller

2. Transmit Receiver (TR) Module in 50MHz and 400 MHz

Transmit Receiver (TR) Module in 50MHz and 400 MHz

3. Indigenous Radar Digital Signal Processing System

This is subsystem for RF Seeker. It is a small form factor Radar Digital Signal Processing unit developed for Nirbhay / BrahMos Missile. This development enables in further indigenisation of sub-systems of RF Seeker for BrahMos Missile. Qualification tests are under progress.

Indigenous Radar Digital Signal Processing System

4. Customer Services Management Information System

Customer Services Management System (CSMS) is a web application which automates the Warranty and AMC activities right from the start till the closure of Warranty & AMC projects being executed by any organization. It caters for projects involving hardware, software and maintenance.

5. X-Ray Baggage Inspection System(EC SCAN 6040)

ECSCAN6040 X-Ray Baggage Inspection System is designed for screening of baggage at transportation hubs, hotels, Government sites and other security sensitive hold areas.

With a powerful X-Ray generator, the ECSCAN 6040 provides high resolution images due to its advanced software and superior technology. The system provides outstanding threat detection and allows bi-directional scanning.

X-ray Baggage Inspection System

CHAPTER 10

JWG Meet with UK delegation in progress at AEC Room on 26.02.2020

OTHER ACTIVITIES

**Shri Sanjay Kumar,
Joint Secretary (A&A),
DAE lighting the lamp on the
occasion of 20th All India DAE OL
Conference held in AMD, Hyderabad**

SCIENCE RESEARCH COUNCIL

DAE-Science Research Council that comprises eminent scientists, continued with the peer reviews of basic research to ensure that highest possible level of excellence is maintained.

BARC-SAFETY COUNCIL

BARC-Safety Council continued its regulatory function to ensure the safety of all the plants and facilities under its purview.

To comply with the requirement of licensing/ authorization for operation of the variety of radiation installations in BARC, the BARC- Safety Council Secretariat had earlier prepared Regulatory Guidelines, which specify the requirements to be fulfilled for reauthorization of existing old facilities of BARC. It also addresses the requirements for new radiation installations in BARC.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), which is the standing Committee of senior officials of the Department of Atomic Energy (DAE), carries out the function of overseeing the Department's emergency preparedness for responding to any radiation emergency in the public domain and coordinating response actions with state or national level public officials / agencies.

Testing of the formal emergency response systems on a regular basis was ensured during the year with an objective to check its efficacy. Also, CMG continued to function as the contact point of DAE to provide its expertise in the field of nuclear / radiological emergency management at various National and International fora.

Availability of the Emergency Control Rooms (ECRs) located at two different places in Mumbai, which are backing-up one another, was ensured throughout the year. These control rooms, manned on round-the-clock basis and equipped with diverse means of communication; were in contact with various nuclear facilities in the country, with Ministry of Home Affairs (MHA) as well as with the International Atomic Energy Agency (IAEA) in Vienna. The Emergency Control Rooms of DAE are the National Contact Point for nuclear and radiological emergency.

During the year 2019-20, India participated in five numbers of International Convention Exercises, known as "ConvEx", conducted by IAEA, which are designed to test various aspects of the International Emergency Preparedness and Response (EPR) framework. As the Competent Authority, Crisis Management Group (CMG) coordinated India's satisfactory participation in these exercises.

The assistance capabilities that India can offer to the other member states of IAEA, in case of a requirement following a nuclear accident or radiological emergency; were registered in IAEA's web platform RANET (Response and Assistance Network). This was done as part of our commitment as a signatory to the IAEA Convention on Assistance in the case of a Nuclear Accident or Radiological Emergency.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and heavy water plants periodically carry out variety of emergency exercises. The numbers of such exercises monitored / participated by CMG during the year 2019-20 are Communication Exercises – 576; Fire Emergency Exercises – 91; Plant Emergency Exercises – 56; Site Emergency Exercises – 16 and Off-Site Emergency Exercises – 04 numbers.

CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Kalpakkam and Kaiga NPP sites. The exercises were found to be effective and satisfactory.

The "Standard Operating Procedure (SOP) of BRIT for 'Safe and Secure Transportation of Radioactive Materials' was reviewed and forwarded to Ministry of Home Affairs for vetting the security measures during transport as specified in the procedure.

The 'Crisis Management Plan of DAE for Nuclear and Radiological Emergencies' was revised in line with the 'Crisis Management Plan of the Government of India-2019'.

INTERNATIONAL RELATIONS

India, a founding member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA), continued to take active part in policy management and programmes of the IAEA. India was represented on a number of IAEA Committees, including those on safety, safeguards, nuclear radiation, nuclear engineering and application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings etc., and offered the services of its experts under the IAEA Technical Cooperation programme in a number of fields. India made contributions towards Innovative Nuclear Reactors and Fuel Cycles (INPRO), Technical Cooperation Fund (TCF) and Regular Budget of the IAEA.

In addition to participation in the Annual General Conference of the IAEA in September 2019, India is actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combat Nuclear Terrorism, and India's own Global Centre for Nuclear Energy Partnership (GCNEP). Secretary, DAE led the Indian delegation comprising of Director, BARC, Chairman, AERB and Joint Secretary (ER) to the IAEA 63rd General Conference which was held at Vienna, Austria from 16-20 September 2019. Chairman, AEC had a number of bilateral meetings on the sidelines of the conference.

Secretary DAE & Chairman AEC launched NCG Vishwam Cancer Care Connect on 17th September 2019 in Vienna on the sidelines of 63rd General Conference of IAEA. By virtue of this, National Cancer Grid (NCG) established and managed by Tata Memorial Centre (TMC), which has 183 participating stake holders from India has been made open to the cancer hospitals and other relevant institutes from foreign countries.

Bilateral meetings with our International partners:

During the year 2019-2020, bilateral meetings in the form of Joint Committee Meetings and Joint Working Group meet were successfully held with Australia, Bangladesh, Canada, France, Ghana, Japan, Kazakhstan, South Korea, Russia, Vietnam, UK and International Atomic energy Agency. The meetings took forward India's Civil Nuclear Cooperation with its foreign partners and focused on capacity building aspects.

JWG Meet with UK delegation in progress at AEC Room on 26.02.2020

Second Indo-Bangladesh Joint Committee meeting taking place on 23.07.2019

Committee on Safety of Nuclear Installations (CSNI)

Hitherto, the status of India in Organisation for Economic Cooperation and Development's (OECD)

Committee on Safety of Nuclear Installations (CSNI) was that of an "Invitee Country". The same has now been changed to that of "Participant Country".

Apart from the above the following events/ exhibitions were organised by External Relation Division, DAE:

Parmanu Tech – 2019

The Department in association with the Confederation of Indian Industry (CII), Maharashtra State, organized a conference cum Expo "ParmanuTech – the New Wave" at DAE Convention Centre, Anushaktinagar on 17.6.2019. This was organized with an aim to familiarize the small and medium scale industries on the technologies developed by DAE in various fields like Food Security, Health Care, Waste Management and Environment, Industrial Application of Radioisotopes and Engineering Technologies. 117 delegates participated in the conference. Site visit to Dhruva reactor was also arranged for the delegates.

MEA's Know India Programme

Department of Atomic Energy, in collaboration with Ministry of External Affairs, hosted a forty (40) member delegation under the "Know India Programme". The programme is an initiative where in young Indian diaspora in the age group of 18-30 are engaged and exposed to the transformational changes taking place in Contemporary India. The delegation visited Tarapur Atomic Power Station (TAPS) and facilities in the Bhabha Atomic Research Centre on 15th & 16th September, 2019.

Global Centre for Nuclear Energy Partnership (GCNEP) is being established at Kheri-Jassaur, Bahadurgarh, Haryana. GCNEP is the sixth R&D unit under the aegis of Department of Atomic Energy (DAE). Phase-I construction of the Centre has been completed and the Centre is operational since April 2017.

From April to December 2019, GCNEP conducted 1 national program & 10 International programs on various topical issues of nuclear safety, nuclear security and for secure and sustainable nuclear energy to the interest of more than 40 countries who participated in these programs. More than 120 foreign participants/ faculty and 230 Indian participants/ faculty took part in these programs. Under Inter Agency Agreement between GCNEP and BAEC (Bangladesh Atomic Energy Commission), 16 Indian technical experts were deputed to provide consultancy services for RNPP (Rooppur Nuclear Power Project), Bangladesh. Three outreach programs on societal applications of nuclear energy were conducted: Exhibition and Public Awareness Programme on DAE Technologies (New Delhi), Roadshow on Advances in Nuclear Agriculture (New Delhi) & Rising Himachal - Global Investor Summit (Dharamshala, HP)

GCNEP Phase-II construction works of three new packages have been started. These packages include construction of Central Building, School Building 2 (GCNEP laboratories), Service Building and Gate House at GCNEP Campus. At GCNEP Township, construction of Guest House Block-B along with Dining & Recreation facilities, Service Building, Gate House, Crèche cum pre-school and Dispensary is in progress.

Indo-US JWG Annual Meeting at GCNEP

Central Building Work in Progress

Various facilities and infrastructure under operational Phase I of the Centre have also been added during this period to enhance institutional capabilities. These facilities include Modelling & Simulation setup, RF based Point to Point communication, Renovation of Guard House, Personnel & Vehicle Monitoring System. The working models of products demonstrating the societal applications of Radiation Technology including Gamma-Chamber (GC500), 700MWe PHWR, Geological Repository Facility model and Bhabhatron have been added to the labs. The work on Sensor Evaluation Test Bed Facility (SETBF) is in progress. Also fitness and recreational facilities have been added at GCNEP Guest House.

During 2019, the Centre also expanded its activities for experiments on decomposition of rice residue using the Trichoderma Technology, crop improvement for wheat, mustard and sesame with the help of NAB&TD BARC.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and is actively participating in their programs for enhancing the safety and reliability of its nuclear power plants. NPCIL is one of the founding members of WANO. Almost all nuclear power plants operating or under construction in the world are its members. NPCIL representatives are in the governing board of WANO Tokyo Centre and WANO Moscow Centre. During the year, WANO Restart Review of KAPS-1, WANO Pre-Start Up Review of KAPP-3 and WANO Peer Reviews of RAPS-2 and RAPS-3&4 were conducted. These reviews provided the opportunity to benchmark our plants against the best international standards and practices.

Group photograph - WANO Peer Review of RAPS-2 & RAPS-3&4 during December 12-26, 2019

WANO organized two Members Support Missions (MSMs) on the topics for which NPCIL had requested specific assistance from WANO to learn from international practices and experience to strengthen its own programmes. So far, WANO has organized more than 70 MSMs in India. One more MSM is planned in this year. Two Benchmarking Visits (BV) to overseas NPPs were conducted by NPCIL teams with the support of WANO TC. These visits were very useful in understanding programs and practices being followed by these stations in the respective aspects. Recommendations by the respective BV teams are being reviewed for implementation. One more BV is planned in this year. NPCIL also participated in the WANO Biennial General Meeting held in London, UK in October 2019. NPCIL continued to submit Performance Indicator data and WANO Event Reports (WERs) to WANO for IAEA safeguarded reactors. NPCIL participated in some of the COG meetings held thru' audio conferences to discuss the issues of mutual cooperation. NPCIL participated in the information exchange programme of COG and had access to its website which contains large database of useful operating experience information related to PHWR plants. NPCIL continued to provide information for IAEA PRIS database.

VIGILANCE

The overall responsibility for vigilance in any unit of DAE rests with its Vigilance Officer/Chief Vigilance Officer (CVO). To ensure effective functioning of the vigilance machinery a senior officer in each of the Constituent Unit and Aided Institution of the Department has been designated as part time Vigilance Officer/Chief Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time Chief Vigilance Officer discharges these responsibilities.

During the year, the Vigilance section at the DAE Secretariat submitted 29 monthly/quarterly/annual returns to various authorities such as Central Vigilance Commission (CVC), Department of Personnel and Training (DoPT), and Central Bureau of Investigation (CBI). Processed 4 new Disciplinary cases of Group 'A' officers. About 87 complaints were downloaded from CVC portal and 4 complaints received through

PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides this, 5 complaints from CBI have also been processed. 16 cases have been closed with the approval of Competent Authority after necessary investigation and status uploaded onto the CVC portal. Around 61 complaints have been received directly in the Department. After confirming the authenticity of the complaint, carried out necessary investigation and with the approval of Competent Authority 22 complaints were closed. Vigilance clearance given for various purposes to 3421 Group 'A' officers of Units, Aided Institutions and PSUs as well as staff in the Secretariat. Appointment of Vigilance Officer/ Chief Vigilance Officer of Constituent Units/ Aided Institutes in the Department was done. Scrutiny of Annual Immovable Property Returns of DAE Secretariat was carried out. Co-ordination between CVC and Units for conducting CTE (Chief Technical Examiner) examination was maintained. Inspection of hired vehicles, compliance of existing guidelines in issue of work orders by DAE Secretariat etc., were carried out as a part of preventive vigilance.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2019" was observed in DAE during October 28th to November 02nd, 2019 on the theme of "Integrity - A way of life (ईमानदारी - एक जीवन शैली)". The week commenced with administering integrity pledge by Secretary, DAE and Joint Secretary (A&A) to all officers and staff on 28.10.2019. During the week, a lecture on "Vigilance, Information Technology & Social Media" was held by Shri Gigi Joseph, SO/H, Computer Division, BARC on 30.10.2019. Further, various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were also held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Shri Pradeep NG, Head-Matl. Proc. (DGM-Supply Chain-Nuclear Equipment Business) and Shri Ajaykumar Dubey, AGM - Marketing, Nuclear Equipment Business, L&T Heavy Engineering, Hazira Manufacturing Complex, Surat delivered a talk on 01.11.2019. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 01.11.2019. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance Awareness Week 2019 Observed in DAE Secretariat with the theme "Integrity: a way of life"

NPCIL strives to put in place effective preventive measures and spreading awareness to eradicate corruption by involving all the stakeholders. Individuals and organizations need to adopt a behavior of 'Zero tolerance' to corruption. As a preventive vigilance measure and to spread vigilance awareness, seven Vigilance Awareness Seminars/ Interactive sessions were held at HQ & sites. The same were addressed by Chief Vigilance Officer (CVO) and Senior Vigilance Officers. Vigilance Awareness Week with the theme of "Integrity- A way of Life" was observed in NPCIL. As per directives of Central Vigilance Commission (CVC), NPCIL conducted outreach activities in 14 colleges and 35 schools. Total 1144 students from colleges and 7210 students from schools participated in these activities. A number of programmes viz. Seminars, Debate Competitions, Quiz competitions, Elocution Competition, Essay writing competition, Slogan writing competition, Short Film Competition, Poster Drawing, Human Chain formation, Street play & Walkathon etc. were held at NPCIL HQs & its sites. Various short film competitions were conducted. They are very effective to communicate the anti-corruption message.

Integrity Pledge through mass pledge was administered at HQ & all sites to employees. Also 3618 students, staff and faculty of various schools and colleges were administered mass Integrity pledge at cities/ towns nearby NPCIL power plants. Mass integrity pledge was also administered to contracts workers at various sites. Vigilance annual magazine 'Chetna' was released by CMD, NPCIL. The magazine contains interesting articles, essays, poetries, slogan,

cartoons and posters contributed by employees, family members of employees and students. Vigilance Officers carried out several inspections at all NPCIL units. Seven CTE (Chief Technical Examiner) type inspections were also carried out. Four Vigilance Officials of Headquarters and Units were imparted short duration training in reputed institutes to increase their capability and skills.

IGCAR observed Vigilance Awareness Week during the period from 28th October, to 2nd November, 2019. The Vigilance Awareness Week began by administering Integrity Pledge to the employees by Director, IGCAR on 28th October, 2019. The theme for the year "Integrity – A way of life", was adequately brought out by holding Essay, Poster, Slogan and Quiz competitions. Shri.P. Selvaganesh, Indian Revenue Service, Competent Authority & Administrator, SAFEM (FOP) & NDPS ACTS, Chennai was invited to deliver lectures on 29th October, 2019 to sensitize the employees on the do's and don'ts to eradicate corruption from public life and set a road map for New India.

OFFICIAL LANGUAGE IMPLEMENTATION

Official Language (OL) activities towards promotion of use of Official Language Hindi in the various fields of Nuclear Sciences and Technology were carried out in the constituent Units of DAE, its PSUs and Aided Institutions. Some notable efforts are mentioned below:

A total no. of Hindi Officers and employees in Units, PSUs and Aided Institutions are 106.

DAE has carried out 10 OL inspections in the Offices of its Units/PSUs/Aided Institutions. During this period a Branch Office of ECIL in Bengaluru was inspected by Hon'ble Parliamentary Committee on Official Language.

20th All India DAE Official Language Conference was held on 15th November, 2019 at Atomic Minerals Directorate for Exploration and Research, Hyderabad. Administrative Heads and In-charges of Official Language posted at various Units, PSUs and Aided Institutes of the Department spread across India have participated.

Shri Sanjay Kumar, JS (A&A), DAE lighting the lamp on the occasion of 20th All India DAE OL Conference held in AMD, Hyderabad

A total no. of 48 offices of the Department have been notified in the Gazette of India under Rule 10(4) of OL Rules, 1976 so far.

Total 30 Seminars and Talks on various topics related to the Nuclear Science and Department were conducted. Souvenirs for most of the seminars were also published in Hindi.

Cabinet notes to be submitted to various Committees of the Parliament were also prepared bilingually. Similarly, Annual Reports, Various Documents, Agreements and MoUs were also prepared and submitted bilingually.

A total no. 66 Hindi Workshops were conducted to impart training of Noting and Drafting in Hindi in which 623 Officers and 1027 employees were trained.

A total no. of 241 employees have participated in the various Incentive Schemes introduced in the Department to increase the use of Hindi in official work.

An amount of ₹ 2,05,968/- was spent on purchase of Hindi Books.

Quarterly meetings of Official Language Implementation Committee (OLIC) in DAE Secretariat was organised regularly and progress of Official Language Implementation was monitored regularly.

Quarterly progress reports and minutes of OLIC meetings of offices of all Units, PSUs and Aided Institutes were reviewed regularly. Hindi Week/ Fortnight/Month were celebrated in all offices of the Department.

Websites of DAE and its 25 establishments are in bilingual and it is being updated regularly. At present, a total no. of 29,497 computers are in bilingual in the Department.

House magazines/News Letters of various establishment of DAE were published in Hindi/ bilingually.

A synergic presentation of musical instrument by the artist of Akashwani, Mumbai was arranged at DAE Secretariat on the occasion of World Hindi Day-2020.

A cultural performance by Artists of Aakashwani, Mumbai on the occasion of Vishwa Hindi Diwas-2020

Under various incentive schemes introduced in DAE for Units/PSUs/Aided Institutes – OL shields were awarded to Atomic Minerals Directorate for Exploration and Research, Hyderabad; Nuclear Power Corporation of India Limited, Mumbai and Institute of Physics, Bhubneswar. House Magazine awards were given to "Gurujal Pratap" of HWP, Kota; "Anumala" of NPCIL, Kakrapar and "Plasma Jyoti" of IPR, Gandhinagar respectively.

"Rajbhasha Bhooshan" award winner were Dr. Srinivas Chaturvedi, SO/H from Atomic Minerals Directorate for Exploration and Research, Hyderabad and Dr.M.L.Parihar, SO/E of Nuclear Fuel Complex, Hyderabad. Nine officers from various offices of the Department were conferred with the "Hindi Sevi Samman" award.

"Hindi Day-2019" and "World Hindi Day-2020" were successfully celebrated in all Units/PSUs/ Institutes of Department. Scientific talks and Kavi Sammelans were arranged during these celebrations.

Chief guest Shri Sanjay Kumar, JS (A&A), DAE distributing prize to a winner of Hindi competitions organised on the occasion of World Hindi Day

A voluntary organisation Hindi Vignan Sahitya Parishad in Bhabha Atomic Research Centre, Mumbai has completed 50 years of its establishment. Parishad has continued regular publication of its quarterly magazine "Vaigyanik"

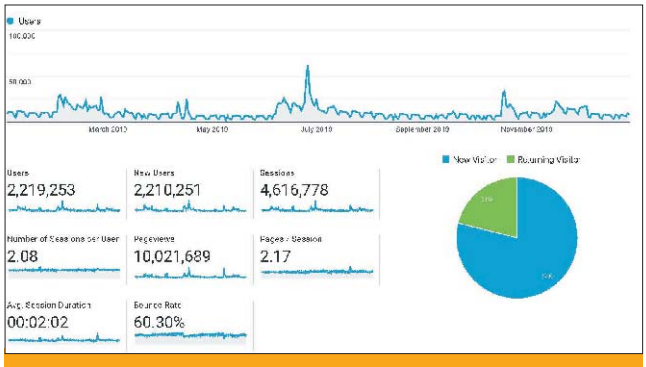
NPCIL is committed to implement the Official Language Policy and instructions/ orders issued from time to time by DAE and Government of India for the same. The apex committee i.e. Official Language Implementation Committee (OLIC) review the progress of the same on quarterly basis under the chairmanship of Chairman and Managing Director. For improving the implementation of OL in NPCIL Head Quarter (HQ) as well as in all sites/ stations/ projects various initiatives have been undertaken. The overall progress in achieving targets set by Department of Official Language; GOI for OL implementation is a commitment of NPCIL. This indicates NPCIL's sincere efforts to meet commitments of OL implementation.

During the financial year, total 4 one day Hindi workshops were organized in HQ as well as at its all sites to apprise the provisions of OL policy to the employees and encourage them to do most of their

official work in Hindi. Hindi Day programmes were organized at HQ as well as at all sites. The CMD Rajbhasha Shield, House Magazine Shield, Hindi Sevi Samman and Rajbhasha Bhushan puraskar have been implemented in NPCIL to encourage and to impart healthy competition for implementation of OL Policy. Every Month a Hindi competition is organized at NPCIL HQ as well as at its all sites. Hindi Scientific Seminars and other programmes were organised at HQ as well as at its sites on World Hindi Day Celebration. A documentary film regarding propagation of Hindi is prepared for highlighting the efforts of OL Implementation in NPCIL.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC is equipped with the state-of-the-art infrastructure to provide seamless access of information to BARC and DAE scientists and engineers in their day-to-day R&D activities. BARC subscribed to 661 periodicals, 8 Standards and 12 Databases and added 488 books and 24 CD-ROMs to the Library collection.



BARC webpage analytics

During Jan-Dec 2019, a total 3539 bibliographic records of various journals, conference proceedings and technical reports published in India were submitted to International Nuclear Information System (INIS) database on Nuclear Science and Technology in addition to 8 full text Non-Conventional Literature. Total 82 requests for articles from member countries were fulfilled under INIS document delivery services. Foreign language translations from foreign language journals, technical guides and manuals, etc., were undertaken in addition to Interpretation services.

Digital institutional repository E-Sangrahay on Saraswati portal now holds more than 18,000 Articles, 1682 NUCNET News and 205 Thesis. As per Scopus database, 7975 papers were published by BARC authors during 2015-2019. More than 1300 similarity checks have been performed for BARC manuscripts prior to their submission to journals. More than 1600 Scientists accessed online library resources remotely using Home Office or Anywhere (HOoA) facility. More than 5400 digitized images of BARC film collection were uploaded to the open source application “Darpan”.

Of the total traffic witnessed on BARC website during the year, 21% are returning users and 79% are new users. The website also clocked total annual sessions of 4,616,778 with total 10,021,689 page views. New BARC Technologies are being continuously added to Entrepreneur Corner. Recruitment, RTI, media relations and BARC Newsletter are regularly updated. Total 2933 Tender/Minor tender informations were hosted during 2019.

The Scientific Information Resource Centre (SIRC) of DAE Secretariat continued to provide library & information services such as Circulation, New Arrivals Services, News Clipping Services, Reference & Information Services, Reprography Services etc. New Books, Periodicals, Journals and other reading materials were added to the resource collection of SIRC. During the year, publication and printing of statutory document such as ‘Annual Report’ and internal publications such as ‘Accounts at a Glance’, ‘DAE Perspective’, ‘DAE Diary’ etc. were printed and published.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a host of Public Awareness programmes on a mission mode to alleviate unwarranted fears, misconceptions, to address apprehensions harboured against nuclear energy. Across the nation there exists a void of any real understanding, on the part of the general population, of anything

related to nuclear energy and technologies that have actually been developed for better quality of life. To keep the public abreast of the latest developments and contributions of atomic energy towards societal welfare, DAE participated in and organized a spectrum of events comprising exhibitions, seminars, workshops, essay and quiz contests in different parts of the country which were well received by the targeted audience.

Some of the major events are elaborated below:

The 107th session of the Indian Science Congress (ISC) was held from 03-07 January, 2020 at GKVK University, Bengaluru. The Hon'ble Prime Minister of India Shri Narendra Modi inaugurated the Indian Science Congress on 3rd January, 2020. The occasion was graced by Eminent Scientists, Nobel Laureates, Dignitaries, former ISCA General Presidents, Industry Leaders, Policy Makers, Innovators, Academicians and thousands of national/international delegates. DAE put up a five day exhibition along with the units viz. BARC, IGCAR, UCIL, ECIL, NFC, AMD, BRIT, IPR, HWB, RRCAT & NPCIL in the Pride of India (PoI) exhibition. Video films and multimedia presentations on nuclear power, applications of radio isotopes in healthcare, agriculture, food processing, industry, hydrology, desalination and advanced technologies etc., were shown. The exhibition was visited by thousands of representatives from R&D Institutions, PSUs, MNCs, Corporate, Policy makers, Researchers, Technocrats, Young innovators, Investors, Educationalists and Students of various schools and colleges. The exhibition provided an excellent opportunity to all to have a glimpse of the diverse activities of DAE under one roof. Various queries from students were attended to during the five day exhibition.

DAE Pavilion at the 107th session of the Indian Science Congress

107th session of the Indian Science Congress (ISC) at GKVK University, Bengaluru

The Public Awareness Division (PAD), DAE organized the fourth series of Journalist's Workshop at RAPS, Rawatbhata during August 05-09, 2019. The aim of this workshop was to reach out to the general public, in the correct perspective about the objectives of DAE, using the media which is a powerful interface. An exhibition on various technologies for better quality of life was set and a Scientist-Journalist meet was organized. The workshop ended with a Panel discussion and feedback from the journalists. The exercise proved to immensely fruitful.

DAE-NUJ (I) Journalist Workshop at RAPS, Rawatbhata, Rajasthan

DAE participated in the 23rd National Science Exhibition on the theme of 'Creative India': A New Dimension in the memory of 150th Birth Anniversary of Mahatma Gandhi at Amarabati Maidan, Sodepur, Kolkata during August 28-31, 2019. It was well received by the students, teachers and general public.

DAE pavilion at the 23rd National Science Exhibition, Kolkata

'Rise in Haryana - 2019' was held at Shree Panchayati Ramleela Ground, Hansi, Haryana during August 29-31, 2019. DAE participated in the exhibition by putting up stalls on various technologies of DAE. A large number of students from schools and colleges participated in the exhibition. The exhibition was first of its kind in Haryana and it was well received by the students and general public.

DAE Exhibition at 'Rise in Haryana - 2019', Hansi, Haryana

DAE participated in 'Vision Rajasthan - 2019' at Udaipur, Rajasthan during September 17-19, 2019. An exhibition was put by DAE in the above event. The programme was attended by studeents, teachers and general public. Quiz for students were held and the programme was well received.

DAE Exhibition at 'Vision Rajasthan - 2019' at Udaipur, Rajasthan

The 7th Indian National Exhibition cum fair 2019 on the theme of Science and Technology for National Development was held at Metropolitan Development Ground, Baishnabghata, Patuli, Kolkata during September 25-29, 2019. DAE participated in this fair.

DAE provided the Financial Assistance in organising a National Conference on "India in Space & Nuclear Energy: Achievements & Challenges-A Centenary Tribute to Space Visionary Dr. Vikram A Sarabhai", on the occasion of his Birthday Centenary Year at Nehru Science Centre, Worli, Mumbai on September 16, 2019.

DAE Exhibition at Nehru Science Centre, Worli, Mumbai

DAE participated in Dr. Vikram Sarabhai Birth Centenary Programme 'Curtain Raiser' at DAE Convention Centre, Anushaktinagar during October 17-18, 2020. A curtain raiser programme was held to start the yearlong celebration of Dr. Vikram Sarabhai Birth Centenary.

The 31st DAE All India Essay Contest - 2019 on Nuclear Science and Technology was held on October 21-31, 2019. As a part of its Public Awareness Programme, PAD, DAE has been organizing, "DAE All India Essay Contest" for undergraduate students on topics relating to "Nuclear Science & Technology'' every year. With a view to continue this fruitful exercise, DAE organised the 31st DAE All India Essay Contest. The topics for the essay contest were: Evolution of Nuclear Power in India; Radioisotope Production & Radiation Technology Applications and Lasers & their Impact on Mankind. The announcement was given wide publicity by contacting over 10,000 colleges within the country. Various news agencies and constituent units of DAE were also approached for giving wide publicity in their office/localities. A total of 36 students were selected for each of the three topics and they were invited in Mumbai to visit various facilities of DAE and to make an oral presentation of their essays. In order to generate a competitive spirit, the selected students were awarded with cash prizes.

Winners of 31st DAE All India Essay Contest – 2019

India International Science Festival 2019 (IISF 2019) was organised by Ministry of Science & Technology and Earth Science and Vijnana Bharati at Biswa Bangla Convention Centre, Kolkata during November 5-8,2019. DAE participated in this event.

Rising Himachal Global Investors' Meet at Dharamshala, District Kangra, Himachal Pradesh during November 7-8, 2019. Exhibitions were put by DAE on this occasion. The programme was well received by the audience.

A conference on "Future of Light Water Reactors Technology in India" was jointly organised by BARC and NPCIL under the aegis of HBNI at DAE Convention Centre, Mumbai during November 11-13, 2019. DAE participated in this conference.

DAE participated in the "11th Agrovision - Workshop, National Expo & Conference held at Nagpur during November 22-25, 2019 to teach and train farmers about new technologies, innovative methods to increase farm yield and bridge knowledge gaps. DAE exhibited its activities and contributions in the areas of agriculture and food processing. Scientists from BARC interacted with the visitors and provided information.

Visitors at DAE Pavilion during 11th Agrovision, Nagpur

DAE's participated in Exhibition for Parmanu Urja Janjagruti Abhiyan at Jabalpur during December 02-07, 2019. The exhibition was organised for students doing their graduation and post-graduation in science. A two day Seminar with popular talks on various activities of DAE was also organised. Speakers from IPR, RRCAT, TMC also delivered lectures which were very well received. Painting and elocution contests were also held for higher secondary school students.

The "National Conference on Science Technology and Application of Rare Earths - 2019 (STAR2019)" was held at Convention Centre, Anushaktinagar, Mumbai during December 05-07, 2019. DAE participated in the conference.

Inauguration of the exhibition pavilion by Dr. S. Banerjee, former Chairman AEC during STAR 2019, Mumbai

The 24th Sunderban Kristi Mela 'O' Loko Sanskriti Utsav during December 20-29, 2019 organised by Kultani Milan Tirtha Society Kultani, West Bengal. DAE participated in the event and provided financial assistance. The event was well received by students and general public.

DAE participated in IWSA's exhibition on "WATER- its uses, conservation and future" at IWSA (Indian Working Scientist's Association) Complex, Vashi during January 17-18, 2020. Teachers and Assistant Professors from various universities from different parts of the country participated in the exhibition. Students from nearby schools and colleges in Vashi, Navi Mumbai visited the exhibition.

Student's Visited at DAE pavilion during IWSA Exhibition

An exhibition organized by DAE in Meghalaya attracted 1500 visitors and participation from several government organizations as well as start-up community from across the country. A meeting of the committee of peers conducted by Rajiv Gandhi Science & Technology Commission, Govt. of Maharashtra held consultations with a team of officers deputed by the Ministry of Micro, Small & Medium Enterprises, Govt. of India. Other outreach events organized were 'ParmanuExpo 2019' held jointly by DAE-Confederation of Indian Industry (CII) for exploring technology transfers and potential partnership opportunities. DAE organized an exhibition on 'Radioisotopes & Radiopharmaceuticals for Healthcare - Contributions of Department of Atomic Energy, INDIA' and 'Radiopharmaceuticals for Healthcare in India: Contributions of DAE' at the International Symposium on Trends in Radiopharmaceuticals (ISTR-2019) organized by International Atomic Energy Agency (IAEA) at Vienna, Austria during 28th October - 1st November, 2019.

Exhibitions to showcase scientific and technical achievements of BARC/DAE were organised during the Vikram Sarabhai Birth Centenary Programme on 12th August 2019 at Ahmedabad. A 100 Rupee commemorative coin was brought out in memory of Dr. Vikram Sarabhai. BARC also participated in the 106th and 107th editions of Indian Science Congress held in Jalandhar and Bengaluru respectively.

DAE unveiled the birth centenary celebration programme of Dr. Vikram Sarabhai in BARC during October 17-18, 2019. Dr. Kasturirangan, Former Chairman, ISRO and Dr. Surendra Sharma, Former Chief Executive, Heavy Water Board, graced the event as the Chief Guest and the Guest of Honour respectively. Shri K.N. Vyas, Chairman, AEC and Secretary, DAE and Dr. A.K. Mohanty, Director, BARC graced the occasion. A short film on the life of Dr. Vikram Sarabhai was made and exhibited on both the days. A 100-page coffee table book on Dr. Vikram Sarabhai was released. Children from various schools in Mumbai, including those from Atomic Energy schools in Anushaktinagar actively participated in the Science Quiz, Debates and Speeches organised during the event.

Shri K.N. Vyas, Chairman AEC, Dr. Kasturirangan, Former Chairman, ISRO, Dr. Surendra Sharma, Former Chief Executive, Heavy Water Board and Dr. A.K. Mohanty, Director, BARC releasing the coffee table book on Dr. Vikram Sarabhai

School students in attendance at the Dr. Vikram Sarabhai Birth Centenary Programme in BARC

Dr. Kasturirangan, Former Chairman ISRO, Dr. K. Sivan, Chairman, ISRO, Shri K.N. Vyas, Chairman AEC, Dr. M.R. Srinivasan, former Chairman AEC and others release the ISRO Coffee table book at a function to commemorate Birth Centenary Year of Dr. Sarabhai held in Ahmedabad on August 12, 2019

School students throng DAE pavilion at an exhibition organized jointly by DAE-ISRO in Ahmedabad on August 12, 2019, as part of Dr. Vikram Sarabhai Birth Centenary Programme

NPCIL has carried out series of Public Awareness (PA) campaigns on regular basis to convey factual and authentic information on nuclear power in a transparent manner with a structured approach. NPCIL has been reaching out to an average of around 5 lakh people per month as a result of various multi-pronged initiatives.

Regular interaction with the population of the surroundings of the Indian Nuclear Power Plants (NPPs); organizing regular visits of villagers, students, officials from various organizations, opinion makers, members from the media and public to nuclear power plants; execution of various awareness campaigns on nuclear power for different target groups like media personnel, policy and decision makers, people's representatives, state officials, students and teachers, medical professionals and the public at large are some of the efforts, which is being continuously carried out across the country. Apart from that, NPCIL is also involved actively in setting up of number of permanent galleries on nuclear energy at the science centres across the country in phased manner to provide factual information in an interesting, innovative and interactive way on numerous applications of nuclear energy.

Use of seminars, lectures, scientific meets, exhibitions, distribution of public awareness publications, screening of short films in vernacular languages, enhanced interaction with press and media, professional tie-ups with other professional agencies like Prasar Bharati, National Council of Science Museums (NCSM) and Department of Science and Technology at state and central level etc., use of social media and digital media for e-public awareness campaigns are also being adopted to enhance the public opinion at large, keeping in mind of new generation.

Web based Public Awareness

Focusing younger generation, NPCIL's social and digital communication approach have been one of the effective and popular platforms for providing useful information. NPCIL web site has been providing large amount of factual and useful information on nuclear power, activities and achievements of the organization. Besides, lots of information about various aspects of nuclear energy is also being shared with public via various social and digital media platforms through innovative and interesting ways.

Publications

Informative, educative and creative public awareness publications on numerous aspects of nuclear power are being distributed to general public, eminent persons, students, teachers etc. on regular basis. For wider reach, these Public Awareness publications are being distributed in regional and vernacular languages also in the states where NPPs are located or where new sites are proposed.

Lectures

The organization has also taken up many other structured Programmes on public awareness on nuclear power. A total of 204 lecture sessions were organized till November 2019. Of these, 41 lectures on nuclear power were organized for the students at schools and colleges in different parts of the country.

Halls of Nuclear Power

Under the permanent capacity addition programme, "Halls of Nuclear Power" have been setup at three science centers, located at Mumbai, Delhi and Chennai, where millions of people visit every year. Fabrication and installation of similar Halls of Nuclear Power at other science centers located across the country are also under process. Many people including students, research scholars, academicians, press and media etc. visit these permanent galleries throughout the year and get benefitted about the various aspects

of nuclear energy and its applications. Miniature galleries are also being planned in large numbers for wider reach to public in the smaller cities in a phased manner. These miniature galleries will be relatively smaller in size and will be established in prominent science centers, planetariums and museums.

Nuclear Power Plant Models

The semi-dynamic NPP models along with self-explaining voice over are being installed to educate and inform general public about the working of nuclear power plants along with its safety features. During the period, Nuclear Power Plant models of 700 MW Reactor and Turbine models are fabricated and installed at Atomic Mineral Division, Nagpur; Department of Atomic Energy, Mumbai; Global Centre for Nuclear Energy Partnership, Bahadurgarh; IGCAR; Kaiga Generating Station; NPCIL office Mahi Banswara, Rajasthan. Similarly, nuclear power plant models of 220 MW Reactor and Turbine are fabricated and installed at District Science Centre Dharampur, Gujarat; Sub-Regional Science Centre Bellary, Karnataka; District Science Centre Kalaburagi, Karnataka; District Science Centre Vellore, Tamil Nadu and Anna Science Centre, Tiruchirappalli, Tamil Nadu.

Films and Multimedia

NPCIL has signed a MoU with Prasar Bharati to make short films on various CSR activities being carried out in the vicinity of all the nuclear power plants. The films will be focusing on various activities including construction of schools and hostels, roads, provision for drinking water, providing medical facilities and other sustainable development Programmes being carried out for the welfare of society and neighborhood. The films will be telecast in multiple languages through all the regional channels of Doordarshan including DD National.

Newspaper-In-Education (NIE) Programme

During the period, a number of workshops were organized across 5 cities including Mumbai, Delhi, Lucknow, Pune and Bengaluru in association with Times of India group under NIE Programme. Special Programmes are being organized to commemorate the centennial year of Dr. Vikram Sarabhai.

Scientific Displays & Exhibitions

NPCIL participated in various exhibitions to directly communicate with lakhs of visitors for dissemination of authentic and factual information and to dispel apprehensions related to nuclear power. Some of the notable participations in the year were, National Science Exhibition at Kolkata, Future of Light Water Reactors LWR-2019 Exhibition at Mumbai, Chutka Scientific Literacy cum health and wellness Festival, Mandla, Madhya Pradesh, Kota Dusshera Mela at Kota, Advances at the Interface of Biology and Chemistry Exhibition, Mumbai. Many exhibitions were also organized by various sites from time to time.

Nationwide Public Relation (PR) and Media Facilitation Programme

With the view of structured and sustainable nuclear power awareness programme for long period with enhanced PA activities, series of campaigns have been organized at various schools and colleges of prominent cities across the 8 states i.e., Maharashtra, Delhi, Gujarat, Madhya Pradesh, Rajasthan, Haryana, Andhra Pradesh and Uttar Pradesh. Under this campaign, many activities including painting competition, essay competition, debates, slogan competition, run for energy, talk shows, Question & Answer session, films screening, rally etc. were organized in many schools along with massive media coverage on positive aspects of nuclear power. Besides these activities, Special Programmes were also being organized to commemorate the centennial year of Dr. Vikram Sarabhai. Many articles on various applications of nuclear energy were published in various newspapers of the country under media facilitation programme. Under this campaign, more than 520 positive news coverage and 96 articles on

Nationwide Public Relation (PR) and Media Facilitation Programme

various applications of nuclear energy had been published so far with participation of more than 24000 students and teachers during this financial year till December 2019.

Public Outreach programs on awareness about the peaceful uses of Atomic Energy through audio-visual presentations were organized by HWP sites at nearby schools/ colleges, villages, state government offices. HWB officials delivered talks and set up exhibits at various national and international events, to create public awareness about non-nuclear applications of deuterium and heavy water in medicine, analytical and technological fields viz., NUJ-DAE meeting during August 5-9, 2019 at Kota; Conference on Green Chemistry at IIT B during 16-17 October, 2019 and celebration of Birth Centenary Program of Dr. Vikram Sarabhai on August 12, 2019 at Ahmedabad and during 17-18 October, 2019 at DAE Convention Centre, 107th Indian Science Congress, Bangalore from 3-7 January, 2020.

RRCAT continued to conduct the eight week certificate course "Orientation Course on Accelerators, Laser and related Science and Technologies". The fifth edition 'OCAL-19' was successfully conducted from May 20 to July 12, 2019. The aim of the course is to impart a holistic professional training to the students and motivating them to take their career in the advanced science and Technology streams of DAE. Thirty nine post-graduate students (M.Sc., M.Tech., M.E.) from 12 states successfully completed the course, which comprised lectures, invited talks, hands-on experiments, laboratories visit, students' seminar and an industrial visit.

Dr. Ratan Kumar Sinha, Former Chairman, AEC and secretary, DAE awarding the certificates to all the qualifying students during Certificate distribution ceremony of OCAL 2019

Under the outreach programme, RRCAT participated in the India International Science Festival held at the Science City, Kolkata during Nov 5-7, 2019. Special events and visits were arranged for various schools, colleges and government institutes like Police Radio Training Institute, Indore and College of Defence Management, Secunderabad, with interactive sessions and scientific experiments. RRCAT, Indore had set up a science and technology pavilion in the Bhopal Vigyan Mela, organized by Vigyan Bharati, Vigyan Prasar and AMPRI, CSIR at BHEL Dussera Maidan, Bhopal. To show case the advanced research and development work in the area of accelerators and lasers working models of Indus 2 (indigenous 2.5 GeV Synchrotron Radiation Source built by RRCAT), NdYAG laser model and interesting physics experiments in cryogenics for the benefit of young students were displayed. A poster exhibition was also set up to showcase the R & D activities of RRCAT. RRCAT was awarded the best science exhibition award.

Public awareness programmes have been conducted in various cities as well as in remote field areas at 52 venues by AMD. A total of 100 events have been organised for students, teachers and general public.

Visit of students during National Science Day at AMD, Hyderabad

As part of continuing efforts on creating awareness about the peaceful uses of nuclear energy, beneficial applications of ionization radiation and role of our Department, radiation awareness programmes were organized by IGCAR for home makers residing

in the townships, class XII students from nearby higher secondary schools around Kalpakkam and teachers from Atomic Energy Central Schools and Kendriya Vidyalaya schools, respectively.

VECC arranged visits of students and faculties of 14 institutes to different laboratories and facilities throughout the year. VECC participated in scientific and technical fairs, exhibiting models of cyclotron, ALICE LHC and other scientific instruments in the stalls. Held outreach programmes outside the city to make the general people aware of the departmental activities. Besides, presented the DAE Career Opportunity series of lectures at more than 10 institutes of West Bengal, Bihar and Orissa.

A wide variety of Outreach and Science Popularisation programmes were conducted by TIFR during the year to convey the importance of exciting new developments in science and technology to the general public with a special emphasis on showcasing the research being done in TIFR. A major focus of this effort is to reach out to school/college students and teachers, especially in under-served communities, and to inspire students to pursue a career in basic sciences. The annual "Frontiers of Science" programme, was held on 24 November 2019 in a new format that allowed a major scale up of the event, and provided an opportunity for 2400 9th/10th standard students and teachers from selected schools to visit TIFR for a day of lectures, science demonstrations and lab visits. TIFR's flagship science café series "Chai and Why?" entered its 11th year, running without a break since 2009. The partnership with Junoon's "Mumbai Local" series was continued, featuring conversations with TIFR scientists, in an effort to bring community engagement with scientists to neighbourhood venues across Mumbai. 2019 being the International Year of the Periodic Table, more than 25 lecture-demonstrations in venues across Mumbai, Pune, Nagpur, Goa, Roorkee, Bangalore, Trivandrum etc. were organized with a periodic table with samples of ~65 pure elements from research labs in TIFR being the highlight. The outreach team also conducted science demos in several rural schools in Aurangabad and Raigad districts. Along with other TIFR centres, and the Astronomical Society of India's outreach programmes, the outreach team will participate in the nationwide campaign to observe the annular solar eclipse on 26 December 2019.

SOCIAL WELFARE

Corporate Social Responsibility, Sustainability and Rehabilitation & Resettlement

NPCIL is committed to economic and social development of the local communities around all its sites. CSR programme so far been implemented at the 14 sites of NPCIL, where either the operating stations or the projects under construction are located. These Sites are located mostly in rural and under developed areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme.

During the FY 2019-20, the Company allocated an amount of ₹ 76.08 Crore for implementation of CSR programme. It is a matter of satisfaction that for the last three consecutive years, NPCIL has spent more amount on CSR programme than that was allocated during that year.

The CSR Policy of NPCIL is available at the company website. Board Sub Committee (BSC) for CSR and Sustainability functions as CSR Committee as defined in the Company (Corporate Social Responsibility Policy) Rule 2014 notified under companies Act 2013. Additionally, Guardian Directors have been assigned to the operating sites of NPCIL to review and assist the CSR programmes of the sites. The effective and expeditious implementation of CSR program is monitored and facilitated at various levels in NPCIL including the Board Sub Committee (BSC) for CSR and Sustainability. The CSR projects have been taken up in line with Schedule VII of Companies Act, 2013 which falls in the areas of education, healthcare, infrastructure development, skill development, sustainable development.

Education

Under education category, the projects like construction of school buildings, furniture for schools, class rooms, multipurpose hall in Girls School, Balvikas Sanstha, boundary wall, development of aganwadis, assistance to schools like drinking water, toilets, science laboratories, play items, digital class rooms, open area flooring, kitchen with store, deployment of

teachers in schools, assistance to students like study materials, note books, sports kit, scholarship and sponsorship, free transport service, organizing quiz etc. were taken up during this year.

The construction of Primary School building completed by Kakrapar Site located at Unchamala benefitting around 160 students

Two mobile hospitals were handed over by Chutka site to Mandla and Seoni District administration benefitting around 40000 people

Healthcare

Under healthcare, the CSR projects included running of primary health center, providing mobile medical van services; organizing medical, eye and special health care camps; providing medical treatment and medicines (OPD services) for villagers; procurement of various equipment's and blood bank van for General Hospital at Gujarat,, funding extension of hospitals like Tata Memorial Hospitals, distribution of assistive devices to disabled persons, construction of gym, installation of water purifiers, mosquito net distribution etc.

Infrastructure Development

Under infrastructure development, the projects like laying of approach roads, development of drinking water facility, construction of community hall, RCC sheds, drainage, construction of compound wall for PHCs, construction and deployment of artificial reefs, base line survey etc. were taken up.

Narora site provided interconnecting paver block road at Udaygarhi village benefitting around 600 people

Skill Development

Skill development initiatives were undertaken to ensure income generation by unemployed adults. Skills in handicraft including plastic basket, flowers making, embroidery and chicken work on fabrics, stone carving skills, mason, tailoring and beautician, carpentry, welding, electrician, plumber, fitter, computers, farming and agriculture etc. were focused upon.

Organized training for 200 youth of Kudankulam village covering stitching, electrical and welding through NSDC

Sustainable Development

Some sustainable development initiatives were also undertaken this year. These included projects for rainwater harvesting, development of village ponds, ground/ underground natural water bodies, breeding

of migratory birds and turtle rearing program, release of fish fingerlings in Kadra reservoir, honey bee culture, distribution of solar lamps, capacity building of farmers on organic agriculture etc.

Kalpakkam site started a Project for deployment 800 artificial reefs in Tiruporur Panchayat Union to enhance bio-diversity, improve fishery resources and increase livelihood for fishermen

Swachha Bharat Mission

Swachhta Pakhwada was introduced in all Central Government Ministries & Departments on the directives of the Hon'ble Prime Minister as a part of the Swachh Bharat Mission. Swachhta Pakhwada was observed in Department of Atomic Energy from 16th February – 28th February, 2020 on the occasion of World Science Day.

The programme comprised Swachha Section Competition, Quiz Contest, Essay Contest, Poster Contest, Poetry Contest and Slogan contest. All the events were held as per the schedule which was circulated in advance. In all these contests, the staff members of DAE participated wholeheartedly. The results of these contests were announced on 28th February, 2020.

The Chief Guest for the concluding session was Joint Secretary (I&M), DAE. He distributed prizes to the winners of the various contests and also felicitated the employees of the Department, who were selected for their contribution in cleanliness.

Swachhta Pakhwada was observed in DAE from 16th February – 28th February, 2020

At IGCAR, construction of toilets (Ladies and gents) for contract workers in FBTR has been physically completed by 51%. Fabrication works and installation of workers toilet cabin near CDO and Central Stores has also been physically completed by 51%.

In order to maintain cleanliness in all DAE units, stores located at different locations collect and dispose different types of scrap, unserviceable and surplus material. The Directorate of Purchase & Stores (DPS), during the current year, had issued about 278 sale orders with a total value of about 29 crores handling about 6600 MT involving 1059 truck load of scrap, about 14,460 unserviceable/surplus items and 55 vehicles. Swatchta Abhiyan programme was conducted in all the units, with special cleanliness drives and implementation of the aforesaid measures.

DCSEM has engaged an agency namely Stree Mukti Sanghathana, expert in the field of domestic waste management and are in the field for last 25 years. Door to door campaign was started. Resident's Associations of the various buildings and volunteers of a group of residents are also involved in this campaign. As a part of Swatchhata awareness programme, a drama showing the various harmful effects of plastic unsegregated waste and present behaviour of the people towards waste was enacted. DCSEM has also organized a campaign for scientific disposal of "Nirmalya" collected at all the Ganapati Pandals. The banners have been displayed at the prominent locations in colony regarding Swacchata awareness.

Director, DCSEM segregating SUP during Swachhata Hi Seva Abhiyan 2019 of DCSEM

At the General Services Organisation (GSO), a Swatch Machine was installed and commissioned at Anpuram Township for Disposal of Plastic Wastes in an environment friendly method. Briqueting Press was installed for compaction of dried leaves to briquettes for reuse. Swatchhata rallies, quiz and talks were conducted during the Swatchchta Pakhwada.

Swachh Bharat' activities have been carried out at Headquarters and seven Regional Centers of AMD.

EMPLOYEES' WELFARE

Employee Health Care

To provide specialised and personalised health care to its employees and the members of their family even after retirement, the Contributory Health Service Scheme (CHSS) was introduced in the Department in the year 1962. The Revised CHSS scheme came into effect from 01/02/1998.

Health Care is one of the most important social security measures in which NPCIL always focused on. To provide best medical facilities to its employees and their dependent family members, NPCIL follows the Contributory Health Service Scheme (CHSS) of DAE.

Children's Education

Atomic Energy Education Society (AEES), an autonomous institution under the Department of Atomic Energy (DAE), Govt. of India, was established in the year 1969 with an aim to provide quality education to the children of the employees of the DAE units working at different centres/ establishments across the country in an environment in which every student discovers and realizes his/her full potential. AEES currently administers 31 Schools/Junior colleges at 15 centres located all over India and provides education to over 27,000 students. AEES provides education to the economically backward children from the rural/tribal areas around its establishments through its Societal Enrichment and Education Programme (SEEP). This programme is meant for some children, who are identified only from those admitted under the Right to Education Act (RTE) category.

The government of India gives the right to free and compulsory education to all children in the age group of six to fourteen years, under the Right to Education Act. The same was implemented in AEES, in the year 2015-16 and it is being continued.

AEES has achieved significant results in its pursuit of excellence in curricular as well as co-curricular activities during these years. The enrichment of school libraries, computer aided education, improved sports facilities, play equipment, in-service training programmes for teaching & non-teaching staff members, multimedia programmes and enrichment programmes for students have helped the institution to set new benchmarks in excellence. Construction of auditoria, additional classrooms and the setting up of Computer, Mathematics, Social Science and language laboratories have greatly contributed to the strengthening of infrastructural facilities in our schools. CCTV surveillance cameras have been installed in all AEC Schools across the country for the safety, security and discipline related problems faced in the Schools/ JCs.

Teachers' Achievement

National Award

Dr. (Shri) Jebin Joel, PGT (Physics), AECS-4, Mumbai received the prestigious National Award for the Best Teacher from the hands of Honourable President of India on the occasion of Teachers' Day on 5th September, 2019.

Dr. Jebin Joel, PGT (Physics), AECS-4, Mumbai receiving the prestigious National Award

Board (Xth and XIIth) Exam Results of AEES Students

All India Secondary School Examination (AISSE)-2019

About 1986 students from 27 AEC Schools which are affiliated to the CBSE appeared for the Class X in March, 2019. The Pass percentage was 99.22 % (97.11 % last year) as compared to the all India CBSE pass percentage of 91.10 % and the Quality Index was 7.73 (7.19 last year). The overall Excellence Index stood at 85.80 (75.49 last year). The pass percentage of 21 (12 last year) schools was 100%.

All India Senior Secondary Certificate Examination (AISSCE)/HSC Exam 2019 CBSE:

About 772 students from 13 AEC Schools which are affiliated to the CBSE appeared for the Class XII examination in March, 2019. The pass percentage was 90.28% (87.19% last year) as compared to the all India CBSE pass percentage of 83.4 and the overall Excellence Index stood at 78.89 (70.60 last year). The Quality Index was 6.74 (6.27 last year). AECS, Mysore produced 100% result. The pass percentage of 7 (8 last year) Schools was above 90%.

STATE BOARDS:

Maharashtra Board

About 363 students from AEC School-1, Tarapur and Junior College, Mumbai which are affiliated to the Maharashtra state board appeared for the Class XII examination in March-April, 2019. The pass percentage was 93.94 % (99.04 % last year) as compared to the all Maharashtra pass percentage of 85.88 % and the overall Excellence Index stood at 55.65 (57.89 last year). The Quality Index was 5.95 (6.40 last year). The pass percentage of 2 (2 last year) Schools was above 90%.

Telangana Board

About 38 students from AEC School-1, Hyderabad which is affiliated to the Telangana state board appeared for the Class XII examination in March-April, 2019. The pass percentage was 78.95% (76.92% last year) as compared to the all Telangana pass percentage of 92.43 % and the overall Excellence Index stood at 63.16 (56.41 last year). The Quality Index was 5.89 (5.62 last year).

Tamil Nadu Board

About 146 students from AEC School-2, Kalpakkam which is affiliated to the Tamil Nadu state board appeared for the Class XII examination in March-April, 2019. The pass percentage was 93.84% (91.19% last year) as compare to all Tamil Nadu state board pass percentage of 91.3% and the overall Excellence Index stood at 58.90 (72.54 last year). The Quality Index was 6.27 (6.67 last year).

Celebrations

Golden Jubilee Celebrations

AEES completed 50 glorious years of service in February 2019. On April 6th, 2019 the Golden Jubilee Celebrations were conducted in the DAE convention center, Anushaktinagar. Essay writing competition, quiz and a Golden Jubilee Logo competition were conducted for the employees of AEES. A souvenir was released on the day of Golden Jubilee celebrations.

Golden Jubilee Celebrations- Cultural program by the staff

Golden Jubilee Celebrations - Cultural program by the students

Republic Day Celebrations

The 70th Republic Day was celebrated in all AEC Schools and Junior Colleges with great enthusiasm. A common function of all Schools located in Anushaktinagar & the Junior College was celebrated collectively at AEJC, Mumbai.

Republic Day Celebrations – March-past by the students

Republic Day Celebrations- Cultural program by the students

Various awards given on this occasion were as follows:

- AEES awards (National Level) for the outstanding teaching and non-teaching staff were conferred on the winners.
- AEES trophies, namely Dr. Vikram Sarabhai, Dr. Raja Ramanna, Dr. Homi Sethna and Dr. Homi Bhabha trophy were given to the winning AEC Schools and Junior Colleges for their best performance.
- Special awards to the outstanding students who excelled in areas like Sports and Games in addition to academics at CBSE/National level and also to those who participated in the Republic Day Parade/Rally held on 26th January, every year.
- "Souradip Ghosh Memorial Award" offered by Shri S.K. Ghosh, for the meritorious students who performed exceedingly well at Scholastic, Co-scholastic areas and Sports & Games in AEC Schools/Junior Colleges. The idea is to promote all-round development of the student. The awards were conferred to one student from Junior Category (Class X) and one student from Senior Category (Class XII).

Co-curricular Activities

Rashtriya Kishore Vaigyanik Sammelan (Children Science Congress)

Three Projects were selected for participation and display at the 45th Jawaharlal Nehru National Science, Mathematics and Environment Exhibition (JNNSMEE) for Children – 2018, which was held at Ahmedabad, Gujarat during November 23 - 27, 2018. From this level, one of the projects was selected for participation in Rashtriya Kishore Vaigyanik Sammelan (Children Science Congress) from January 3-6, 2019 during the 106th Indian Science Congress – 2019 held at Lovely Professional University at Jalandhar, Punjab.

Inter AECS debate in Hindi

Inter AECS debate in Hindi was conducted on 30.11.2019 at AECS-3 Mumbai. The winners from the 4 zones took part in this debate.

Inter AECS science quiz in Hindi

Inter AECS science quiz in Hindi was conducted by Hindi Vigyan Sahitya Parishad of BARC.

Extra-curricular Activities

Participation of Students in the Republic Day Parade at Delhi

Kum. Laxita Manocha, Class X of AECS-2, Rawatbhata has participated in Republic Day Parade/ Camp held in Delhi in connection with the Republic day celebration on 26.01.2019.

Inter AECS Art competition

School level Art competition was conducted on 09.12.2019. The selected entire from all the schools were sent to AECS-1 Mumbai. These entries will be adjudged and exhibited on Republic Day in the multipurpose hall of AEJC Mumbai.

Inter AECS cultural (Music) meet

Inter AECS cultural (Music) meet 2019 was held from 08.11.2019 to 10.11.2019 at AECS Narora. Approximately 600 students from all the schools took part in this.

Summer Sports Coaching Camp

AEES in collaboration with the Department of Atomic Energy Sports and Cultural Council organizes Summer Sports Coaching Camp for school children in various sports. This year also summer sports coaching camps in all the schools of AEES were conducted in the months of April and May, 2019. In all around 1400 students took part in the camps.

In-Service Training Programme

The concept of an orientation programme emphasizes the importance of teachers as agents of socio-economic change and national development and underlines the need to make them skill-oriented teachers. AEES has teamed up with Kendriya Vidyalaya Sangathan's (KVS's) Zonal Institutes of Education and Training (ZIET) and other KVs, for imparting training of quality and value to the teachers. About 82 teachers attended the 1st spell of training which was successfully held for PRTs, TGTs & PGTs at ZIET, Mumbai and at various other KVS from 6th June, 2019 to 17th June, 2019 and the 2nd spell of the training was held in the month of December 2019 which was conducted by KVS.

Principals' Meetings

A Principals' Meeting was held from February 21-23, 2019 at Kudankulam. The agenda of the meeting covered various academic developments and non-academic matters and accounts related matters of the schools. Again from 2 -3 August, 2019 Principals' Meeting was held at Central Office, Mumbai.

Recruitments

Recruitment for the post of Teachers under Direct Quota and the Recruitment of UDC, Senior Clerk, HM, Vice-Principal and Principal under Promotion Quota were held during the year.

DAE SPORTS & CULTURAL ACTIVITIES

The DAE Sports and Cultural Council (DAE S&CC) has been facilitating promotion of sports, physical fitness, yoga and cultural activities among DAE employees and their family members located at various units all over India for more than thirty four years now. Considering that the mandate of sustainable nuclear power needs the inculcation of positive attitude, team work, nurturing of excellence and building up of competitive spirit amongst the employees, DAE S&CC's thrust has been to encourage facilitation of activities towards these themes. In addition, programs are also designed to develop positive health and attitude towards achievement of excellence amongst family members of employees.

A brief summary of activities undertaken by DAE S&CC during the year 2019 are as follows:

About 1000 employees participated in the Inter DAE meets which is aimed at encouraging healthy competition amongst DAE employees in various sports and cultural events to facilitate inter as well as intra-unit synergy, constructive team work and sportsman spirit among employees. Teams to participate in National events like Kabbadi, Bridge, Table Tennis, Ball Badminton, Badminton etc. were also selected during the meet. Participation of all DAE units were through eight leader groups (Ajanta, Dwaraka, Ellora, Golkonda, Konark, Nagarjuna, Pushkarand Rameswaram). Selection trials were conducted by each leader group at various DAE units to represent the leader group. The events of XXXV Annual DAE meet has commenced. All the sixteen games will be played from this year onwards at various DAE units across India. DAE S&CC also supported the participation of players in National Championships by payment of affiliation fees, provision of kit allowance and arrangement of training camp.

Ajanta Team: Cricket Overall Championship Winner

35th Annual DAE Volleyball Meet

35th Annual DAE Athletic Meet

35th Annual DAE Basketball Meet

DAE S&CC organized summer coaching camps (Coaching in various games and sports like Athletics, Swimming, Cricket, Football, Basketball, Table Tennis, Badminton, Lawn Tennis etc.) for DAE school children for four weeks jointly with AEES at various DAE schools located at different units of DAE. Council shares one third of the cost of summer camp and frames the camp guidelines. More than 2700 students participated in preliminary camp and 1500 students participated in the main camp. Selection for advanced coaching was done based on performance of the players in summer coaching camps.

BARC Open State Level Bridge Championship organised by BARC Staff Club in association with DAE Sports and Cultural Council was held at New Community Centre, Anushaktinagar on 23rd and 24th November, 2019 under the aegis of Maharashtra Bridge Association (MBA). It is a prestigious event where numerous players including many National Level Players participate every year from various cities of Maharashtra. It is a matter of pride that one of these 11 tournaments was held in Anushaktinagar in the name of BARC Open State Level Bridge Championship for the 28th year in a row.

BARC Staff Club in association with DAE Sports & Cultural Council organised Inter Ministry Kabaddi

Tournament from 29.05.2019 to 31.05.2019 at Nalanda Square, Anushaktinagar, Mumbai. Seven teams from various central government establishments located in Mumbai (BARC, Indian Post, Central GST, Income Tax, Naval Dockyard, DAE and Material Organisation) participated in the tournament. Children staying in Anushaktinagar and Mandala colony played an exhibition match just before the final match. Central GST won the final match and Indian Post were Runner up.

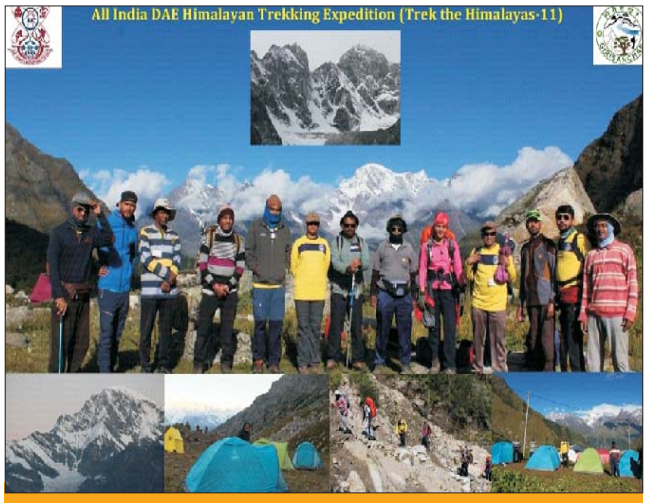
Inter Ministry Kabaddi Tournament organised at Nalanda Square, Anushaktinagar, Mumbai

Regular yoga activities as well as camps were organized at different centers at various levels for employees as well as for their family members. To encourage Yoga and Fitness, units of DAE were encouraged and financially supported to set up fitness centers for their employees and family members. One month Summer Yoga Course – 2019 was organised from 1st May to 31st May 2019 and around 390 people participated in it. Twelve regular Yoga Classes were conducted in Brindavan Yoga Hall. Yoga classes have also been started at PTAAF complex, Anushaktinagar. Around 410 participants attended daily Yoga Classes. Programmes were also arranged on 21 June-2019 to celebrate International Yoga Day on a Grand scale.

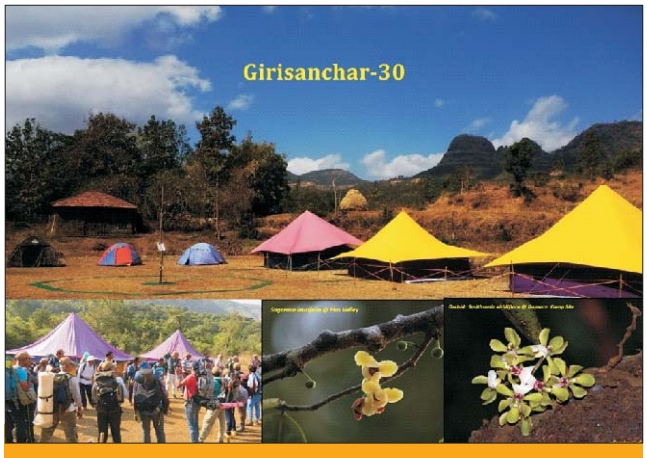
DAE S&CC and BARC Staff Club, Mumbai had successfully organised 5th National Yoga workshop on the theme "Complete Health Management" on 19th and 20th October, 2019. This workshop was organised at Multipurpose Hall, Training School Hostel (TSH), Anushaktinagar and it was a grand success. This particular workshop addressed physical, mental, social and spiritual health issues. Physical therapy, music therapy, humour and philosophical discourses kept the audience enthralled. Few senior teachers also presented their papers. It's well-known fact that the system of "Yoga in daily Life" can assist in overcoming the stress and grant people a new, positive aim and purpose in life. Yoga brings Harmony for body, mind and soul.

5th National Yoga workshop on the theme "Complete Health Management" was held on 19th and 20th October, 2019 at Anushaktinagar, Mumbai

Under Nature & Adventure related activities, Team Girisanchar of DAE S&CC had arranged various Nature & Adventure related activities throughout the year. These includes Himalayan Trekking expeditions, Girisanchar-30 (DAE Annual Trekking expedition), Monsoon treks, Nature & Adventure Camp for school children, Cyclothon & Cycling Expedition, Walkathon, Know Your Trees Walk for school Children etc. Himalayan trekking expedition (Trek the Himalaya-11) was organized in Bagini Glacier region. Also, team Girisanchar played a lead role in organisation of "Girimitra Sammelan" in Mumbai. Dr. Anil Kakodkar, Former Chairman, AEC presided over the function.

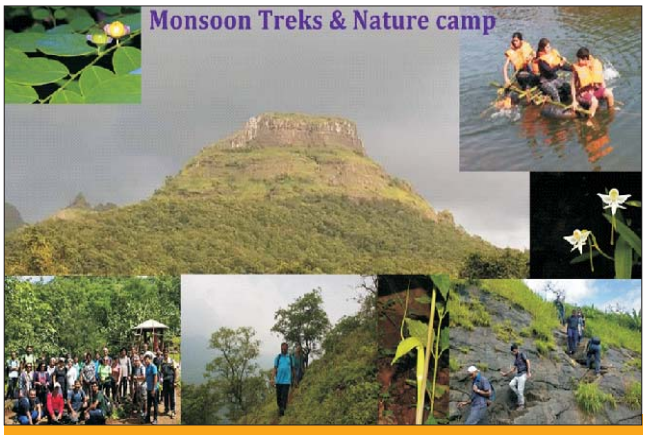


All India DAE Himalayan Trekking Expedition (Trek the Himalayas-11)



Girisanchar-30

Walkathon and Cyclothon 2019



Monsoon Trek and Nature Camp

This year in line with DAE's outreach programme, efforts were made to reach out to the villages and village schools near Girisanchar camp sites. Lectures and events were organized for the school students and all these activities were very-well received and appreciated by the local villagers, school children & teachers.

DAE Cultural Centre has initiated various activities like Dance, Drama, Music, Literature, Traditional Art, Films, photography workshops etc. Training initiatives in Hindustani classical music (vocal) classes, tabla and flute, classical dance Western dance forms (Hip-Hop & Salsa) and Indian folk dance forms (Garba, Gondhal, Bhangra, Bihu etc.) has been started and is being successfully conducted for the DAE fraternity. DCC has also started the 'Anusangeet' series providing opportunities to listen and directly interact with reputed artists of national/international level. The 'Darbar' series has also been introduced to encourage budding and talented artists in DAE fraternity.

Publication ceremony of book named "Pannalal Ghosh", a book in English, on the flute maestro Pt. Pannalal Ghosh authored by "Dr Vishwas Kulkarni" of BARC followed by a Cultural event "Flute recital & Vocal" was organised by DAE Cultural Centre and BARC Staff Club at Ravindra Natya Mandir, Mumbai on 2nd November, 2019. The programme was a grand success.

The 3rd DCC Photography Exhibition was inaugurated by Shri K.Jayrajan, Vice President DAE Sports & Cultural Council on 6th December at DCC

Hall, NRB, Anushaktinagar, Mumbai. More than 100 selected photos taken by DAE fraternity were displayed.

DAE Cultural Centre organized a 'One Day Wildlife Photography' Workshop at Multipurpose Hall, TSH, Anushaktinagar on 28th September 2019. The workshop covered basis aspects of wildlife photography by renowned speaker and field expert Radhika Ramasamy along with some hands on training on wildlife photography.

On 4th March 2019, more than 450 music lovers present in DAE Convention Centre main auditorium, Anushaktingar were enchanted by an amazing live performance by the band, Aziz Ozouss of Morocco. This event was hosted by DAE Sports and Cultural Council in association with ER Division, DAE and Indian Council for Cultural Relations (ICCR).

Rocking Music Performance by the Moroccan Band, Aziz Ozouss

DAE Sports & Cultural Council & BARC Staff Club jointly conducted Anushakti Monsoon Marathon 2019 (AMM 2019) on Sunday 28/07/2019 and got overwhelming response. Event was held in 3 categories namely 2.5Km, 5Km and 10Km distances and it was a resounding success. There were overall 410participants. Also, BARC Staff Club athletic meet was organized on 13th Oct at Anushaktinagar PTAAF complex and was conducted successfully.

Anushakti Monsoon Marathon 2019 (AMM 2019)

Some of the promotional activities undertaken by DAE S&CC included participation of DAE teams in National Level inter institutional tournaments supported by national federations (Table tennis, Kabaddi, Badminton, Bridge & Ball Badminton); Support to district level promotional tournaments at Anushaktinagar to facilitate advanced coaching children in Table Tennis, Tennis, Cricket & Badminton; Financial subsidy to welfare groups of various units (ARWA for sports, BARC Hospital, BARC Staff Club Yoga Circle, etc.) and New Community Center (NCC) for Annual competitions SPLASH and financial grants to Special children for conducting sports camp Shoushilya at Anushaktinagar.

New Community Centre (NCC), in Anushaktinagar, is an entity formed under the DAE S&CC as a demonstration model community centre on a self-supporting basis as an example to all other units to encourage and promote sports and cultural activities among employees, ex-employees of DAE and their family members. NCC is engaged in various sports and cultural activities on regular basis like Badminton, Table Tennis, Fitness for Gents & Ladies (consisting of Aerobics, Gym, Zumba & Power Yoga), Bridge, Billiards and Carom etc. NCC also provides regular and advance coaching to children in Badminton, Table Tennis, Chess, Cricket, Musical Instruments, and Western Dance etc. Some of the players trained through NCC programmes have represented in state and national levels.

Annual Sports and Cultural Festival of New Community Centre "SPLASH-2019" was conducted during November, 09-17, 2019. Overwhelming

response was received with more than 1250 entries for 17 sports and cultural events. Two new events Rubik's cube and Kabbadi were introduced this year which attracted good response. The Splash-2019 was inaugurated by Shri Abhay kumar, Director Finance, DAE on November 09, 2019. Shri A.K. Wankhede, Chairman, LMC and head CSDD, CTG, chaired prize distribution function for kids on November 15, 2019. Chief Guest Dr. P.K. Pujari, AD RC&IG, BARC embellished the closing ceremony and final prize distribution function on November 17, 2019.

"SPLASH-2019" was conducted during November, 09-17, 2019

RTI COMPLIANCE

At NPCIL, an elaborate RTI Application management mechanism exists with functional arrangement of 8 CPIOs and 7 APIOs, one at each NPCIL Station/ Sites along with one CPIO and one APIO at NPCIL Head Quarters, to deal with the requests received under the RTI Act 2005. There is an Appellate Authority at NPCIL Head Quarters. The mandatory information required under the Act [section 4(1) (b)] is posted on NPCIL website and the information is updated from time-to-time. Presentations/ lectures/ Trainings were organized in NPCIL for creating awareness about the importance and ways to implement the Act.

During the Financial Year 2019-20, as on 31.12.2019, 656 RTI applications and 114 Appeals under the RTI Act, 2005 were disposed off. Department of Personnel & Training (DoPT) RTI online portal is used effectively in NPCIL. The online RTI applications and appeals so received are being disposed through portal online.

IGCAR has fully complied with the provisions of RTI Act, 2005. In this regard, the Unit has suo moto declared information under the provision of Section 4 of RTI Act 2005. This suo moto declaration is updated regularly as and when there is any change. During the year 2019, 166 applications were received of which 9 applications were transferred to other PIOs. Information was provided to the applicants within the prescribed time limit. Similarly, 10 RTI Appeals were received during the same year which was disposed of within the prescribed time limit.

During the year, from April 2019 to December 2019, RRCAT received 113 RTI applications and out of these 107 were disposed of.

During the period from 01.04.2019 to 31.12.2019, 116 RTI applications were received at IREL, out of which 100 applications have been replied and balance 16 applications will be replied within prescribed period as per RTI Act, 2005.

ECIL received 120 RTI queries and out of that 106 queries were replied.

Number of applications received at BHAVINI as per RTI Act 2005 were 65 out of which 57 have been replied and the reply for the remaining 8 applications are being prepared. Total 4 appeals were received and all have been replied to.

During the year, the DPS received 84 RTI applications and out of which 80 have been answered.

RTI related issues have been dealt with efficiently at AMD. A total of 117 RTI applications were received out of which 112 were replied and 5 are transferred. 13 appeals for first appellate authority were received and replied. 4 CIC hearings on second appealwere attended and orders passed by CIC.

DCSEM has received 88 RTI queries and 7 Appeals and out of that 82 RTI queries and all Appeals were replied.

AWARDS & PRIZES

Several awards in areas of Safety and Performance, Vigilance, Public Awareness (PA) activities, Corporate Social Responsibility (CSR) and Official Language (OL) were bagged by various units of NPCIL and Headquarters. These are mentioned as under:

TAPS-3&4 won first prize under Scheme-II (Longest accident free period, Factories working more than 25 Lakh Man-Hours in a year) on September 27, 2019, from National Safety Council - Maharashtra Chapter during Safety Awards 2018. It also won 'Prashansha Patra' - NSC Safety Awards-2018.

National Safety Council - Maharashtra Chapter Safety Award – 2018: TAPS-3&4 received the First prize under Scheme-II (Longest accident free period, Factories working more than 25 Lakh Man-Hours in a year) on September 27, 2019

KAPS-1&2 won Certificate of appreciation from National Safety Council of India in Group-C - Power generation sector for achieving the most outstanding performance in OSH (Occupational Safety and Health) for the Assessment Period of three years-2015 to 2017. It also won the AERB Fire Safety Award-2018 in category-I.

KGS-1&2 won "Sarvashreshtha Suraksha Puraskar" (Golden trophy) NSCI Safety award - 2019 from National Safety Council, Mumbai; "Unnatha Suraksha Puraskara-2019" award from National Safety Council Karnataka Chapter and "Shreshta Suraksha Puraskar" (Silver trophy) NSCI Safety award - 2018 from National Safety Council, Mumbai.

Kaiga Station bagged the prestigious "Unnata Suraksha Puraskar" for the year 2019 from National Safety Council of India,Karnataka Chapter under Power generation category for the third time consecutively

KGS-3&4 won "Unnata Suraksha Puraskar" for the year 2019 from National Safety Council of India, Karnataka Chapter under Power generation category for the third time consecutively. It also won the "Shreshta Suraksha Puraskar" for the year 2019 from National Safety Council of India under manufacturing category.

In the Official Language, NPCIL was honored with DAE Rajbhasha Shield consecutively for eleventh year (2008-2019); NPCIL was also honored with 1st prize for excellent OL Implementation in the category of large enterprises by Mumbai PSU Town Official Language Implementation Committee for the year 2018-19; NPCIL has been honored with Third prize in the category of large enterprise for the year 2018-19 by an NGO "Ashirwad" which works for promoting and propagating Rajbhasha Hindi in Mumbai since four decades; Tarapur Maharashtra Site received First Prize

for Excellent Hindi Implementation from NARAKAS, Thane; Tarapur Maharashtra Site received Second Prize for its in-house magazine 'Anubharti' from DAE on November 15, 2019; Two employees of TAPS received first prize in poster competition and consolation prize in Hindi slogan competition during 36th DAE Safety and Occupational Health Professionals Meet (DAE-SOHPM), 2019 at NFC Hyderabad; MAPS has been awarded with 3rd prize for best Hindi Science Skit by Hindi Vaigyanic Sahitya parishad, BARC Mumbai and Five employees of Kaiga Station received six prizes in Paper presentation, LOGO, Poster, Cartoon & Hindi Slogan competitions during 36th DAE Safety & Occupational Health Professionals Meet (DAE-SOHPM) held at NFC, Hyderabad.

MAPS has been awarded with 3rd prize for best Hindi Science Skit by Hindi Vaigyanic Sahitya parishad, BARC Mumbai

Public Awareness awards won by NPCIL includes SCOPE Award-2019 was conferred to NPCIL for coffee table book "100 Lives Around Us" at Delhi; Department of Posts, Govt. of India, released a 'My Stamp' and 'Special Cover' commemorating the 50 years of commercial operation by TAPS-1&2 on December 28, 2019 and Department of Posts, Govt. of India, released a 'My Stamp' and 'Special Cover' commemorating the achievement of KGS-1 for establishing the world record of 962 days of continuous operation on November 28, 2019.

HWP, Manuguru has won Indian Chemical Council Award for year 2018 for "Excellence in Management of Environment". The FICCI Award for the year 2019 was won by HWP, Manuguru for Most Environment Friendly Company in Chemical & Petrochemicals Sector. HWP, Kota won AERB Fire Safety Awards for the year 2018 in Category-I. HWP, Hazira won Indian Chemical Council (ICC) award for excellence in Energy Conservation and Management for the year 2018. This year the plant has also won National Safety Award by Ministry of Labour & Employment, Government of India for maximum accident free man-hours in year 2017 & lowest average frequency rate for the period of 3 years, from 2015 to 2017. HWP, Thal has won AERB Industrial Safety Award in Category-1 of production units for the year 2018 and Certificate of Merit by National Safety Council for the year 2018 for achieving zero accidents frequency rate for fourth time in succession.

IREL received many awards these includes India's Most Trusted Company Award 2018 conferred by IBC Infomedia; Best Community Development Award in National CSR Leadership Congress; CAPEXIL "Top Export Award for the year 2015-16 & 2016-17"; International Leadership Innovation Excellence Award conferred to CMD, IREL by Institute of Economic Studies in Colombo, Srilanka and Rajbhasha Shied (Runner-up) for the year 2018-19 for excellent implementation of Official Language Policy amongst DAE PSU Headquarters located pan India, in 20th Rajbhasha Sammelan organized by DAE on 15.11.2019 at AMD, Hyderabad.

IGCAR was awarded the Certificate of Excellence (second position among the DAE units) for the exemplary performance during the Swachhta Pakhwada activities (February 16-28, 2019). IGCAR bagged the 'Swachhta Pakhwada Award" amongst constituent units of DAE for the second consecutive year.

Scientists from TIFR won prestigious awards during this period. Prof. Shankar Ghosh has been awarded the Shanti Swarup Bhatnagar Prize for the year 2019 in Physical Sciences by the Council of Scientific and Industrial Research, New Delhi. Prof. Suvrat Raju and Dr. Basudeb Dasgupta were awarded the 2019 ICTP Prize by International Centre for Theoretical Physics. Prof. Satyajit Mayor was conferred the distinguished Chevalier de l'Ordre national du Mérite award in November 2019. Dr. Samriddhi Sankar Ray received the Dr. APJ Abdul Kalam Cray HPC

Award for 2019 by Cray, USA. Prof. Mustansir Barma has been awarded R. D. Birla Memorial Award in Physics by the Indian Physics Association. Prof. Rajesh Gopakumar received the IIT Kanpur Distinguished Alumnus Award 2019. Dr. P. V. Shivaprasad of NCBS has been awarded C V Raman award by the Government of Karnataka. Prof. Eknath Ghate was awarded the JTM Gibson Award for Excellence by Mayo College, Ajmer, Rajasthan. Dr. Tanmay Deshpande and Dr. Anukul Jana were awarded the INSA medal for Young Scientists (2019) by the Indian National Science Academy. Prof. Mandar Deshmukh was awarded the "Young Nano Scientist India 2019 Award" by OXFORD Instruments India Pvt. Ltd. Prof. Krishna Kumar Mishra of the Homi Bhabha Centre for Science Educat ion (HBCSE) has been awarded the "K.N, Bhaal Award" for his book on "Jal Sansadhan - Gaharata Sankat", by the Uttar Pradesh Hind Sansthan, Lucknow.

Dr. RA Badwe, Director, TMC was recognized by the ASCO (American Society of Clinical Oncology) as one of the top ten oncologists in the world. Dr. RA Badwe, Director TMC was also recognized by the World Prevention Alliance, France for his outstanding contribution to cancer control during National Cancer Institute Directors Meeting-USA, July 2019.

CHAPTER - 11 :

IMPLEMENTATION OF PERSONS WITH DISABILITIES (EQUAL OPPORTUNITIES, PROTECTION OF RIGHTS & FULL PARTICIPATION) ACT, 1995

The Department of Atomic Energy has a mandate to develop peaceful uses of nuclear energy in areas like power generation and basic research in frontier areas of science and technology. In view of the nature of activities carried out by the Scientific and Technical persons in various Research Centres, Public Sector Undertakings, Industrial Units and Aided Institutions of the Department, this Department is not in a position to implement the provisions of reservation of posts fully as required under the "Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act, 1995". Therefore, this Department has already sought exemption for the Units like Heavy Water Boards and Nuclear Power Corporation of India Ltd. From the provisions of the said Act. No specific scheme under plan projects for the benefit of persons with disabilities has been introduced in the Department. In-spite of the constraints, all the Units/PSUs/Aided Institutions have attempted to identify posts, where persons with disabilities could be employed without impairing the activities or causing inconvenience.

The sanctioned strength and number of persons with disabilities in various posts in Group A, B, C & D against 3% vacancies to be reserved for them under Section 33 of the said Act is indicated in the pages that follow.

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **CONSTITUENT UNITS**

Group	Number of Employees					Direct Recruitment									By Promotion						
						No. of vacancies reserved				No. of appointment made					No. of vacancies reserved			No. of appointment made			
	Total	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)
Group A	8801	1	3	43	1	0	0	1	0	111	0	0	0	0	0	0	0	28	0	0	0
Group B	8148	5	8	70	1	1	2	3	0	29	2	1	0	0	0	0	0	133	0	0	2
Group C	9934	18	46	113	0	2	8	19	0	113	0	0	2	0	0	1	0	168	0	0	0
TOTAL	**26883**	**24**	**57**	226	**2**	**3**	**10**	**23**	**0**	**253**	**2**	**1**	**2**	**0**	**0**	**1**	**0**	**329**	**0**	**0**	**2**

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **AIDED INSTITUTIONS**

Group	Number of Employees					Direct Recruitment									By Promotion							
						No. of vacancies reserved					No. of appointment made					No. of vacancies reserved				No. of appointment made			
	Total	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)	
Group A	1730	3	0	13	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Group B	3011	6	4	23	1	2	2	5	0	3	0	0	0	0	0	0	0	0	0	0	0	
Group C	2582	4	17	32	0	3	1	2	0	4	1	1	1	1	0	0	0	0	0	0	0	
TOTAL	**7323**	**13**	**21**	**68**	**1**	**5**	**4**	**8**	**0**	**7**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Group	Number of Employees					Direct Recruitment									By Promotion						
						No. of vacancies reserved				No. of appointment made					No. of vacancies reserved			No. of appointment made			
	Total	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)
Group A	7317	11	7	56	16	2	3	1	0	91	0	1	0	0	0	0	0	230	1	0	3
Group B	5006	11	11	64	6	1	4	3	1	57	1	4	3	0	0	0	0	0	0	1	1
Group C	4270	16	11	43	10	8	6	5	1	164	0	2	10	0	0	0	0	0	0	0	0
TOTAL	**16593**	**38**	**29**	**163**	**32**	**11**	**13**	**9**	**2**	**312**	**1**	**7**	**13**	**0**	**0**	**0**	**0**	**230**	**1**	**1**	**4**

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

CHAPTER - 12 :

CITIZEN CHARTER

I) OUR VISION

The vision of the Department of Atomic Energy is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

II) MANDATE

The mandate of the Department, on which its programmes are based, covers :

- Increasing share of nuclear power through deployment of indigenous and other proven technologies, along with development of fast breeder reactors and thorium reactors with associated fuel cycle facilities;
- Building and operation of research reactors for production of radioisotopes and carrying out radiation technology applications in the field of medicine, agriculture and industry, cancer care, water related technologies, waste management etc.;
- Developing advanced technologies such as accelerators, lasers, supercomputers, advanced materials and instrumentation, and encouraging transfer of technology to industry;
- Support to basic research in nuclear energy and related frontier areas of science; interaction with universities and academic institutions; Support to research and development projects having a bearing in DAE's programmes, and international cooperation in related advanced areas of research, and
- Contribution to national security.

III) OUR ACTIVITIES

- The Department is engaged in the design, construction and operation of nuclear power / research reactors and the supporting nuclear fuel cycle technologies covering exploration, mining and processing of nuclear minerals, production of heavy water, nuclear fuel fabrication, fuel reprocessing and nuclear waste management. It is also developing advanced technologies which contribute to the national prosperity. The human resource developed and technical services being rendered by the Department have been greatly helping the Indian industry.
- The Department is also developing better crop varieties, techniques for control/eradication of insects thus protecting the crops, radiation based post harvest technologies, radiation based techniques for diagnosis and therapy of disease particularly cancer, technologies for safe drinking water, better environment and robust industry.

IV) OUR CLIENTS

- User Ministries/Departments of Central Govt. and State Govt. dealing with energy, agriculture, food, health, education, oil and petroleum, industry, science and technology etc.
- Quasi Govt. Organisations, NGOs, industrial organizations, educational institutes.
- Electricity Boards, Hospitals, Research / Medical / Educational / Academic Institutions, agriculturists etc.

V) LINK TO RTI PORTAL

- Visit the link www.rti.gov.in

VI) WHOM TO CONTACT

I. Public Grievance and Complaints

Shri Sanjay Kumar,
Joint Secretary (A&A) &
Public Grievance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

II. Vigilance Complaints

Shri Sanjay Kumar,
Joint Secretary (A&A) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

III. Nodal Officer / Contact Officer for Citizen's Charter of DAE

Shri Sanjay Kumar,
Joint Secretary (A&A) &
Nodal Officer/Contact Officer for Citizen's Charter of DAE
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

IV. Public Relations

Shri Ravi Shankar,
Head, Public Awareness Division,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22823144
Email: - amrita.rs@dae.gov.in

Government of India
Department of Atomic Energy
Anushakti Bhavan, C.S.M. Marg,
Mumbai - 400 001

NOTICE

We, the public servants of India do hereby solemnly pledge that we shall continuously strive to bring about integrity and transparency in all spheres of our activities. We also pledge that we shall work unstintingly for eradication of corruption in all spheres of life. We shall remain vigilant and work towards the growth and reputation of our Department. Through our collective efforts, we shall bring pride to our Department and provide value based service to our countrymen. We shall do our duty conscientiously and act without fear or favour.

This office is thus committed to maintaining the highest level of ethics in its working towards achieving the above objective, all are requested:

- Not to pay bribe
- If anybody in this department or its offices asks for bribe : or
- If you have any information on corruption: or if you are a victim of corruption in any of our offices.

You MAY COMPLAIN TO:-

Shri Sanjay Kumar, Joint Secretary (A&A) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

YOU CAN ALSO COMPLAIN TO THE :-

CENTRAL VIGILANCE COMMISSION,
SATARKTA BHAWAN, BLOCK 'A',
GPS COMPLEX, INA,
NEW DELHI – 110 023.

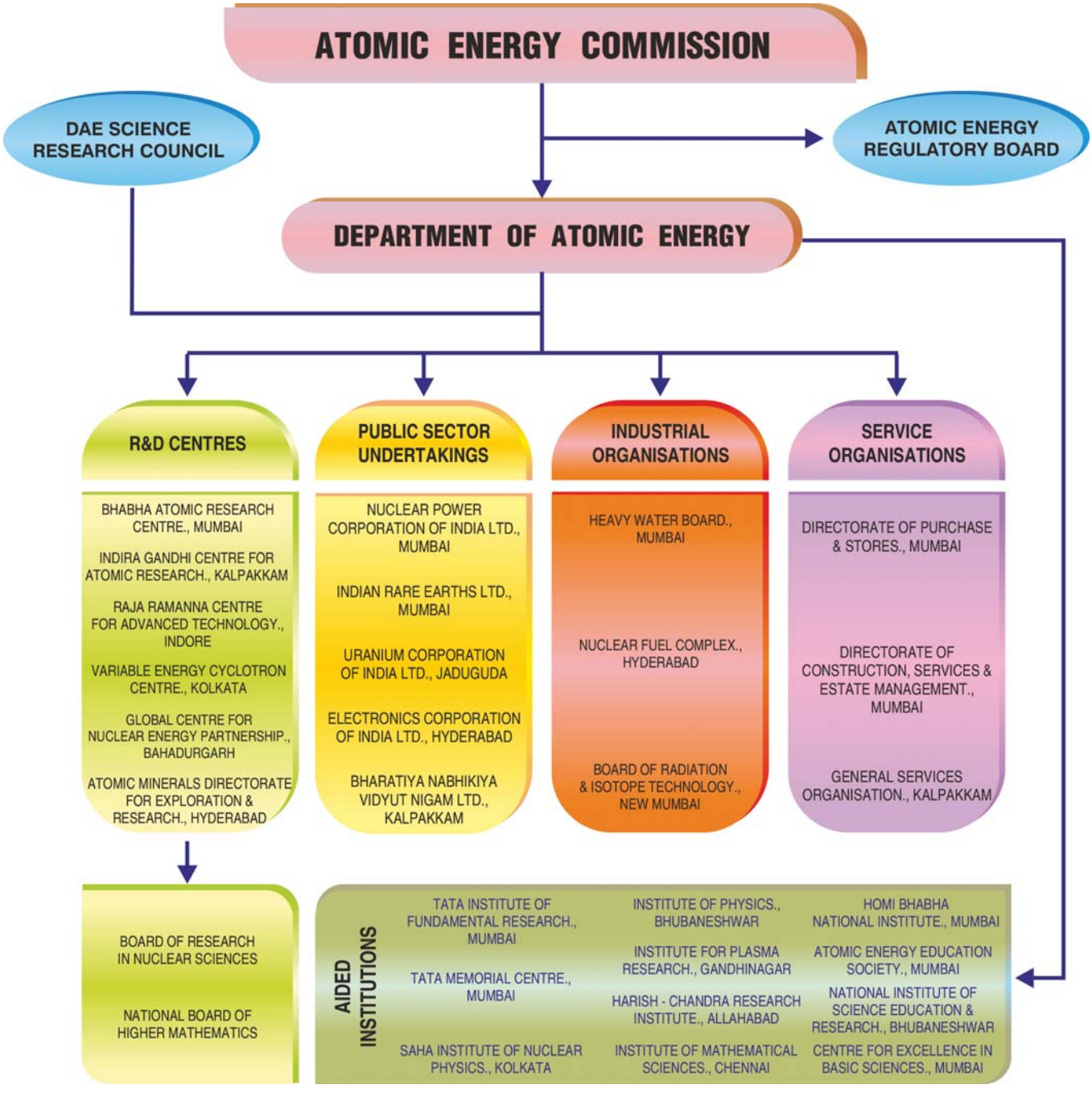
ANNEX - I

THE ORGANISATION

The Department of Atomic Energy (DAE), that came into being on August 3, 1954, has been engaged in the development of nuclear power technology, applications of radiation technologies in the fields of agriculture, medicine, industry and basic research.

As integrated group of organizations, the Department comprises six Research Centres, three Industrial Organisations, five Public Sector Undertakings and three Service Organisations. It has under its aegis two Boards for promoting and funding extra-mural research in nuclear and allied fields and mathematics, and a national institute (deemed university).

It also supports ten institutes of international repute engaged in research in basic sciences, astronomy, astrophysics, cancer research and education, etc., and a society that provides educational facilities to the children of DAE employees.


ATOMIC ENERGY COMMISSION
DAE SCIENCE RESEARCH COUNCIL
ATOMIC ENERGY REGULATORY BOARD
DEPARTMENT OF ATOMIC ENERGY
R&D CENTRES
BHABHA ATOMIC RESEARCH CENTRE., MUMBAI
INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH., KALPAKKAM
RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY., INDORE
VARIABLE ENERGY CYCLOTRON CENTRE., KOLKATA
GLOBAL CENTRE FOR NUCLEAR ENERGY PARTNERSHIP., BAHADURGARH
ATOMIC MINERALS DIRECTORATE FOR EXPLORATION & RESEARCH., HYDERABAD
PUBLIC SECTOR UNDERTAKINGS
NUCLEAR POWER CORPORATION OF INDIA LTD., MUMBAI
INDIAN RARE EARTHS LTD., MUMBAI
URANIUM CORPORATION OF INDIA LTD., JADUGUDA
ELECTRONICS CORPORATION OF INDIA LTD., HYDERABAD
BHARATIYA NABHIKIYA VIDYUT NIGAM LTD., KALPAKKAM
INDUSTRIAL ORGANISATIONS
HEAVY WATER BOARD., MUMBAI
NUCLEAR FUEL COMPLEX., HYDERABAD
BOARD OF RADIATION & ISOTOPE TECHNOLOGY., NEW MUMBAI
SERVICE ORGANISATIONS
DIRECTORATE OF PURCHASE & STORES., MUMBAI
DIRECTORATE OF CONSTRUCTION, SERVICES & ESTATE MANAGEMENT., MUMBAI
GENERAL SERVICES ORGANISATION., KALPAKKAM
BOARD OF RESEARCH IN NUCLEAR SCIENCES
NATIONAL BOARD OF HIGHER MATHEMATICS
AIDED INSTITUTIONS
TATA INSTITUTE OF FUNDAMENTAL RESEARCH., MUMBAI
TATA MEMORIAL CENTRE., MUMBAI
SAHA INSTITUTE OF NUCLEAR PHYSICS., KOLKATA
INSTITUTE OF PHYSICS., BHUBANESHWAR
INSTITUTE FOR PLASMA RESEARCH., GANDHINAGAR
HARISH - CHANDRA RESEARCH INSTITUTE., ALLAHABAD
INSTITUTE OF MATHEMATICAL SCIENCES., CHENNAI
HOMI BHABHA NATIONAL INSTITUTE., MUMBAI
ATOMIC ENERGY EDUCATION SOCIETY., MUMBAI
NATIONAL INSTITUTE OF SCIENCE EDUCATION & RESEARCH., BHUBANESHWAR
CENTRE FOR EXCELLENCE IN BASIC SCIENCES., MUMBAI

ATOMIC ENERGY ESTABLISHMENTS IN INDIA

Major Programmes and Sub-Programmes

MP 1		MP 2		MP 3		MP 4		MP 5		MP 6		MP 7	
1.01	PHWR	2.01	Fast Reactors	3.01	Advanced Heavy Water Reactor	4.01	Research Reactors	5.01	Mathematics & Computational Sciences	6.01	Human Resource Development	7.01	Infrastructure
1.02	LWR	2.02	Materials	3.02	Thorium Fuel Cycle	4.02	Isotope Processing	5.02	Physics	6.02	Sponsored Research	7.02	Housing
1.03	Front End Fuel Cycle	2.03	FBR-Front End Fuel Cycle	3.03	Other Thorium Reactor Systems	4.03	Agriculture	5.03	Chemistry	6.03	Prospective Research Fund		
1.04	Back End Fuel Cycle	2.04	FBR-Back End Fuel Cycle	3.04	Accelerator Driven Sub-critical Systems	4.04	Food Processing	5.04	Biology	6.04	Homi Bhabha Centre for Science Education		
1.05	Health, Safety & Environment	2.05	Repair and Inspection Technologies	3.05	Materials	4.05	Health	5.05	Cancer	6.05	Information Technology Application Development		
1.06	Waste Management	2.06	FBR-Health, Safety & Environment	3.06	Hydrogen Energy	4.06	Water	5.06	Synchrotrons & their Utilisation				
				3.07	Fusion Reactor	4.07	Industrial Applications	5.07	Cyclotrons & their Utilisation				
						4.08	Accelerators	5.08	Fusion & Other Plasma Technologies				
						4.09	Lasers	5.09	Material Science				
						4.10	Special Materials	5.10	Interdisciplinary Areas				
						4.11	Advanced Technologies	5.11	International Research Collaborations				
						4.12	Special Programmes						

MAJOR PROGRAMMES

MP-1 : Nuclear Power Programme-Stage-1
MP-2 : Nuclear Power Programme-Stage-2
MP-3 : Nuclear Power Programme-Stage-3 and beyond
MP-4 : Advanced Technologies and Radiation Technologies and their Applications
4A : Advanced Technologies and their Applications (Includes sub-programmes 4.01, 4.08 to 4.12)
4B : Radiation Technologies and their Applications (Includes sub programme 4.02 to 4.07)
MP-5 : Basic Research
MP-6 : Research Education Linkages
MP-7 : Infrastructure & Housing

ANNEX - II

REPLIES TO AUDIT OBSERVATIONS

Report No.2 of 2019, Chapter-III: Financial Audit, Union Government

Para No.3.8 - Incorrect budgeting and violation of DFPRs

Rule 8 of the Delegation of Financial Powers Rules, 1978 (DFPRs), categorizes the object class six for acquisition of Capital Assets and other Capital Expenditure, wherein the object heads viz., 51 to 56 and 60 are grouped. These object heads pertain to booking of expenditure of capital nature and therefore should correspond with capital major heads only. All other object heads falling in other than class six are revenue in nature. Accordingly, these object heads should ordinarily not correspond with the capital major heads.

In Grant No.4 pertaining to Department of Atomic Energy, object head 27 – Minor Works' was operated under Capital Major heads (4861-Capital Outlay on Atomic Energy Industries and 5401-Capital Outlay on Atomic Energy Research) and expenditure of ₹ 61.13 crore was budgeted and booked in violation of DFPRs.

Action Taken:

Initial ATN was forwarded to Director (Inspection), CAG, New Delhi on Dt.16/10/2019.

ANNEX - III

REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2020)				Number of appointments made during the calendar year 2019									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	8801	619	182	1020	157	4	1	16	231	22	4	2	0	0
Group B	8148	1527	779	2338	29	3	3	14	190	42	17	3	0	0
Group C	9934	2008	906	3420	210	40	29	55	209	36	33	1	0	0
TOTAL	**26883**	**4154**	**1867**	**6778**	**396**	**47**	**33**	**85**	**630**	**100**	**54**	**6**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2020)				Number of appointments made during the calendar year 2019									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	1730	116	16	157	116	3	5	13	7	2	0	0	0	0
Group B	3011	457	153	669	259	47	16	85	5	2	0	0	0	0
Group C	2582	721	163	554	144	25	5	60	32	10	3	0	0	0
TOTAL	**7323**	**1294**	**332**	**1380**	**519**	**75**	**26**	**158**	**44**	**14**	**3**	**0**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2020 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2019 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2020)				Number of appointments made during the calendar year 2019									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	7317	885	321	1401	114	22	13	32	1199	174	49	1	0	0
Group B	5006	872	434	1419	57	9	3	25	717	132	88	0	0	0
Group C	4270	726	588	1056	162	19	9	70	427	113	59	0	0	0
TOTAL	**16593**	**2483**	**1343**	**3876**	**333**	**50**	**25**	**127**	**2343**	**419**	**196**	**1**	**0**	**0**

ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
ACB	Anti Convection Barrier
ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADU	Ammonium Di-Uranate
AEC	Atomic Energy Commission
AECS	Atomic Energy Cetnral School
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AEWTP	Advanced Effluent Water Treatment Plant
AFFF	Advanced Fuel Fabrication Facility
AFM	Atomic Force Microscopic
AFR	Away from Reactor
AFRP	Advanced Facilities for Radiopharmaceuticals Production
AGV	Automatic Guided Vehicle
AHWR	Advanced Heavy Water Reactor
AISSCE	ll India Senior Secondary Certificate Examination
AISSE	All India Secondary School Examination
AKRUTI	Advanced Knowledge & RUral Technology Implementation
ALARA	As Low as Reasonably Achievable
ALIP	Annular Linear Induction Pump
AMD	Atomic Minerals Directorate for Exploration & Research
AMM	Anushakti Monsoon Marathon
AOTWM	Automatic Orbital TIG Welding Machine
APC	Astroparticle Physics & Cosmology
APCBM	Automated Pipe Cutting and Beveling Machine
APWR	Advanced Pressurized Water Reactor
ARPES	Angle Resolved Photo Electron Spectroscopy
ARPF	Agricultural Radiation Processing Facility
ASCO	American Society of Clinical Oncology
ATAL	Asian Tropopause Aerosol Layer
ATI	Administrative Training Institute
ATPS	Adenosine Tri Phosphate Sulfurylase
ATR	Aluminothermic Reduction
ATTF	AHWR Thermal Hydraulic Test Facility
ATZC	Augmentation of Township at Zirconium Complex
AUSC	Advanced Ultra-Super Critical
BARC	Bhabha Atomic Research Centre
BARCIS	BARC Channel Inspection System
BBCI	Dr. B. Barooah Cancer Institute
BEL	Bharat Electronics Limited
BFP	Boiler Feed Pumps
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BNCT	Boron Neutron Capture Therapy
BNHS	Bombay Natural History Society
BoG	Board of Governors
BPI	Beam Position Indicator
BPM	Beam Position Monitor
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BSC	Board Sub Committee
BSOI	Beach Sand and Offshore Investigations
BWR	Boiling Water Reactor
CBI	Central Bureau of Investigation
CCA	Coolant Channel Assembly
CCE	Centre for Cancer Epidemiology
CCPS	Capacitor Charging Power Supply
CECE	Combined Electrolysis & Catalytic Exchange
CFD	Computational Fluid Dynamics
CFFP	Ceramic Fuel Fabrication Plant
CGCRI	Central Glass & Ceramic Research Institute
CGGC	Chottanagpur Granite Gneiss Complex
CGWB	Central Ground Water Board
CHSS	Contributory Health Service Scheme
CIC	Compensated Ionization Chamber
CII	Confederation of Indian Industry
CMB	Cosmic Microwave Background
CME	Continuing Medical Education
CMG	Crisis Management Group
CMLF	Core Melt Localization Facility
CMR	Custom Made Sources
CNN	Convolutional Neural Network
CNRS	French National Center for Scientific Research
COG	CANDU Owner's Group
CPC	Compound Parabolic Concentrators
CPWD	Central Public Works Department
CRU	Common Readout Unit
CSMS	Customer Services Management System
CSNI	Committee on Safety of Nuclear Installations
CSP	Core Sub-assembly Plant
CSR	Corporate Social Responsibility
CSS	Containment Spray System
CTE	Consent to Establish
CTE	Chief Technical Examiner
CTS	Cobalt Teletherapy Sources
CVC	Central Vigilance Commission
CVO	Chief Vigilance Officer

DAC	Director's Advisory Committee
DAE	Department of Atomic Energy
DAE S&CC	DAE Sports and Cultural Council
DAMAB	Department of Agricultural Marketing and Agri Business
DBGM	Design Basis Ground Motion
DCS	Distributed Control System
DCSEM	Directorate of Construction Services & Estate Management
DDC	Dual Directional Coupler
DDFS	DAE Doctoral Fellowship Scheme
DFDL	Doppler Free Dichroic Lock
DFRP	Demonstration Fast reactor fuel Reprocessing Plant
DGFS	DAE Graduate Fellowship Scheme
DHBVN	Dakshin Haryana Bijli Vitran Nigam
DLX	Double Layer Experimental
DMG	Disease Management Group
DMRIT	Diploma in Medical Radio Isotope Techniques
DOER	Direct Oxide Electrochemical Reduction
DOPT	Department of Personnel and Training
DPE	Department of Public Enterprises
DPR	Detailed Project Report
DPS	Directorate of Purchase & Stores
DSR	Diverse Safety Rod
DSRC	Design Safety Review Committee
DSRDM	Diverse Safety Rod Drive Mechanisms
DST	Department of Science and Technology
DTDDF	DAE Technology Display & Dissemination Facility
EBP	Elemental Boron Plant
EBW	Electron Beam Weld
ECCS	Emergency Core Cooling System
ECDL	External Cavity Diode Laser
ECFM	Eddy Current Flow Meter
ECI	Election Commission of India
ECIL	Electronic Corporation of India Limited
ECME	Electron Cyclotron Maser Emission
ECR	Emergency Control Room
ECT	Eddy Current Testing
EDF	Électricité de France
EGSS	Environmental Gamma Spectrometry System
EIT	Electromagnetically Induced Transparency
EMCCR	En-masse Coolant Channels Replacement
EMFR	En-masse Feeders Replacement
EMI	Electromagnetic Interference
EMIS	Electromagnetic Isotope Separator
EPA	Electrical Penetration Assembly
EPR	Emergency Preparedness and Response
ESL	Environmental Survey Laboratory
ESP	Environment Stewardship Programme
ETF	ECCS Test Facility
EURADOS	European Radiation Dosimetry Group
EVM	Electronic Voting Machine
FAC	Flow Assisted Corrosion
FBG	Fiber Bragg Grating
FBR	Fast Breeder Reactor
FBTR	Fast Breeder Test Reactor
FCT	Fast Current Transformer
FCVD	Fluidization based Chemical Vapor Deposition
FDG	Fluorodeoxyglucose
FET	Fluro Ethyl–L-Tyrosine
FFF	Fuel Fabrication Facility
FFL	Finished Floor Level
FFP	Fuel Fabrication Plant
FHCS	Fuel Handling Control System
FHSDS	Fuel Handling System Dynamic Simulator
FHSTS	Fuel Handling SystemTraining Simulator
FISH	Fluorescence in-situ Hybridisation
FLT	Flurothymidine
FMTF	Fuelling Machine Test Facility
FOFES	Fiber Optic Front End System
FPA	Final Power Amplifier
FPC	First Pour of Concrete
FRENA	Facilities for Research in Experimental Nuclear Astrophysics
FRFCF	Fast Reactor Fuel Cycle Facility
FRP	Fuel Reprocessing Plant
FSCTR	Fire-side Corrosion Test Rig
GCNEP	Global Centre for Nuclear Energy Partnership
GDR	Giant Dipole Resonance
GEM	Gas Electron Multiplier
GFA	General Framework Agreement
GHAVP	Gorakhpur Anu Vidyut Pariyojana
GIS	Geographical Information System
GMP	Good Manufacturing Practices
GMRT	Giant Metrewave Radio Telescope
GRAS	Generally Recognized As Safe
GRMS	Grievance Redressal and Monitoring System
GSFL	Green Star Fertilizer Limited
GSO	General Services Organisation
HAP	Hydroxyapatite
HBCHRC	Homi Bhabha Cancer Hospital & Research Centre
HBCSE	Homi Bhabha Centre for Science Education
HBGS	Hybrid Biofilm Granular Sludge
HBNI	Homi Bhabha Nationa Institute
HBP	Hamster Buccal Pouch
HBS	High Burnup Structure

ABBREVIATIONS

HEF	Head End Facility
HGCAL	High Granularity Calorimeter
HLLW	High-Level radioactive Liquid Waste
HPC	High Performance Computing
HPCC	High Performance Computing Cluster
HPS	Helium Purge System
HRTF	Hydrogen Recombiner Test Facility
HSA	Human Serum Albumin
HSCMS	Hydrogen and Steam Concentration Monitoring System
HTS	Horizontal Test Stand
HTS	High Temperature Superconductor
HVHF	High Voltage High Frequency
HWB	Heavy Water Board
HWP	Heavy Water Plant
IAEA	International Atomic Energy Agency
IBIL	Ion Beam Induced Luminescence
IBR	Indian Boiler Regulations
ICC	Indian Chemical Council
ICCM	Integrated Centre for Crisis Management
IEC	Institutional Ethics Committees
IFSR	Indian Facility for Spallation Research
IGA	Inter-Governmental Agreement
IGBC	Indian Green Building Council
IGC	Inter Granular Corrosion
IGCAR	Indira Gandhi Centre for Atomic Research
IGKV	Indira Gandhi Krashi Vishwavidyalaya
IHTR	Innovative High Temperature Reactor
IIFC	Indian Institutions Fermilab Collaboration
IIPS	International Institute of Population Sciences
IIT	Indian Institute of Technology
ILGTI	Indian Lattice Gauge Theory Initiative
IMMT	Institute of Minerals and Materials Technology
IMO	International Mathematics Olympiad
IMSBR	Indian Molten Salt Breeder Reactor
IMSc	Institute of Mathematical Science
INCTR	International Network for Cancer Treatment and Research
INGA	Indian National Gamma Array
INIS	International Nuclear Information System
INO	India-based Neutrino Observatory
INPRO	Innovative Nuclear Reactors and Fuel Cycles
IOCL	Indian Oil Corporation Ltd.
IOP	Institute of Physics
IOT	Inductive Output Tube
IPHWR	Indian Pressurized Heavy Water Reactor
IPIG	Instrumented Pipeline Inspection Gauge
IPR	Intellectual Property Rights
IPR	Institute for Plasma Research
IREL	Indian Rare Earths Limited
IRFEL	Infra-red Free Electron Laser
IRMA	Immunoradiometric Assay
ISC	Indian Science Congress
ISI	In-Service Inspection
ISNS	Indian Spallation Neutron Source
ISRO	Indian Space Research Organisation
ITER	International Thermonuclear Experimental Reactor
IWM	Indian Women in Mathematics
IWM	Indian Women in Mathematics
JIPMER	Jawaharlal Institute of Postgraduate Medical Education & Research
JNNSMEE	Jawaharlal Nehru National Science, Mathematics and Environment Exhibition
JNPP	Jaitapur Nuclear Power Project
JSPCB	Jharkhand State Pollution Control Board
KAMINI	KAlpakkam MINI Reactor
KAPP	Kakrapar Atomic Power Project
KAPS	Kakrapar Atomic Power Station
KARP	Kalpakkam Atomic Reprocessing Plant
KGS	Kaiga Generating Station
KKNPP	Kudankulam Nuclear Power Plant
KMCH	Kovai Medical Centre and Hospital
LASMART	Laser based Sag Measurement Application for Reactor Tubes
LDED	Laser based Directed Energy Deposition
LET	Linear Energy Transfer
LHC	Large Hadron Collider
LLCB	Lead Lithium cooled Ceramic Breeder
LLRF	Low Level Radio Frequency
LRP	Large Rotatable Plug
LVDT	Linear Variable Differential Transformer
LVPS	Low Voltage Power Supply
LWR	Light Water Reactor
MAA	Macro Albumin Aggregates
MACE	Major Atmospheric Cerenkov Experiment Telescope
MAPCDS	Minor Actinide Product Conversion Demonstration System
MCE	Magneto Caloric Effect
MCF	Medical Cyclotron Facility
MCM	Magneto Caloric Materials
MFL	Magnetic Flux Leakage
MHA	Ministry of Home Affairs
MHRD	Ministry of Human Resource Development
MMC	Madhava Mathematics Competition
MoEFCC	Ministry of Environment, Forest and Climate Change
MOPA	Master Oscillator Power Amplifier
MoU	Memorandum of Understanding
MOX	Mixed Oxide
MPC	Magnetic Particle Collector
MPMMCC	Mahamana Pandit Madan Mohan Malaviya Cancer Centre

MRECL	Mixed Rare Earths Chloride
MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
MSBR	Molten Salt Breeder Reactors
MSM	Members Support Missions
MSME	Ministry of Micro, Small and Medium Enterprises
MTTS	Mathematical Training and Talent Search Programme
NAPS	Narora Atomic Power Station
NBHM	National Board of Higher Mathematics
NBWL	National Board for Wildlife
NCA	No Carrier Added
NCC	New Community Center
NCG	National Cancer Grid
NCSM	National Council of Science Museums
NDC	Non Destructive Evaluation
NDCT	Natural Draught Cooling Tower
NDE	Non Destructive Examination
NEA	Nuclear Energy Agency
NET	Neuro Endocrine Tumors
NFC	Nuclear Fuel Complex
NGADU	Nuclear Grade Ammonium Di-Uranate
NIE	Newspaper-In-Education
NISER	National Institute of Science Education & Research
NIT	Notice Inviting Tender
NLD	Nuclear Level Density
NMC	Nuclear Medicine Centres
NMMIT	Nuclear Medicine and Molecular Imaging Technology
NODRS	National Occupational Dose Registry System
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NSC	National Steering Committee
NSCI	National Safety Council of India
NSDF	Near Surface Disposal Facility
NUJ	National Union of Journalists
NUOFP	Natural Uranium Oxide Fabrication Plant
OCC	Off Campus Centre
OCES	Orientation Course for Engineering graduates and Science postgraduates
ODS	Oxide Dispersion Strengthened
OECD	Organization for Economic Co-operation and Development
OHC	Occupational Health Centre
OLIC	Official Language Implementation Committee
PAC	Project Appraisal Committee
PAD	Public Awareness Division
PAMES	Post-Accident Monitoring of Electrical Systems
PAZ	Precautionary Action Zone
PBT	Profit Before Tax
PCP	Primary Coolant Pump
PCPTF	Primary Coolant Pump Test Facility
PCRD	Passive Catalytic Recombiner Devices
PCS	Precision Cooling Station
PCT	Patent Co-operation Treaty
PDB	Protein Data Bank
PET	Positron Emitting Tomography
PFBR	Prototype Fast Breeder Reactor
PFT	Private Freight Terminal
PHT	Primary Heat Transport
PHWR	Pressurised Heavy Water Reactors
PIE	Post Irradiation Examination
PIGIS	Penning Ion Gauge Ion Source
PKI	Public Key Infrastructure
PLD	Pulsed Laser Deposition
PLF	Pelletron LINAC Facility
PMD	Photon Multiplicity Detector
PMT	Photomultiplier Tubes
PNGF	Purnima Neutron Generator Facility
PPS	Pulsed Power Supplies
PRESAM	PREssure tube SAg Measurement
PSA	Probabilistic Safety Assessment
PSD	Position Sensitive Detectors
PSI	Pre-service Inspection
PSMA	Prostate Specific Membrane Antigen
PSP	Primary Sodium Pump
PTFE	Polytetrafluoroethylene
PuCAM	Plutonium Continuous Air Monitor
QIC	Quantum Information and Computation
QWR	Quarter Wave Resonator
RAAMS	Radiation & Air Activity Monitoring System
RAL	Radioanalytical Laboratory
RAL	Radiological Assessment Laboratory
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RBMK	Reaktor Bolshoy Moshchnosty Kanalny
RCGA	Real Coded Genetic Algorithm
RCM	Reactivity Control Mechanism
RCP	Relative Cooling Power
REE	Rare Earths Elements
RFCTLARR	Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement
RFPI	Radio Frequency Protection Interlocks
RFQ	Radio Frequency Quadrupole
RIA	Radioimmunoassay
RIS	Radiation Induced Segregation
RMC	Radiation Medicine Centre
RMRE	Rare Metal and Rare Earth
RMW	Radiation Monitoring Watch

ROS	Reactive Oxygen Species
RPC	Radiopharmaceutical Committee
RPh	Radiopharmaceuticals
RPP	Radiation Processing Plant
RPP	Radiation Processed Psyllium
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RTC	Room Temperature Cyclotron
RTE	Right to Education
RTE	Ready To Eat
RTI	Right to Information
RUP	Reprocessed Uranium Oxide Plant
SAD	Sodium Aerosol Detector
SANS	Small Angle Neutron Scattering
SAP	Severe Accident Phenomenology
SAS	Saturated Absorption Spectroscopy
SBO	Station Black Out
SCRF	Superconducting Radio Frequency
SDS	Shutdown Systems
SEEP	Societal Enrichment and Education Programme
SEM	Scanning Electron Microscope
SETBF	Sensor Evaluation Test Bed Facility
SFSB	Spent Fuel Storage Bay
SGDHR	Safety Grade Decay Heat Removal
SGP	Steam Generation Plant
SGTF	Steam Generator Test Facility
SGTMF	Steam Generator Tube Manufacturing Facility
SIEM	Security Information and Event Management
SINP	Saha Institute of Nuclear Physics
SIRC	Scientific Information Resource Centre
SKA1	Square Kilometre Array
SLM	Supported Liquid Membrane
SMF	Secure Manufacturing Facility
SNM	Special Nuclear Material
SOP	Standard Operating Procedure
SPDT	Single Pole Double Throw
SPECT	Single Photon Emission Computed Tomography
SPNCL	Supercritical Pressure Natural Circulation Loop
SPP	Solvent Production Plant
SQA	Software Quality Assurance
SRC	Safety Review Committee
SRP	Small Rotatable Plugs
SRS	Synchrotron Radiation Source
SSD	Safe Separation Distance
SSP	Secondary Sodium Pump
SSR	Superconducting Spoke Resonator
SSS	Secondary Shutdown System
SST	Steady-State Superconducting Tokamak
STS	Soft Tissue Sarcomas
SXP	Solvent Extraction Plant
SXRD	Synchrotron X-ray Diffraction Data
TACTIC	TeV Atmospheric Cerenkov Telescope with Imaging Camera
TAPS	Tarapur Atomic Power Station
TBM	Test Blanket Module
TBM	Tumour Bearing Mice
TBP	Tributyl Phosphate
TBRL	Terminal Ballistic Research Laboratory
TCDM	Trombay Chhattisgarh Dubraj Mutant
TCE	Tri Chloro Ehtylene
TCF	Technical Cooperation Fund
TCS	Timing Control System
TDA	Topological Data Analysis
TDC	Technology Development Council
TDO	Trainee Defence Officers
TERS	Tip Enhanced Raman Spectroscopy
THAI	Thermal-hydraulics, Hydrogen, Aerosols and Iodine
THM	Total Heavy Mineral
TIFR	Tata Institute of Fundamental Research
TIP	Travelling In-core Probe
TLD	Thermo Luminescence Dosimeters
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TMIS	Training Management Information System
TMS	Tarapur Maharashtra Site
TOC	Total Organic Concentration
TRF	Tray Rod Facility
TRTP	Tool Room Treatment Plant
TSO	Trainee Scientific Officer
UAT	Unit Auxiliary Transformer
UBT	Urea Breath Test
UCIL	Uranium Corporation of India Limited
UHV	Ultra High Vacuum
UNS	Uranyl Nitrate Solution
UOC	Uranium Ore Concentrate
UOP	Uranium Oxide Plant
UTOPA	Unprotected Transient Over Power Accident
VECC	Variable Energy Cyclotron Centre
VFD	Variable Frequency Drive
VGN	Vertical Graphene Nanosheets
VVPAT	Voter Verifiable Paper Audit Trail Printers
WANO	World Association of Nuclear Operators
WEC	Westinghouse Electric Company
WHO	World Health Organization
WMP	Waste Management Plant
WSN	Wireless Sensor Network
XRD	X-Ray Diffraction
XRDLPA	X-ray Diffraction Line Profile Analysis
YSRP	Young Scientist Research Programme

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