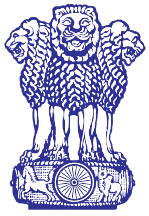
सत्यमेव जयते

GOVERNMENT OF INDIA

DEPARTMENT OF ATOMIC ENERGY

ANNUAL REPORT
2018-19



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Cover page front : Bird's Eye View of KAPP-3 & 4 main plant construction area

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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 2018-19, 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. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. One of these operating reactors namely Kaiga Generating Station Unit-1 has registered world record of continuous operation by recording 962 days of continuous operation. Tarapur Atomic Power Station (TAPS)-1&2 reactors have registered 50 years of safe operation in May 2019. 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 LWRs at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Various 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 in fleet mode towards launching these projects. At GHAVP-1&2 excavation is completed, contract is awarded for Main plant civil works and site mobilization is in progress. At KKNPP 5&6, excavation is in progress. Various preparatory activities such as land acquisition and Rehabilitation & Resettlement, Environmental clearance, procurement of long delivery items and components, studies for regulatory clearance, site infrastructure development, public outreach, tendering for main plant civil works etc. are in various stages of progress in respect of 10 PHWRs in fleet mode. 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 upgradation, continuous improvement in Quality Management, Quality Assurance/ surveillance, Pre-Service Inspection/ In-Service Inspection and interface with regulatory body.

Power Generation

Unit-1 of Kaiga Generating Station (KGS-1, 220MW) surpassed the earlier record of 940 days of continuous operation, held by Heysham-2 Unit-8 of the United Kingdom, on December 10, 2018. The unit was manually shutdown for planned maintenance activities and inspections on December 31, 2018, and thus

completed 962 days of continuous operation registering higher than highest continuous operation record world over.

During the FY 2018-19, five reactors i.e. KGS-1 (962 days), KGS-2 (697 days), RAPS-3 (777 days), KGS-3 (541 days) and MAPS-2 (512 days) achieved continuous run for more than a year. So far, the continuous operation of more than a year has been achieved 28 times by various reactors operated by NPCIL.

Nuclear power reactors in operation registered 500 reactor years of safe operation by the end of FY 2018-19. Various stations won several awards in areas of safety and performance.

During the Calendar Year (CY) 2018, NPCIL registered generation of 39051 Million Units (MUs) and the overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation at 73% and 75% respectively. The actual generation in the Financial Year (FY) 2018-19 is 37813 MUs and with overall PLF and AF for all the reactors in operation at 70% and 73% respectively. In the previous CY 2017, the generation was 37180 MUs (in addition, there was an infirm power generation of 1427 MUs from KKNPP-2 during year 2017) and the overall PLF and AF for all the reactors in operation were 71% and 73% respectively. Actual generation during the previous FY 2017-18 was 38336 MUs and the overall PLF and AF for all the reactors in operation were 70% and 72% respectively.

In both units at Kakrapar Atomic Power Station (KAPS), major works relating to En-Masse Coolant Channels Replacement (EMCCR) and En-Masse Feeders Replacement (EMFR) were undertaken in project mode since August 1, 2016. KAPS-2 was re-started and synchronized to Grid at 12:50 Hrs on 22nd September-2018, three and half months ahead of schedule. KAPS-1 was re-started and synchronized to Grid at 06:44 Hrs on 25th May 2019, also completed over three months ahead of schedule.

Projects under construction

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 LWRs at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Various pre-project activities are in progress for GHAVP-1&2 (2x700 MW PHWRs), KKNPP-5&6 (2x1000 MW LWRs) and for 10 PHWRs in fleet mode towards launching these projects.

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

Unit-3 is in advanced stage of commissioning. All the major civil works of unit- 3 have been completed. Feeder erection work is completed. A major milestone of "Hydro test of Primary Heat transport (PHT) system" has been completed successfully. In May 2019, an important milestone of Primary containment Proof and Integrated Leakage Rate Test (ILRT) is also completed. The preparation for Hot Conditioning of Primary Heat Transport (PHT) system is in progress. This will be followed by Initial Fuel loading and approach to first Criticality. There are continued supply constraints to achieve required pace of physical progress. In Unit-4, construction of Inner Containment (IC) dome is completed. Pre-stressing of IC containment was completed in April-2019. A major milestone of "Coolant channel installation" is completed.

Bird's Eye View of KAPP-3&4 main plant construction area

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

In Unit-7, construction of IC Dome has been completed and pre-stressing work is nearing completion. Erection of feeders is nearing completion. In Unit-8, Construction of IC wall is completed and ring

Main Construction area of RAPP-7&8

beam is nearing completion. Construction of SG vaults is completed.

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

Civil works and procurement activities are in progress. Construction of Reactor Building-3 up to containment slab at +5.4 m elevation and Reactor Building-4 up to corium slab at +1.1 m elevation completed. Construction of Reactor Auxiliary Building, Emergency Power Supply Building, Turbine Building, Tunnels etc. is in progress. Manufacturing and delivery of various equipment and components are in progress. Six Bulk Vessels containing various equipment / components have been delivered during the Financial Year 2018-19.

Kudankulam Nuclear Power Project (KKNPP) Unit-3&4

Sanctioned Projects

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

All civil construction drawings up to ground

Ground improvement works at GHAVP Unit-1&2

level have been issued. Main Plant Excavation is completed. Ground Improvement in the Main Plant area has been completed and in the balance area, it is in progress. First Pour of Concrete (FPC) consent application submitted and is under review by Atomic Energy Regulatory Board (AERB). Main Plant civil package is awarded. Purchase orders are placed for major equipment/components like Primary Coolant Pump, Steam Generators, Caldaria, End-shields, Reactor Headers, Moderator and D2O Heat Exchangers, etc.

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

Consent for excavation of main plant building pits has been obtained from AERB. Excavation work is in progress. Selection and Approval of Subcontractors is in progress for manufacturing equipment in Russian Federation. Purchase order has been issued for procurement of mechanical cleaning devices. Contract for delivery of equipment and materials (Balance of Plant-BOP) has been signed in December 2018.

Ten 700 MW PHWRs in Fleet Mode

Preparatory activities like land acquisition, environmental clearance related activities, site studies, etc. are in various stages of progress for commencement of construction of these units, at Chutka in Madhya Pradesh, Kaiga-5&6 in Karnataka, GHAVP-3&4 in Haryana and Mahi Banswara in Rajasthan. Purchase Order is placed for Forgings for Steam Generators (6 units-24 Nos.), SS 304L Lattice Tubes and Plates for End Shields (4 Units) and further activities like raw material procurement and

manufacturing are in progress. Procurement processes for Pressurizer & Bleed Condenser (BCD) and Steam Generator (SG) (28 Nos.), Reactor Headers (8 units-64 Nos.), Primary Coolant Pump (PCP) motor units, etc. are in progress.

New Project / Sites

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. In respect of Jaitapur, Land is acquired, Techno-commercial discussions with Électricité de France (EDF), France are in progress and the "Industrial way Forward Agreement (IWFA)" has been signed between NPCIL and EDF. At Kovvada land acquisition process is in progress. Possession of part of the land is acquired and activities are in progress for taking possession of balance land. Terms Of Reference (TOR) is approved by Ministry of Environment, Forest and Climate Change (MoEFCC). Studies related to the Environmental Impact Assessment (EIA) at site are in progress. Discussions with Westinghouse Electric Company (WEC) is under progress. At Mithi Virdi site 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, Coastal Regulation Zone (CRZ) clearance is available. MoEFCC would be approached again for obtaining the clearance based on the progress of land acquisition. At Haripur site in West Bengal, land acquisition is contingent to initiative by State Govt. and an alternate site is also under consideration by GOI.

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 / In-service Inspection (PSI/ISI) activities of Projects/Stations has been completed successfully. Regulatory Interface on QA & PSI/ISI activities has been carried out on timely manner to meet the project and station schedule. Corporate Peer reviews of operating stations have been conducted based on WANO guidelines. Corporate QA audits & PSI audits of KAPP-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 programme 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, boiling water reactors and fast breeder reactor.

Heavy Water Production

Heavy Water Board has contributed successfully to the first stage of Nuclear Power Programme by producing Heavy Water for all Pressurized Heavy Water Reactors in a cost effective manner enabling the department to provide nuclear power at an affordable cost to 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. Over a period of time, HWB has emerged as the largest global producer and a trusted global supplier of this material. HWB continued to nurture and facilitate R&D activities in the area of non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology.

Heavy Water Board has achieved 100.7% of overall targeted heavy water production. HWP, Hazira operated excellently, and with consistently high deuterium recovery, it has achieved 126.4% of targeted production. The plant has set record of lowest specific energy consumption for any Ammonia-Hydrogen Exchange process based plant, of 22.92 GJ/kg D_2O in 2018-19. HWP, Kota has also operated excellently producing 110.7% of the target.

At HWP, Tuticorin, revamping jobs for targeted restart up of the plant is in full swing. Compressors were overhauled, safety valves & calibration was completed and DG set has been installed. Civil work related to solvent production plant is in an advanced stage of completion. Engineering activities for solvent production plant are under progress.

Diversification Activities

HWB has made major progress on the extended mandate on development, demonstration and deployment of technologies for in-core and out of core material inputs for Indian Nuclear Power Program i.e. Solvents for front and back end hydrometallurgical operations of nuclear fuel cycle; demonstrating Solvent Extraction technologies for nuclear hydrometallurgy; producing stable isotope like ^{10}B for Fast Breeder Reactors (FBRs); production of nuclear grade Sodium for FBRs and production of ^{18}O for societal applications. Progress made in some of the key areas during the period is as follows:

Solvent Technology

The Board continued to meet the complete requirement of organo-phosphorus solvents in various DAE units involved in front end and back-end operations of nuclear fuel cycle, through the industrial facilities at Baroda and Talcher. HWP, Tuticorin, has been building experience over the last few years in synthesis of new organo-phosphorus solvents. An industrial scale Solvent Production Plant is being set up there for production of solvents like TiAP, DHOA, D2EHPA-II, TAPO & TOPO. Synthesis of some special solvents viz. DGA, Calixarene etc. is also in hand, based on collaborative efforts with DAE units as requested by them. At HWP, Talcher, 30 MT of TBP & 20 MT of D2EHPA was produced during the financial year 2018-19.

HWB has successfully demonstrated the solvent extraction technology in industrial proto-type scale at its Technology Demonstration Plant at Mumbai for various nuclear hydrometallurgical operations. Based on this knowhow, 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.

Boron Enrichment

To support the second stage of NPP, HWB has set up Boron enrichment and Boron Carbide pellet production facilities at Talcher and HWP, Manuguru. HWB has successfully delivered the entire quantity of enriched Boron for the first core of PFBR. At the Boron production facility at HWP, Manuguru, the targets of Enriched Elemental Boron of B-10 IP $\geqslant$ 90% & 67% and B4C powder with B-10 IP $\geqslant$ 90% were achieved. The B4C powder (B-10 $\geqslant$ 90%) was micronized through a vendor for further processing. CSR grade B4C pellets produced at HWP, Manuguru are confirmed as acceptable as per IGCAR requirements.

Sodium Metal

HWB has taken up activities for indigenous production of sodium used as coolant for PFBRs. There is no manufacturing unit for Sodium Metal in the country and is presently being imported as finished product. HWB has developed the closed cell technology for production of sodium. A test cell of 2 kA has been operated to collect the data and fine tune the operating parameters. Scaled up design has been completed and construction activities are taken up for 24 kA proto type cell, which will be operated prior to setting up of 600 MTPA plant at HWP, Baroda.

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 utilization 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 (U3O8) reserve of over 29,398 tonnes in the areas of Andhra Pradesh, Jharkhand, Rajasthan and Karnataka.

Significant uranium anomalies were located in Haryana, Jharkhand, Meghalaya, Chhattisgarh, Rajasthan, Andhra Pradesh, Telangana and Karnataka. About 2,50,808m reconnoitory, exploratory and evaluation drilling was carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of uranium and REE 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, Chhattisgarh and Madhya Pradesh. New Potential/significant blocks have been identified at Himachal Pradesh, Odisha, Chhattisgarh and Andhra Pradesh.

Geochemical surveys (4,521 sq km) have been carried out in different parts of the country for delineating targets for detailed investigations. Ground geophysical surveys (Regional: 516 sq km and Detailed: 386 sq km) have delineated potential low magnetic zones in Madhya Pradesh Chhattisgarh and high chargeability zones in Haryana and Madhya Pradesh. Airborne survey and remote sensing surveys over 42,056 line km have been carried out in parts of Rajasthan, Madhya Pradesh Andhra Pradesh & Telangana.

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 Tamil Nadu and Andhra Pradesh.

Jaduguda mine has been brought back to operation after receiving final clearance in September 2018 for renewal of forest land diversion of Jaduguda mine.

Environmental Clearance for Uranium Recovery Plant from copper tailing at Mosabani for the capacity of 0.9 million TPA processing has been obtained. Pre project activities for setting up of the uranium recovery plant from copper tailings, such as transfer of land and obtaining consents for electricity and water supply are in progress.

UCIL has entered into 'Agreement' with M/s MECON Ltd. wherein M/s MECON shall undertake all procurement & work contract services and project related work of UCIL. This will help in better resource management of the Company. Pre-project activities for Rohil Uranium Project, Jajawal Uranium Project, Gogi Uranium Project and Kanchankayi Uranium Project have been initiated.

Rohil Project - Rajasthan

Agreement on taking up Exploratory mining activities by UCIL on behalf of Atomic Mineral Directorate for Exploration and Research (AMD) at Rohil in Rajasthan has been signed with AMD.

A breakthrough in uranium extraction at Tummalapalle in alkali leaching conditions has been achieved through in-house research. It was found that generation of excess sodium bicarbonate during alkali pressure leaching is retarding uranium precipitation. By adding a small quantity of sodium hydroxide, conversion of excess sodium bicarbonate in recycle liquor to required sodium carbonate has been achieved, thereby increasing overall extraction (about 4%) and substantially reducing the consumption of Sodium Carbonate. It has a considerable effect on reduction in cost of extraction leading to saving of Rs. 30 Cr per year.

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.

The Indian Rare Earths Limited (IREL) received 'Excellent' MoU rating for its performance in the year 2017-18 after a gap of more than a decade.

Production of NGADU stood at 34.9 tons which is the highest production in last decade. Production of minerals increased by 6.7% (prov.) with respect to previous fiscal, which is also the highest production achieved since the last 7 years. Production of Mixed Rare Earth Chloride increased by about 55% compared to the previous fiscal.

1 kg of Hafnia with purity level of 99% was produced by IREL in laboratory scale. Samples have been sent to BARC for confirmation on the purity.

IREL has also produced yttria stabilized zirconia in laboratory scale, 1 kg of which was supplied to reactor Design & Development Group, BARC for use in PHWR application. The product was found suitable and IREL has been asked to supply additional quantities for further testing.

Environment Clearance for the much awaited Capacity Expansion Project of Mineral Separation Plant of OSCOM, Odisha received in January 2019. Request for Proposal (RFP) to appoint an Agency to implement the project on Engineering, Procurement, Construction (EPC) basis floated and site visit & pre-bid meeting completed.

Understanding between BARC and IREL (India) Limited for development and transfer of technology in the value chain of Rare Earths, to be demonstrated in the Rare Earth and Titanium Theme Park in Bhopal, Madhya Pradesh was inked in January 2019 in the presence of Chairman, AEC and Secretary, DAE. Activity of lease deed execution for taking over the land is in progress and will be completed by the 1st quarter of current fiscal. RFP has been floated for appointing an Architect to design the buildings.

Operations of Manavalakurichi (MK) Unit of the Company located in Tamil Nadu, which were in a standstill from January 2017 due to inadequacies in the CRZ Notification 2011, resumed from April 2018 after receiving Environment & CRZ clearance from MoEFCC.

Directorate General of Foreign Trade (DGFT) vide notification dated 21.08.2018 has designated IREL as State Trading Enterprise (STE) for canalization of export of beach sand minerals.

At BARC, an efficient process for recovery of hafnium from scrub raffinate of Zirconium Oxide Plant (ZOP) was demonstrated on pilot-scale using in-house synthesized Alkyl Phosphine Oxide (APO) solvent having higher separation factor and loading capacity compared to conventional TBP solvent.

An "ore to yellow cake" large-scale processing facility (300 kg/batch) for demonstration of process flowsheet for U ores by sulfuric acid leaching was set-up at Jaduguda with AERB approval.

Solvent extraction process flow-sheets have been developed and demonstrated to produce high purity (>99%) Y_2O_3, Dy_2O_3 and Tb_4O_7 from heavy rare earth concentrate of monazite mineral.

Fuel Fabrication

Nuclear Fuel Complex (NFC), an ISO 9001, ISO 14001 & OHSAS 18001 organisation under Department of Atomic Energy (DAE), is 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 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. NFC also caters 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.

NFC has Completed supply of one reactor charge of Coolant tubes and Garter Springs for meeting the requirement of En Mass Coolant Channel Replacement (EMCCR) for KAPS-I and KAPS-II 220MWe PHWRs which have become operational now. NFC has also supplied 37 element fuel bundles for initial core requirement of KAPS-3 700MWe PHWR with modified design of appendages.

NFC-Kota, a green field project is under execution at Rawatbhata, Rajasthan to produce 500 tpy of UO_2 Pellets and 65 tpy of Zircaloy Products to meet the fuel requirement of four 700 MWe PHWRs. The basic site infrastructural activities are completed, major package of construction of Plant & Non-Plant building is in progress and procurement of various equipments is in progress. An overall progress of 29.92% was achieved in the project. Apart from this, 16 sanctioned projects are being executed at NFC, Hyderabad. In principle approval for 7 projects were obtained and 4 of 7 new project proposals were put up to Project Appraisal Committee for obtaining financial sanction.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

Forty samples of dissolver solution of irradiated fuel were analysed for Pu concentration by ID-TIMS for the input accountability of Pu in reprocessing plant. In addition, one hundred and thirty three samples of reprocessed depleted Uranium were analysed for isotopic composition by TIMS. The Induction Skull Melting (ISM) Facility was operated successfully and demonstrated consistent and reliable operations to produce different alloys which are of interest to DAE. The ISM Facility was under regular operation for the production of Aluminium-Silicon.

BARC has also developed a Vacuum Induction Levitation Melter indigenously for producing high purity metallic samples for material characterization.

Waste Tank Farm of Power Reactor Thoria Reprocessing Facility (PRTRF) was commissioned after getting clearance from various safety committees.

Subsequent to the hot commissioning of Alpha Demonstration Facility (ADF), two drums of waste comprising of cellulose and rubber/plastics have been successfully treated. An alpha solid waste treatment facility is being set up at BARC Trombay, based on the feedback of the ADF. The facility has received the regulatory consent for construction from the apex safety committee of BARC.

Radioactive Waste management facilities (TL-7), BARCF, Vizag, is planned for the management of radioactive wastes generated from the operations of technological laboratories/facilities at BARCF, Vizag (Phase I). As a part of TL-07, BARC facility, Vizag, the Alpha Waste Transit Storage Facility is being set up for safe interim storage of alpha contaminated waste generated from the O&M activities of Technological Laboratories.

A process involving in-situ corrosion of mild steel under aerobic conditions has been developed for separation of low concentration of uranium (at ppb level) from aqueous solutions. Alloy 693 a superior structural material for the vitrification of nuclear waste having better mechanical properties, coupled with high corrosion resistance was examined. 30,000 lit of High-level Rad-Waste was processed with the recovery of valuables.

Plasma pyrolysis based demonstration setup has been installed as a first of its kind facility in India for management of potentially radioactive all combustible Plant protective wears. About 350 kg of simulated waste was processed using both graphite and Cu-Hf based torches. The system was hot commissioned with actual radioactive waste using BARC developed Cu-Hf torch. Total 501 kg actual waste (a mixture of cellulose + rubber+ plastic) was processed safely achieving volume reduction factor of more than 30. Environmental discharges were monitored and were well within the prescribed limits.

Towards effluents' management, receipt and collection (by pipeline, tanker, cask and carboy modes), treatment and discharge of Low-Level Radioactive Liquid Waste generated by various plants and laboratories in Trombay was continued safely to ensure uninterrupted operation of various laboratories and plants in Trombay.

R&D OF POWER SECTOR

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

Experimental set-up for the study of the coating of silicon carbide (SiC) and alumina ($Al2O_3$) on the surface of different substrates, viz. Stainless Steel (SS),

high density graphite, Inconel etc. by Fluidization based Chemical Vapor Deposition (FCVD) has been cold commissioned. The set-up is ready for hot commissioning. Safety clearance for the same from ULSC-CEO is awaited.

A vertical scanning system was developed and used for fine scanning and accurate characterisation. The system allows controlled fine movement in axial and circumferential directions to enable scanning of the spool samples. Linear Variable Differential Transformer (LVDT) based PRESAM (PREssure tube SAg Measurement) inspection system is developed. It consists of a tool head, data acquisition system and signal processing algorithms. For removal of calandria tube from 220MWe PHWR, induction heating followed by fast cooling based Calandria Tube Rolled Joint Detachment (CTRJD) system has been developed in BARC. As part of research activities to address direct contact condensation and water hammer behaviour, a Water and Steam Interaction Facility (WASIF) has been set up at SRI, Kalpakkam. An indigenous numerical code based on six-equation, two-fluid model has also been developed for simulating Condensation Induced Water Hammer (CIWH).

HEALTH SAFETY & ENVIRONMENT

A plastic scintillator based 4πβ-γ coincidence system is developed as an absolute standard for radioactivity measurements. 4πβ-γ coincidence technique is a powerful tool and widely recognised method to determine the absolute activity concentration of radioactive solutions. An Integrated Centre for Crisis Management (ICCM) in BARC was constructed to consolidate crisis management activities in BARC Trombay. The ICCM facility was inaugurated by Honourable President of India on 15.05.2018. ICCM was established at Trombay for Prevention, Preparedness and Response to Chemical, Biological, Radiological & Nuclear (CBRN) and Security Threats/Emergencies. The centre is having a Personnel Decontamination Centre (PDC), Mobile Radiological Laboratory (MRL) and Emergency Ventilation System for 72 hours continuous operation. A stand-alone prototype light weight miniaturized, portable, wearable and in-built battery powered Personal Air Sampler (PAS) (10.5 X 7 X 14 cm.) has been indigenously developed. A total of 8260 occupational workers were monitored for external and internal radiation exposure in the front end nuclear fuel cycle operations. National Uranium Project (NUP) was executed in collaborative project mode in phased manner (phase 1 to 4) and compilation of national database. Till 2018, 82 projects were sanctioned by BRNS, DAE, covering 403 districts out in 718 districts of India. The radiological safety of general public around Nuclear Power Plants (NPPs) is considered as one of the top priorities of DAE during design, construction and operation. Environmental Survey Laboratories (ESLs) carried out the environmental surveillance around nuclear power plants which clearly indicated that the dose to the member of public at fence post (1.6 km) is only a small fraction of regulatory limit of 1000 μSv/year stipulated by Atomic Energy Regulatory Board (AERB) and negligible compared to the dose received by the public from natural sources. Environmental gamma radiation monitoring, using thermoluminescent dosimeters (TLDs) placed around all the nuclear installations in India were being carried out by BARC.

NPCIL has recorded about 500 reactor years of safe operation of reactors by the end of financial year 2018-19. 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 AERB 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. Industrial and Fire Safety aspects is being ensured through comprehensive Oversight and Support Function and implementation of Safety Management System at work locations of NPCIL.

The Environment Stewardship Programme (ESP), a voluntary activity of NPCIL for the conservation of nature in and around the plant sites was continued.

The overall safety standards of Heavy water Plants are far better than similar chemical process industries in the country.

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 IGCAR Centre continues as test bed for irradiation of fuel & structural materials in fast neutron flux and has completed 33 years of operation. FBTR was operated at the highest reactor power level of 32 MWt; a major milestone in its history, during the 27th irradiation campaign, with the turbo generator synchronised to the grid delivering an output of 7 MWe. The safety of FBTR has been strengthened by completion of all the post-Fukushima recommendations stipulated by Atomic Energy Regulatory Board (AERB).

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. After completion of construction, manufacture & erection of all the systems/components of PFBR, commissioning of the individual systems and the integrated commissioning are in progress.

East side view of PFBR

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

In sodium systems, succesful commissioning and operation of electro magnetic pump after carrying out the appropriate modifications with marginal design changes was completed. Subsequently, commissioning & stable operation of secondary sodium loops after replacing the pump internal assembly of one of the stalled secondary sodium pumps was also carried out.

With respect to Fuel handling system, initial commissioning trials of the various fuel handling equipment are in progress.

In conventional tertiary system, performance guarantee tests of auxiliary sea water pumps and condenser cooling water pumps have been completed.

Presently, works are in progress for commencement of sodium filling in Main Vessel after

completion of rectification works in Large Rotatable Plug bearings. This will be followed by isothermal testing, fuel loading and first approach towards criticality.

IGCAR is continuing to provide necessary support for the commissioning of 500 MWe Prototype Fast Breeder Reactor (PFBR).

FBR Fuels

As a part of chemical quality control of FBTR fuel, Pu bearing nuclear materials were analysed for metallic impurities. Non-destructive analysis methods were developed to assay plutonium content in the sealed samples of any geometry. A miniaturised transmission absorption spectrophotometry system for monitoring U (VI) concentration in process streams has been developed.

Fast Reactor Fuel Reprocessing

License for operating CORAL (COmpact Reprocessing facility for Advanced fuels in Lead cells) has been successfully renewed for a period of five years and routine reprocessing campaigns of FBTR fuel have commenced. Remote handling equipments and tools have been developed for the pyro-processing R&D facility. The construction activities for the Fast Reactor Fuel Cycle Facility (FRFCF) continue to make steady progress. A single, uninterrupted pour of concrete of size 8000 cu.m. has been successfully completed in Fuel Reprocessing Plant in 130 hours, making it the largest pour in Department of Atomic Energy (DAE) till date.

FBR Related Technologies

The Research and Development activities for the fast reactors and associated fuel cycle includes Commissioning and Operation of Mobile Purification Loop for Purification of FBTR Flooding Circuit Sodium; Development of Out-of-pile Version of Fuel Instrumented Capsule; Development of 2 t Hoist for Remote Disassembly & Material Handling within Argon Containment in the Engineering Scale Pyro Facility; High Temperature Testing of Indigenously Developed 2MHz Ultrasonic Transducer; Design and Development of a High Speed Data Acquisition System for PFBR SG Tube Inspection; Development of Sodium Resistance Geo Polymer Concrete (GPC); Performance Evaluation of DCCP and PMFM of FFLM; Development of Indigenous Control Rod Gripper Bellows for FBTR; Design, Development and Testing of sodium submersible miniature size Annular Linear Induction Pump (ALIP); Fabrication of Irradiation capsule containing Tungsten (W) & Tungsten Carbide (WC) specimens and Endurance testing of Transfer Arm gripper central guide in sodium.

Future FBRs

A significant milestone in the history of IGCAR has been the dedication of the Metal Fuel Fabrication Facility (MFFF) to the nation by Shri Ram Nath Kovind, Honourable President of India on May 15, 2018; inaugurated remotely from BARC. Future FBRs are planned with metallic fuel, hence the major focus is on the development of metallic fuel. The irradiation of the sodium bonded metallic fuel test pins with different compositions, which had been initiated earlier continued this year also in FBTR, without any pin failure. In order to establish the viability of aqueous reprocessing of metallic fuels, as an alternate to pyro-processing, the dissolution aspects of U-Pu-Zr alloy fuels have been studied.

Health, Safety & Environment

In the field of radiological safety, a state-of-the-art calibration facility for calibration of gamma radiation survey instruments used in radiological facilities with a maximum dose rate range of 10 Sv/hr has been commissioned and accredited by AERB.

Effective radiological surveillance and health physics services were provided for the radioactive facilities. 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. Radiation awareness programme for students and teachers from various schools around Kalpakkam, women residents in Kalpakkam and Anupuram were conducted for promotion of DAE activities in nuclear energy sector and societal applications.

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

AHWR physics design was focussed on the safety studies required for regulatory clearances for thorium-plutonium fuel core. A modified design of the control rods improved the core power distribution. Computer codes were developed to model the core perturbations. Decay heat removal during prolonged Station Black Out (SBO) was demonstrated in the Integral Test Loop for more than 7 days without operator intervention. Hydro dynamic forces in Gravity Driven Water Pool (GDWP) were estimated. Thermal Hydraulic Tests in Tarapur established that AHWR can be operated under natural circulation with adequate safety margin and stable channel flow during power manoeuvring from cold start-up (2% full power) to 130% full power. A Flow Instability Detection and Warning System (FIDWS) was developed to detect the onset of flow oscillations in coolant channels of nuclear reactors. The system was qualified for extreme conditions of humidity, temperature and radiation as may be required for C&I of NPPs. In order to improve the core discharge burn-up and power distribution, worth of reactivity devices were re-assessed. Passive Poison Injection System (PPIS) was developed to shut down AHWR passively, in the event of wired shut down system failure. A scaled experimental facility was built for integrated study of poison injection and performance of passive devices. The system actuation by high pressure steam was demonstrated successfully simulating reactor conditions. Passive Containment Isolation System (PCIS) was designed to prevent release of radioactivity from AHWR in the event of Loss of Coolant Accident (LOCA) or Main Steam Line Break. CFD (Computational Fluid Dynamics) simulations of PCIS were validated by experiments.

KAlpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) relicensed till June 2020 continued to operate successfully with improved Safety Control Plate (SCP) drive mechanisms and Integrated Control and Information System (ICIS) developed by BARC. KAMINI reactor has been operating at 30 kWt and serving as a unique facility for neutron activation studies, neutron radiography of pyro-devices of Indian Space Research Organization (ISRO) and neutron detector testing.

Research Reactors

The APSARA Upgraded Research Reactor Facility is a 2 MWth swimming pool reactor with compact core loaded with Low Enriched Uranium (LEU) fuel, light water as coolant & moderator and Beryllium Oxide as reflector. This reactor will provide enhanced facilities for various kinds of research, shielding experiments and training of scientists and engineers. The APSARA-U Reactor became critical on 10th September 2018 at 18:41Hrs. Installation and commissioning of Instrumentation & Control Systems, Reactor Regulating Systems and COIS Data Servers and Operator workstations has been completed for APSARA-U.

View of Apsara-U reactor

Upgraded APSARA research reactor uses five Reactivity Control Mechanisms (RCMs) namely: two Shut-off Rods, two Control-Cum Shut-off Rods and One Fine Control Rod. Design of RCMs was qualified on a full-scale test station. Dedicated test consoles have been designed and fabr icated for the purpose of prototype testing and out-of-pile testing at the reactor site. Various Sub-assemblies and Components such as Reactor Trolley, Core Support Structure, Ion Chamber Support Structure-I & II, Grid Plate and Outlet Plenum were manufactured in-house for APSARA-U.

Indigenous bulk gamma monitor reactor has been developed for failed fuel detection of DHRUVA reactor. The detector probe comprises of a cylindrical, NaI based Scintillation crystal attached to a PMT. The monitor has protection against radiation over-exposure. Successful field evaluation test of the unit was carried out in loop-3 of Dhruva reactor.

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

The first five-cell, 650 MHz ($\beta = 0.92$) Superconducting Radio-Frequency (SCRF) cavity fabricated at RRCAT was processed and tested using in-house facilities. This five-cell cavity was electro-polished, annealed at 800 ºC, high pressure rinsed, baked at 120 ºC and tested at 2 K in vertical test facility using a 650 MHz low level RF system and a 500 W solid state amplifier. An excellent low field quality factor of 4 x 1010 and an accelerating gradient of 17.5 MV/m was achieved.

Electro-polishing of five-cell 650 MHz cavity

An improved second five-cell 650 MHz ($\beta = 0.92$) superconducting radio frequency (SCRF) cavity was fabricated using the experience gained during fabrication of the first 650 MHz SCRF cavity. The second cavity was fabricated with better control on geometrical accuracy and optimized beam welding parameters. The field flatness of the as-fabricated cavity before processing was measured to be 85%, which is a big improvement over the earlier developed five-cell cavity where the fabricated field flatness was 45%. The final length of the cavity is 1401.12 mm, which is also within the acceptable tolerance of ± 3 mm to design length of 1400.245 mm.

A filament based multicusp arc discharge type pulsed H^- ion source of 50 keV and 8 mA current has been successfully coupled with a magnetic Low Energy Beam Transport (LEBT) system for beam transportation and characterization studies.

The experimental setup of ion source coupled with LEBT

A general methodology has been developed to design a compact lattice for the 1 GeV H- Indian Spallation Neutron Source (ISNS) superconducting linac by following the non-equipartitioned design approach, yet ensuring beam stability in end-to-end beam dynamics simulations through careful design of suitable matching sections, and by appropriate adjustment of field/phase of the cavity along with the strengths of focusing magnets.

Design of a suitable lattice consisting of bending magnets, focusing quadrupoles, chromaticity correcting sextupoles, corrector magnets, RF cavities, injection and extraction magnets and Beam Position Indicators (BPIs) has been completed for the proposed 1 GeV proton Accumulator Ring of ISNS, which will convert the 10 mA, 2 ms H- pulses from the injector linac to proton pulses through a charge exchange injection scheme. It will also suitably paint a broader stable beam inside the accumulator ring with pulse width compressed to 0.65 μs.

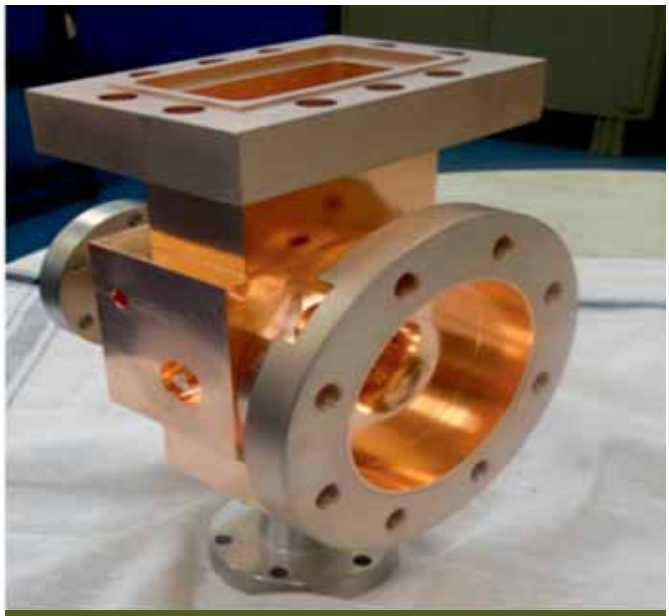
As a part of technology development, a prototype 100 kW, 1 MHz pulse RF power amplifier system has been developed for the accumulator ring of the pulsed proton accelerator. The RF power amplifier, assembled with a Tetrode tube, anode power supply, grid power supply, RF driver amplifier, and HV RF matching network was tested with pulsed RF power of 100 kW at 1 MHZ

100 kW, 1 MHz RF amplifier

A prototype of 20 kV IGBT based solid state switch has been developed for replacing the Pulse Forming Network (PFN) charging a thyratron tube in the 6 MW peak power microwave system of a 10 MeV electron linac. The switch has been tested in actual operating conditions at 220 Hz pulse repetition rate with the microwave system installed with the linac.

Charging switch test setup at 10 MeV Linac microwave system (left), along with the close up view of charging switch (right)

A 1.6 cell, S-band laser photocathode radiofrequency gun has been designed, developed, tuned to desired RF parameters with a field flatness < 5 %, and qualified through low and high power RF testing. This photocathode RF gun is designed to deliver 1 nC charge in 10 ps bunches with an energy > 2 MeV and a normalize RMS electron beam emittance < 5 mm mrad. This RF gun can serve as a high brightness injector for future light sources projects.



Laser photocathode RF gun

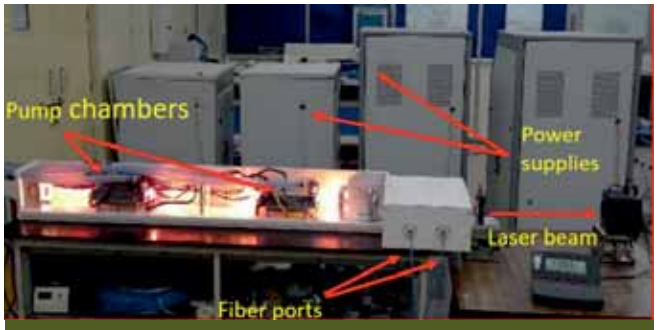
At VECC, the beam-line between 3rd and 4th Linac modules (L3 & L4) having two 45 degree bending magnets, 19 quadrupole magnets, inter-connecting beam-tubes, beam diagnostic boxes, vacuum pumps etc. has been installed in their optimized locations. The 4th and 5th LINAC modules have been installed, low power RF measurements have been completed and high power conditioning up to 3 kW power has been done.

The design of the Quarter Wave Resonators (QWR) has been completed and ordered for fabrication. This activity is being pursued in collaboration with TRIUMF, Canada.

At BARC, a networked and automated system consisting of 30 varied intelligent radiation monitors for Gamma, X-Ray and Neutron flux were developed for LEHIPA (Low Energy High Intensity Proton Accelerator) to track and monitor the accelerator beam loss and for radiation safety of personnel. Helium vessel jacketing of Niobium Superconducting Single Spoke Resonator was completed. The stainless steel vessel built around Niobium cavity was delivered to FERMI Lab, USA, and tested for high power performance.

Laser Technology Development and Applications

An optical fibre coupled dual cavity dual flash lamp ceramic reflector pump chamber based Nd:YAG (Neodymium-doped Yttrium Aluminum Garnet) laser has been developed. The average and peak output power achieved are 1040 W and 20 kW respectively. The pulse duration is in the range 2-40 ms, and electrical to laser conversion efficiency achieved was 5%. This laser has potential application in cutting and welding of thick sections of steel.

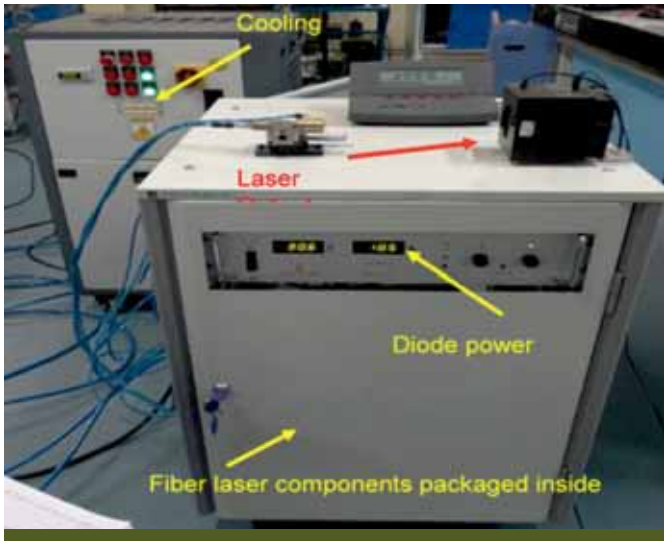


In-house developed ceramic reflector based Nd:YAG laser

In-house developed Nd:YAG laser system for welding of fuel pins at BARC

A 250 W average power, pulsed Nd:YAG laser system with a three- port time-shared fiber-optic beam delivery has been developed, along with a vacuum chamber for laser welding of nickel alloy fuel pins. This laser system provides a maximum pulse energy of 100 J at 20 ms pulse duration, and can deliver variable pulse duration from 2-20 ms with pulse frequency in the range of 1-100 Hz. It has been installed at the Integrated Fuel Fabrication Facility (IFFF), BARC for the production of fuel pins.

An engineered version of a 250 W, all-fiber, single transverse mode Yb-doped CW fiber laser at 1080 nm wavelength with an optical-to-optical conversion efficiency of 76% has been developed for laser material processing applications at NPCIL.



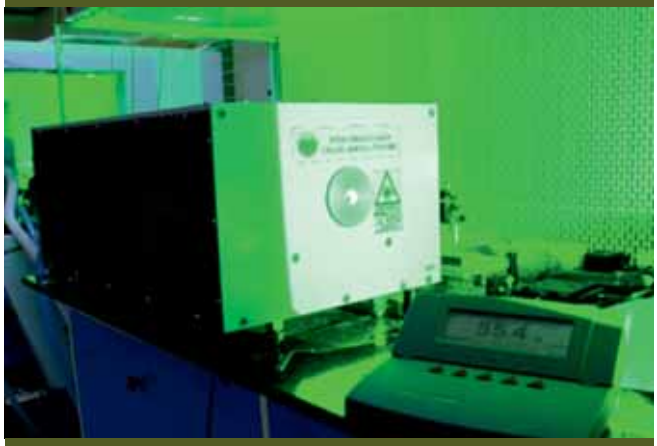
An engineered version in-house developed all-fiber Yb-doped CW fibre laser

The output power of a 500 W CW Yb-doped fiber laser developed earlier has been increased to 700 W with an all-fiber configuration, and with an optical-to-optical

conversion efficiency of 76% maintaining single transverse mode output. This all-fiber Yb-doped fiber laser is capable of cutting up to 8 mm thick stainless steel with less than 200 m kerf width and can be used for a welding depth of about 4 mm in Stainless Steel.

Two numbers of engineered models of DPSS (Diode Pumped Solid State) green lasers with output power more than 50 W at 532 nm wavelength at 9 kHz repetition rate with less than 40 ns of pulse duration and two numbers of engineered models of DPSS green lasers each delivering 45 W of average power at 532 nm at 6.25 kHz repetition rate with less than 40 ns of pulse duration were indigenously developed and successfully installed at BARC.

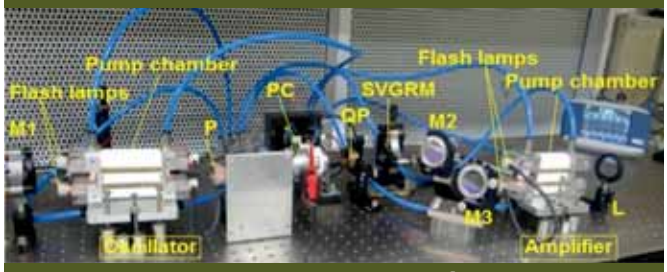
Diode pumped green lasers with control and power supply



Close-up of DSS green laser 55W of average power at 532 nm

A high power, multi-module, diode pumped CW Nd:YAG laser (1064 nm) delivering more than 2.5 kW with optical conversion efficiency of more than 39% has been developed. This laser with beam-parameter-product of about 48 mm-mrad, has been coupled into a 900 μm core diameter optical fiber with a transmission efficiency of about 90%.

High power (2.5 kW), multi-module Nd:YAG Laser



High energy (7 J) Nd:YAG laser oscillator-amplifier system

A lamp-pumped, electro-optic Q-switched, high energy Nd:YAG laser (1064 nm) oscillator-amplifier system delivering more than 7 J energy within 10 ns pulse duration has been developed for laser shock peening applications. The laser system, based on a master oscillator and a single stage, single pass amplifier, produces laser beam of 15 mm diameter with nearly flat-top spatial beam intensity profile.

Five numbers of indigenous, compact, card based laser diode drivers rated for 10 A / 20 V have been developed using switch-mode power converter technology. They can be operated in continuous as well as slow-pulsed mode. The drivers will be used in laser marker systems being developed at RRCAT.

An indigenous refurbishment technology has been developed for imported sealed off CO2 lasers. The technology was applied to refurbish non-functional lasers of Indian Security Press (ISP), Nasik which resulted in significant saving of foreign exchange.

The other Laser technologies developed at RRCAT for various applications includes Development of a hyper-spectral synchronous fluorescence imaging system; Development of a portable fluorescence imaging device for detection of bacterial bio-burden in wounds; Development of a compact and portable opto-mechanical module for the measurement of Raman spectra from concealed food/biological samples;

Development of a fluorescence probe for interrogating sub-surface depths in a layered turbid sample; Raman spectroscopic study for the detection of palm oil adulteration in clarified ghee samples; Technology transfer of 'TuBerculoScope' and 'Raman Probe' to Indian Industry; Laser cutting of bellow lip weld joints during En-masse Coolant Channel Replacement (EMCCR) campaign at KAPS-1 reactor; Laser based removal of two selected coolant channels of the RAPS-4 reactor; Underwater laser cutting of pressure stubs of RAPS-4 and MAPS-1 reactors for post irradiation data; Laser based cutting of stuck north end of S-07 coolant channel of KAPS-2 reactor; Development of an optical viewing system for end-shield leak detection at MAPS-1; Qualification of a laser grooving process for removal of over-rolled steam generator tubes from tube sheet at Kaiga -4 (KGS) reactor; Development of a Powder Bed Fusion based Laser Additive Manufacturing Station; Development of a large volume Laser Additive Manufacturing System; Enhancement in surface defect tolerance of spring steel through laser peening; Loading of cold 87Rb atoms in an optical dipole trap and Dual-isotope magneto-optical trap for fermionic (83Kr) and bosonic (84Kr) atoms.

At BARC, a Laser-TIG hybrid welding system has been developed by integrating a one kilowatt continuous wave Nd-YAG laser with a TIG welding power source. Hybrid welding studies of RAFMS steel, RAFMS-SS316L and SS316L-CuCrZr dissimilar joints were made using this system.

Electronics & Instrumentation

Development and "Technology Transfer" of highly compact high voltage DC and pulsed power supplies for IMS based explosive detection system developed at ECIL. Twelve sets of power supplies have been developed at ECIL under the expert guidance of RRCAT, and are being integrated with the detector units. The DC power supply is rated for -5 kV / 250 μA, and the pulsed power supply is rated for -5 kV / 200 μA. The "Technology Transfer" process for the high voltage supplies has been completed and required training has been imparted to the ECIL technical personnel for fabrication and integration of the supplies with the detector unit.

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

Application of mutation breeding in crop improvement has made significant contribution in terms of varieties released in cereals and pulses. Three crop varieties have been released, two in rice and one in cowpea. In case of rice, semi-dwarf Trombay Chhattisgarh Dubraj Mutant -1 (TCDM-1) was identified for release by Indira Gandhi Krishi Vidyapeeth, (IGKV),

"TCDM-1 (Trombay Chhattisgarh Dubraj Mutant-1) (released for Chhattisgarh State)

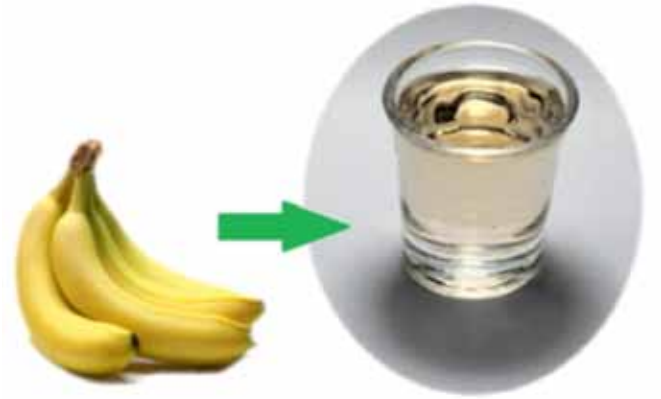
Chhattisgarh State. Another rice variety, Trombay Karjat Kolam, BARCKKV-13 with dwarfness and early maturity developed through collaborative research with Regional Agricultural Research Station, Karjat, DBSKKV, Dapoli, has been recommended for release for cultivation in the Konkan region of Maharashtra.

In pulses, high yielding Trombay cowpea variety TC-901 resistant to yellow mosaic virus and root rot diseases has been released and notified as the first central variety for summer growing regions of north zone, comprising of Gujarat, Rajasthan, Haryana, Uttarakhand, Madhya Pradesh and Maharashtra States. A mutant line, TBM-9 in banana with a bunch weight of 29 kg with early maturity (294 days) is being multiplied at National Research Centre for Banana, Trichy, Tamil Nadu.

In biotechnological approach for crop improvement, irradiated chitosan as a 'biostimulant' has been 'Recommended for Release' by the Joint AGRESCO in commercial cultivation of sugarcane. In controlling rice pathogen, bioactive peptide histatin-5 (hst5) has been found to inhibit growth of Magnaporthe oryzae causing rice blast disease.

Food Technology

During the year 2018, radiation processing alone or in combination with other treatments including chemicals or heat was used for improving the shelf life of many fruits, several ready to eat or cook ethnic snack items, fish derived products and intermediate moisture spiced chicken cubes. Different functional foods enriched with dietary fibre or having antidiabetic potential like jamun strips were developed. In the current year, the technologies for preparation of banana juice, debittering of Karela juice, Xanthan gum production and intermediate moisture shrimp were made available to public domain. As an alternative to plastic, biodegradable thermoplastic sealable film was also developed. Besides this, an intelligent packaging was also developed in order to indicate the spoilage of fish during storage. Radiation processing was also shown to improve the functionality of dietary fibres like psyllium and locust bean gum which in turn used for development of functional foods. In the area of basic research, the nutraceutical compounds with antimutagenic properties



Fresh Banana Juice Technology

were identified from honey and spinach. New radiochromic dye-based dosimeter for the dose range of 1-7 kGy was also developed.

Experimental irradiation using the 10 MeV electron linac-based system at Agricultural Radiation Processing Facility (ARPF), RRCAT was used by various researchers from all over the country for irradiation on agricultural and industrial samples. The irradiation experiments carried-out at the facility during this year included Nagpur mandarin fruits (Citrus reticulate Blanco), various varieties of rice seeds irradiation of

E-beam irradiation of different varieties of rice seeds for mutation breeding

gems, sewage sludge having useful macro and micro elements, semiconductor thin films and electronic devices.

Nuclear Medicine and Healthcare

Regular production and supply of new ready-to-use radiopharmaceutical injections based on Ga-68 (PSMA-11 and DOTA-TATE) (PET radiopharmaceuticals), useful for the diagnosis of prostate cancer and neuroendocrine tumors (NET) has been started during the reported period of 2018-19. These supplies were possible after the facility for imported ^{68}Ge-^{68}Ga Generator was installed and validated for regular use at BRIT.

More than 617 Ci of I-131 products in ~23000 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).

New therapeutic product based on I-131 radiolabelling, ^{131}I-Lipoidal injection for the treatment of Liver Cancer, was produced by RPhD, BARC and supplied by BRIT in the reported period.

Nearly 47 Ci in 490 consignments of theraputic products, other than I-131 based radioactive products, such as ^{153}Sm, ^{177}Lu and ^{32}P for bone pain palliation, were supplied to nuclear medicine hospitals upto March 2019.

Regular production and supply of new therapeutic radiopharmaceutical, ^{177}Lu-DOTA-TATE injection for the treatment of sstr positive neuroendocrine tumors, has been continued for treating NET successfully.

Total 2107 consignments containing approximately 515 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 2018-19.

More than 15600 consignments of Technetium-99m cold kits (19 Products; BRIT Code: TCK) for imaging various organs have been supplied to nuclear medicine centres in India. Production and regular supply of new products, ^{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, which started last year, continued, during the reported time.

Production of Kit for the preparation of ^{99m}Tc-HYNIC-TATE injection, useful for imaging neuroendocrine tumors, started as a part of technology transfer from RPhD, BARC.

Various Tc-99 cold kits were exported to Molecular Supplies SpA, Santiago, Chile. These include kits for the preparation of ^{99m}Tc-Radiopharmaceuticals, such as kits for preparation of ECD injection, EC injection, HSA-Nanocolloid for sentinal node imaging, and Q-Tech kits.

A total of 1278 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 482 batches of TCK cold kits, ready-to-use radiopharmaceuticals injections and oral radiopharmaceuticals. This also includes recently launched radiopharmaceuticals based on Lu-177, Ga-68 and ^{99}Mo-^{99m}Tc COLTECH Generators.

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. During the Year 2018-19, more than 14100 TFS sources of various sizes, shapes and tritium content were supplied to defence establishments and used for illumination of various types of gadgets and instruments. 150 Ci of Tritiated water was supplied to M/s ONGC.

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.

The Medical Cyclotron Facility (MCF) of BRIT continued the synthesis and supply of Positron Emitting Tomography (PET) radiotracers, the maximum being [F-18]-FDG. Other PET radiopharmaceuticals include [F-18]-NaF, [18F]-FLT, and [F-18]-FET, which are produced in smaller scales. So far 300 Ci of [F-18] FDG in 476 consignments have been supplied to various hospitals in Mumbai for PET imaging upto December 2018. More than 15000 patients are benefitted with PET investigations in the reported year 2018-19.

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 Variable Energy Cyclotron Centre (VECC).

During the year at BARC, considerable progress has been made towards the development of various PET imaging agents. Gallium-68-labeled NOTA-UBI (Ubiquicidin 29-41), an infection imaging agent was developed. Gallium-68-labeled BPAMD is a well-known PET agent used for the skeletal imaging of patients suspected to be suffering from bone metastases.

Alternative Applications of Heavy Water

The $H_2{}^{18}O$ of 95.5% O-18 enrichment is used in PET scanning and 10% O-18 enrichment is useful in metabolic studies. The first indigenously developed O-18 production plant at HWP, Manuguru has reached the enrichment of O-18 up to 75% during the report period.

Cancer Diagnostics & Treatment Services

Tata Memorial Centre (TMC), an established authority on cancer management in India continued to treat cancer patients who flocked from all over the country.

The year 2018 saw the registration of almost 75,000 patient, 4 % more than last year. The Preventive Oncology patient registration rose by more than 25 % to a figure of 7179. There was 15 % increase in the number of patients for Radiotherapy as a result of extension of the working hours. Single-Photon Emission Computed Tomography (SPECT) scan patients rose by almost 25 % as compared with last year. The Medical Social service sector counselled and guided over 50,000 patients; an increase by over 25 %. The recent introduction of a special Home Care team from ACTREC campus by the Palliative Medicine department was very well appreciated by the patients.

The numbers of patients registering online increased to more than 8500. The cancer related drugs and consumables were supplied to all the patients (of TMC & its satellite centres) at a substantial lower cost than the Maximum Retail Price (MRP). Taking digitalization forward the hospital became almost paperless, filmless and cashless. The TMC-Navya online second opinion cancer services continued to be popular with the general public. The year 2018 saw the full-fledged activities for the commissioning of the 179 bed Homi Bhabha Cancer Hospital (HBCH), Varanasi in the month of May. The bed strength of HBCH, Sangrur was increased from 30 to 100. To accommodate the growing needs of TMH and the increasing patient load, the Government of Maharashtra allocated a 5-acre plot of land in the Haffkine Institute for Training, Research and Testing in Parel, Mumbai near the hospital.

Industrial Applications of Radioisotopes & Radiation

At BRIT, twenty teletherapy sources (CTS) of ^{60}Co containing activity in the range of 153 and 232 RMM were supplied to different cancer hospitals in India and abroad during 2018-19. Co-60 teletherapy source of 1MCi was exported to REVISS Services (UK) Ltd. in July

2018. This is the biggest export order executed in the history of BRIT. Three CTS sources were exported to Sri Lanka and one source exported to IMO, International Health Systems Ltd., Nigeria. Co-60 source with total activity of 55,560 Ci in forty two source pencils were loaded in four units of Gamma Chamber 5000 (GC-5000).

Seventy two W-91 Irradiator sources of industrial grade & 163 BC-188 Irradiator sources with 3842 kCi activity in 16 consignments were supplied to 14 radiation processing plants within the country during the year 2018-19. A total of 646 consignments (with total activity of 24,597 Ci) of ^{192}Ir & ^{60}Co Radiography sources were supplied to NDT user's during the year 2018-19. 750 consignments of Co-60 Custom Made Reference (CMR) sources with total activity of 1.38 Ci were supplied to various users upto March 2019. Dose mapping of Gamma Chamber - 5000 unit was done with Cs-137 source.

At BARC, a cotton-based superabsorbent for selective absorption of oils from oil-water mixture was developed by electron beam assisted topography and surface energy modification. Based on the electron beam grafted superabsorbent, a prototype was developed for separation of hydrocarbons from a mixture of hydrocarbons and water. Radiotracer investigations were carried out in paper-pulp digesters and wastewater treatment plant and in an ethyl acetate production reactor at Punjab. BARC carried out extensive nuclear radiation based radiometry and imaging investigations for industrial components and assemblies for various departmental projects, including critical non-destructive evaluation studies for engineering specimens used in power reactor engineering and test reactor loops and prototype facility for radiochemistry work.

Radiation Processing

About 2664 Cubic meters of medical supplies have been sterilized using gamma radiation processing at ISOMED, BRIT during 2018-19. Radiation Processing Plant extended their services to irradiate about 4340 MT of spices and allied products during the reported time period. Radiation Processing Plant Facility at Vashi was certified for ISO 9001:2015 (Upgraded from 9001:2008 to 9001:2015). Surveillance audits for ISO 22000:2005 (Food Safety Management Systems) and ISO 9001:2008 were also carried out by the certifying agency and found in full compliance with standard's requirement. Plant commissioning dosimetry AMC of 'Dry Sludge Gamma Irradiator' was completed. Plant commissioning dosimetry for Class III and Class VI products of M/s Electromagnetic Industries was also completed during the reported period. 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 2 Lakhs Ceric-Cerous Sulphate Dosimeters were done for various gamma irradiators in the country and abroad for the measurement of absorbed dose.

BRIT signed nine 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 2018-19.

Radiation Technology based Equipment & Services

At BRIT, forty seven numbers of Radiography Cameras, ROLI-2 model, were supplied to various NDT users within India and services were provided for 500 numbers of BRIT and imported radiography cameras. Four Blood Irradiators – 2000 (BI-2000) units with 15 kCi of Cs-137 source in 24 pencils were supplied to hospitals in India during the year. Replenishment of source to ACTREC was made. Gamma Chamber–5000 units with 27,959 Ci have been supplied to IIT, Roorkee, India, and another one was exported to Vietnam for research purposes during 2018-19. The services was provided by BRIT for 10 units of GC-5000. Also, services for decommissioning of five units was given to users.

At BARC, indigenous rechargeable phantoms have been fabricated in-house at Radiopharmaceuticals Division for their use in quality assurance of gamma cameras installed at two different nuclear medicine centres in Mumbai. In the area of affordable cancer treatment, to improve clinical performance, radio therapy machine Bhabhatron has been integrated with Multi Leaf Collimator (MLC) system to provide radiation field to irregular tumour geometries. Hon'ble President of

India inaugurated the Bhabhatron unit with MLC, installed at ACTREC, Kharghar, Navi Mumbai during his visit to BARC.

Water Purification, Water Desalination & Isotope Hydrology

BARC developed a 5 cubic meter/day Brine Concentrator Unit (BCU) with Thermo Vapour Compressor, to address the environmental issue of disposal of brine from desalination plant. Indigenous development of BCU provides the technological knowhow of the process for management of brine from desalination plants to achieve Zero Liquid Discharge (ZLD) systems. Isotope hydro-geological investigations were carried out for the identification of paleo-channels in Haryana, Gujarat, Rajasthan and Uttar Pradesh. Isotope study showed existence of paleo-channel in Kurukshetra, Haryana, and Allahabad, Uttar Pradesh.

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

At TIFR, work was carried out on several questions and problems in Algebra, Analysis, Lie Groups, Number Theory, Algebraic and Differential Geometry and Combinatorics. A complete answer to a conjecture of Kleinbock on p-adic dichotomies in dynamics was given. Progress was made concerning the relationship between the etale fundamental group and the stratified fundamental group. A proof of a cubulation theorem for surface-by-free groups was given. A well-balanced numerical methods for solving Euler equations with gravity which work for very general solutions have been developed.

At HRI, important results have been obtained in the study of finite groups which provide a wealth of set theoretic solutions of the quantum Yang-Baxter equation. The classification of integrable modules for certain Lie algebras has been obtained. This is of great interest in both mathematics and physics.

Physics

Under basic research activities, research on investigating the binding of copper with different oxidation states with neuro peptides is carried out using MALDI-TOFMS for targeted drug delivery biomedical applications. The isotope selective two-photon ionization scheme through the hyperfine component of ^{176}Lu was explored for possible applications in nuclear medicine. Using the Pelletron-Linac facility, measurement of ^{59}Ni(n,xp) reaction cross section relevant to fusion technology as well as reaction studies involving weakly bound projectiles has been carried out. Several high pressure physics studies viz., High pressure structural investigations on hexagonal $YInO_3$; Phase Transition in Metal-Organic Complex trans-$PtCl_2(PEt_3)_2$ under pressure; Molecular geometry modifications for triggering structural phase transitions in metal-organic Platinum complexes; were carried out. Nuclear moments, hyperfine structure of heavy elements were determined by a novel cryo-cooled discharge approach to record hyperfine structure (HFS) using high resolution Fourier Transform Infrared Spectroscopy.

Under the Astrophysics research and development activities, several gamma ray emissions recorded using TACTIC, enhanced gamma-ray emission has been observed from Mrk 421 using TACTI and is reported. The work related to the assembly of the MACE telescope is at an advanced stage at Hanle. First engineering trial runs of the telescope with 50 mirror panels and 64 CIMs have been performed and the results indicate satisfactory performance.

A record of ten different atmospheric science instruments were launched from TIFR Balloon Facility, Hyderabad. Successfully conducted a balloon launch on 28-10-2018 carrying TIFR Far-Infrared 100 cm telescope (T100). At TIFR's National Centre for Radio Astrophysics, Pune, the work on upgrading the GMRT has crossed most of the final milestones. The PLF (joint facility of TIFR and BARC), was operated for research in nuclear physics and other allied interdisciplinary areas with about 75% uptime. A novel signatures in the shape

of the cosmic microwave background (CMB) spectrum of decaying dark matter and new unstable particles in the early Universe were proposed.

The Rossby-mode instability windows and the gravitational wave signatures of neutron stars in the slow rotation approximation using the Equation of State (EoS) obtained from the density-dependent M3Y and SEI effective interactions have been studied at VECC. It is found that the young and hot rotating neutron stars and neutron stars with low L value lie in the r-mode instability region and hence emit gravitational radiation.

Relativistic Feynman-Metropolis-Teller treatment of compressed atom with Coulomb screening in strong quantizing magnetic field has been applied to develop the EoS. It is found that inclusion of Coulomb interaction modifies WD masses further upward and significantly greater than Chandrasekhar limit.

The nuclear fusion at very low energies plays important role in nucleosynthesis of light elements in stellar core and fusion reactors. Quantum tunneling through Coulomb barrier of interacting nuclei using square-well potential with imaginary part well describes fusion reaction. The variations of astrophysical S-factors for the D+D, D+T, D+3He, p+D, p+6Li and p+7Li fusion reactions with energy have been explored.

An analytical model based on nuclear reaction theory for non-resonant fusion cross sections near Coulomb barrier has been developed. The astrophysical S-factors involving stable and neutron rich isotopes of C, O, Ne, Mg and Si for fusion reactions are calculated in the centre of mass energy range of 2-30 MeV.

Various nuclear physics experiments were performed in the field of charged-particle spectroscopy, gamma-ray spectroscopy, fission dynamics etc., using beams from K-130 cyclotron at VECC and other accelerators facilities in INDIA.

The Hon'ble Vice President of India, Shri M. Venkaiah Naidu has inaugurated the new state-of-the-art Facility for Research in Experimental Nuclear Astrophysics (FRENA) at Saha Institute of Nuclear Physics, Kolkata on Thursday, 28th June 2018. FRENA is the first dedicated facility for Research in Experimental Low Energy Nuclear Astrophysics which is centered around a 3 MV Tandetron capable of delivering high intensity ion beams of proton, deuteron, helium to heavy ions till gold with variable energy of high precision.

At HRI, in astrophysics the phenomenon of black hole shadow formation has been studied. The associated experimental observation is one of the major astrophysical results in recent years.

At IOP, the broad areas of research in theoretical high energy physics were string theory, high energy physics phenomenology and cosmology. 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.

Synchrotrons and their Applications

Both the synchrotron radiation sources, Indus-1 and Indus-2 are being operated in round the clock mode as a national facility for the Synchrotron Radiation (SR) users. Indus-1 was operated at 450 MeV energy, 125 mA current and Indus-2 was operated routinely up to 200 mA stored current at 2.5 GeV energy. During the period from April 01, 2018 to March 31, 2019, Indus-1 and Indus-2 were operated round the clock on 321 days. Indus- 2 under-went a major upgrade with the installation and commissioning of the sixth radio frequency (RF) cavity. Along with this sixth RF cavity, a kicker cavity was also installed in the ring for implementation of a Longitudinal Multi-bunch Feedback (LMBF) scheme for the suppression of longitudinal beam instabilities. The usage of Indus facility increased further this year.

Indus-2 synchrotron radiation source is regularly operated using an electron beam optics having emittance of 135 nm-rad at 2.5 GeV. In order to increase the spectral brightness of the photon beam, several beam dynamical parameters have been optimized and an emittance change over scheme was evolved and implemented at 2.5 GeV. This method helped in keeping strict control on the betatron tunes, closed orbit distortions, beta function distortions, etc. to prevent any beam loss. Due to this the horizontal beam emittance of this source was reduced from 135 nm-mrad to 45 nm-rad at 2.5 GeV. The electron beam size was also reduced from 420 μm corresponding to 135 nm-rad to 280 μm, which corresponds to 45 nm-rad.

For the upgradation of Indus-2 many activities had taken place these includes Development of beam current pulse profile measurement system for booster synchrotron; Distributed, multi-channel, isolated, high accuracy, simultaneous sampling, fast Data Acquisition (DAQ) system in Indus-2; Disaster Recovery Setup (DRS) for Indus Control System: Development of combined function harmonic sextupole magnets for Indus-2; Indigenous development of ferromagnetic resonance bench for characterization of microwave ferrite & garnets for high power circulator; Development of prototype capacitive displacement sensor for monitoring the mechanical position stability of a beam position monitor; Upgradation of electrode assembly for integrated type Beam Position Indicators (BPIs) for Indus-2; Improvement in the Indus-2 storage ring cooling water supply temperature stability; Installation and Commissioning of the sixth RF cavity in Indus-2; Deployment of an indigenous high power RF circulator in Indus-2 RF system; Development of pulsed focusing electromagnet power supply for klystron of 20 MeV injector microtron of Indus complex; Development of large coating system; Development, installation and commissioning of power converter for LS-1 (Long Section) quadrupole defocussing magnet 1 (Q1D) in Indus-2; Development of fast pulse power supplies for Indus-2 pinger magnets; Installation of smoke exhaust system, fire alarm and detection system and upgradation of public address system for the Indus complex and Development of power supplies for Fast Orbit Feedback (FOFB) system.

View of the sixth RF cavity installed in Indus-2

View of installed RF circulator at Sixth Indus-2 RF station

Several upgrades and additional facilities were added to the Synchrotron beamlines under physics group at RRCAT. These include installation of A Small and Wide Angle X-ray Scattering beamline at Indus-2; A setup for in situ EXAFS experiments during photocatalytic reaction at BL-09 Energy Scanning EXAFS beamline at Indus-2; Facility for in-situ study of ion batteries using x-ray diffraction at ECXRD beamline at Indus-2; and Upgrade for an improved signal to noise ratio in complete mid-IR region in the Infrared beamline at Indus-1.

Cyclotrons & their utilisations

The DAE Medical Cyclotron Facility has been established at Chalkgaria, Kolkata, by Variable Energy Cyclotron Centre (VECC). The cyclotron along with two beam lines has been commissioned during September, 2018. A test irradiation of enriched water sample and production of FDG has also been carried out. The main objective of the facility is to produce radioisotopes to be used in nuclear imaging for medical diagnostic and therapeutic purposes for cancer care. The facility will also be used for various research and development purposes.

Beam dynamics simulations have been done to find out the transmission efficiency of ion beams through narrow vertical space of Super-Conducting Cyclotron (SCC). The first harmonic component of the magnetic field of SCC corrected from 50 Gauss to 28 Gauss after repositioning of the cryostat. Installation and commissioning of a helium compressor for hooking up with the liquid helium plant.

The Room Temperature Cyclotron (RTC) has been operating in round the clock shift basis and delivering ion beams to various experimental research programs. The external 14.45 GHz Electron Cyclotron Resonance Ion Source (ECRIS) developed indigenously is regularly producing high charge state heavy ions and light ions which are accelerated in cyclotron.

Fusion and Other Plasma Technologies

Systems have been developed at IPR and are at various stages of deployment/evaluation for Plasma Sterilization of Medical devices, components and baby utensils; Atmospheric plasma system for food grain processing; Plasma system for In-line textile treatment; Rotatable magnetron for plasma-coating industry, denim fading system using non-thermal air plasma; Spark plasma sintering process for producing multi-layered W/Cu functionally graded material. Technology has been transferred for metal oxide nano powder production technology.

Aditya-Upgrade Tokamak experiments have demonstrated extended discharge duration 30% higher than the design value. A magnetic field of 1.3 Tesla, 85% of the design value, has been demonstrated. Doubling of plasma density has led to observation of rotation reversal of plasma, reported in very few tokamaks worldwide. In the Steady-State Superconducting Tokamak (SST-1), 2.7 Tesla toroidal magnetic field has been produced corresponding to 90% of the design value.

Chemistry

At BARC, density functional theoretical calculations were performed in order to understand the extraction and complexation behaviour of mixed N and O ligands for the extraction of Am^{3+} and Eu^{3+}. Poor selectivity between trivalent actinides and lanthanides for this class of ligands is attributed to non/weak participation of the 'N' atoms of the heterocyclic rings in the direct bonding with the metal ions. Np was separated from acidic feeds containing mixture of actinides viz. U, Np, Pu and Am. Radio-ruthenium recovery was attempted using ^{103}Ru tracer taken in acidic feeds using $NaIO_4$ as an oxidant and n-dodecane as the trapping agent for RuO_4. Nuclear probes like positron annihilation spectroscopy was used to show the phase separation of ethanol-water binary mixture confined in mesoporous silica.

At TIFR, a novel nanoparticle-based method was developed to fluorescently probe the orientation of membrane proteins. A peptide based copper-binding mimics of blue-copper protein were developed and characterized. A versatile theoretical framework capable of describing electron transport through molecules in a wide variety of natural and synthetic environments was developed.

Biology

At BARC, the focus was on studying molecular mechanisms of stress responses in bacteria, plant and mammalian systems and exploitation of the fundamental knowledge for various biotechnological / biomedical applications. Whole genome sequencing, gene assembly and annotation was performed for Chryseobacteriumculicis. Microarrays were synthesized by indigenous micro-arrayers and optimized detection of disease causing mutations. Microarrays were developed for 32 mutations causing inherited breast cancer. A simple, label-free detection methodology for detecting single point DNA mutations using an electrochemical biosensor utilizing electrospun graphene doped manganese III oxide nanofibers (GMnO) was developed. As a proof of concept, ultrasensitive detection of del185AG, a mutation specific to BRCA1 gene was demonstrated.

At TIFR, "Fed-microRNAs" that stop the production of proteins required during fasting were identified. A paradigm to physiologically stimulate touch neurons without optogenetics has been established to correlate the trigger of Calcium release. In Neurobiology, a key investigation highlighting the mode of intraflagellar transport in the inner ear revealed a mechanism on how protocadherin-15 (Pcdh15) is transported in the hair bundle found in the hair cells of the inner ear. A study revealed that although butterflies harbour distinct microbiomes across taxonomic groups and dietary guilds, the dramatic dietary shifts that occur during development do not impose strong selection to maintain distinct bacterial communities across all butterfly hosts. A key event in 2018 was the inauguration of the National Cryo EM Facility.

Materials Science

Technology for producing roll bonded corrosion resistant single-layer cladded and double-layer cladded sandwich steel plates with SS 317L as cladding and ASTM 516 Gr 60 Carbon Steel (CS) as backing materials has been developed at BARC. Solid state lithium electrolyte based on lithium germanium phosphate glass ceramics with NASICON structure was synthesized. Cells were fabricated with different combination of cathode and anode and tested. Capacity of 80% of theoretical value has been obtained at lower C-rate. A new multistage sintering methodology was developed to densify Al_2O_3 to more than 99% TD at a considerable lower temperature. Al_2O_3 to SS were joined using Active Brazing Alloying (ABA) technique to fabricate Ceramic brake for Fast Current Transformer (FCT).

BARC has developed a hand held ballistic shields having capability of stopping Armour Piercing (AP) bullets (Level IV). BARC has developed two test panels (300 mm X 300 mm) using hot pressed Boron Carbide and Carbon Nanotube (CNT) impregnated polymer. These panels were tested against multiple shots of AP bullets and were found to stop them with low back face signature (less than 20 mm). More than 400 pieces of 50 X 50 X 7 mm B4C-CNT composite tiles were hot pressed. 4 numbers of hard armour panels were fabricated using these tiles after machining them into required dimensions. The ballistic performance of these composite armours was found to be satisfactory against AK 47 hard steel core bullets and SLR.

Ballistic Shield before and after ballistic test

The main activities carried out in the field of Materials Science at RRCAT were Establishment of experimental facility for terahertz time domain spectroscopy at low temperatures and in high magnetic fields, leading to the first measurements on the dielectric properties of a Fe_3O_4/Si thin film; Design, fabrication and

Experimental set-up for terahertz time domain spectroscopy at low temperatures and in high magnetic fields

testing of variable temperature insert for measurement of residual resistivity ratio, magnetoresistance and magnetostriction; Role of tailor-made additives for controlling vapour growth asymmetry of acentric materials; X-Ray magneto circular dichroism spectra of full Heusler alloys, Co_2PtGa and Mn_2PtGa; Fabrication and characterization of Er, Nd co-doped Y_2O_3transparent ceramic; Probing oxygen defects in (1-x)NBT–x$BiCrO_3$ ferroelectric by micro-Raman spectroscopy; Inter-diffusion study of GaP on Ge using Raman spectroscopy; Surface modification of InAs nanowires using Raman spectroscopy; Fabrication of oriented laser elements from the in-house grown Nd:$GdVO_4$ single crystals, and evaluation of their lasing performance; Pt-CA catalyst activity evaluation for CECE based decontamination application; Photo-catalytic degradation of dye with Au-ZnO nano-composite; Realization of ns fast nonvolatile resistive memory switching in Au/TiO_2/Pt devices; Development of a simple and inexpensive mask-less photolithography system; Development and application of high responsivity GaAs based photodetectors; Fabrication of a spin-hall device using mask-less photolithography and Development of GaN metal-oxide-semiconductor ultraviolet photodetectors.

Material science research done at VECC include Microstructural characterization of proton irradiated niobium using X-ray diffraction technique; An approach in analysis of microstructural parameters of Proton Irradiated T91 through XRDLPA using synchrotron Laboratory and source and Depth profiling of ion-induced damage in D9 alloy using X-ray diffraction.

At IGCAR, in the materials front, development & demonstration of welding and inspection procedures involving dissimilar metal between 10%Cr Steel & Alloy 617M in the rotor for Advanced Ultra-Super Critical (AUSC) coal-fired thermal plant was accomplished. ZrO_2 dispersed 9Cr-Oxide Dispersion Strengthened (ODS) steel for in-core material, yttria coating on graphite crucibles for pyro-chemical reprocessing application, production of Phase Pure Tungsten Carbide (WC) pellets by spark plasma sintering (SPS) for FBTR irradiation experiments and successful demonstration of an advanced phased array ultrasonic based methodology for inspecting thick dissimilar welds are some of the significant achievements. Towards evolving non-destructive evaluation methods, focused surface differential eddy current array probes have been indigenously developed, qualified and employed for detecting scratch (minimum depth of 50 micron) in calendria tube at Kakrapar Atomic Power Station (KAPS), Gujarat.

Cancer Research

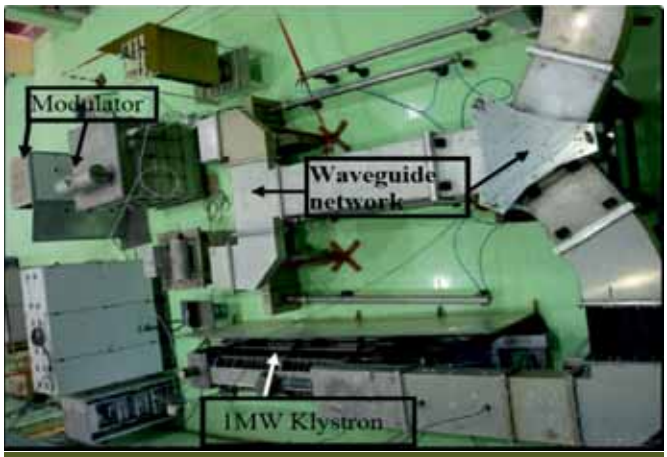
Radiation induced pneumonitis is one of the side effects of thoracic radiotherapy. Currently, corticosteroids are employed as drugs to reduce inflammation in lungs. A new radioprotector molecule, Diselenodipropionic acid (DSePA) which showed promising effects as an adjuvant drug to treat radiation induced pnemonitis was developed. One of the challenges in use of chemotherapy drugs is its poor selectivity to tumor cells. Such non-selective biodistribution of drugs results in serious side effects to healthy tissues and organs. New cost effective nanoformulations were developed to improve therapeutic index and reduce side effects of common chemotherapy drugs.

International Research Collaborations

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 TIFR-Belle group continued to play a leading role in the analysis of e+e- collision data recorded near various Υ(nS) resonances with the Belle detector at the KEK B-factory in Japan. The group was closely involved in the analysis of the Phase-II data of Belle II. At TIFR's International Centre for Theoretical Sciences, Bengaluru the works carried out in the Astrophysical Relativity includes development of Bayesian model selection method to identify strongly-lensed gravitational-wave signals from binary black holes. It performed the first search for strongly lensed gravitational-wave merger events in LIGO-Virgo data.

At VECC, the Photon Multiplicity Detector (PMD) has been made ready to take data in Pb-Pb collisions at LHC, about 65Million events have already been collected by PMD. Two GEM chambers after successful test have been sent to FAIR-Germany for integration in the mini-CBM experiment.

At RRCAT, a 100 kV, 20 A, 1.6 ms converter type, long pulse, solid state modulator has been designed and developed for energizing a 1 MW, 352.21 MHz CERN LEP klystron. The klystron has been successfully tested using this indigenously developed pulsed modulator, and 1 MW RF power has been extracted from the klystron at 352.7 MHz. The droop and variation of the RF pulse was within ± 1%, and the phase stability of the RF output power within the pulse, and pulse-to-pulse, was less than ± 2.5 %.



Top view of the RF test stand of 1 MW LEP klystron

ITER-Project

The ITER project, where India is an equal partner, reported over 58% physical progress. Significant progress has been made by ITER-India for delivery of Cryostat, Cooling Water System Components

& Cryogenic Distribution Lines to the ITER Project site in France. Site acceptance test of 100 kV, 7.2 MW Power Supply made by M/s ECIL based on IPR's design, has been completed at Padova, Italy.

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 at RRCAT are national facilities with sixteen operational beamlines on Indus-2 and six operational beamlines on Indus-1. Two of the Indus-2 beamlines (BL-23 & 24) are dedicated exclusively for machine diagnostics, which provide essential information for the proper running of Indus-2. The number of user experiments at Indus beamlines in the calendar year 2018 was 855. The Indus facilities have been used by researchers from all over the country for a wide variety of studies leading to 167 papers being published in international peer reviewed journals in 2018. Users from different universities, national laboratories and institutes are regularly coming to Indus beamlines for experiments.

Along with the above utilisation, there has been a continuous effort in improving the facilities at the beamlines and related aspects. Important areas of research in which experiments have been carried out at the Indus beamlines include: catalysts, multiferroics, superconductors, semiconductors, protein crystallography, thin films, elemental quantification, etc.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

The Homi Bhabha National Institute (HBNI), a deemed to be University, aided by DAE 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. During the year 2018-19, 231 PhD degrees and 176 M.Tech degrees were awarded by HBNI.

Training

BARC continued to provide highly skilled human resources to DAE through its two flagship programmes–OCES (Orientation Course for Engineering graduates and Science postgraduates) and DGFS (DAE Graduate Fellowship Scheme). A total of 65 graduating TSOs after successful completion of the training, were placed in various units of DAE. To promote DAE activities and to attract best talent, visits to as many colleges and universities as possible were conducted. BARC conducted One-year Diploma in Radiological Physics Course (post M.Sc. programme) under the aegis of Homi Bhabha National Institute (HBNI). It also conducted various training cum certification programmes on radiation safety in medical, industrial and research applications of radiation sources for societal benefits.

BARC Training School at IGCAR has successfully completed its 12th year and twenty nine young trained scientists and engineers have been placed in various units of DAE. The programmes of Homi Bhabha National Institute (HBNI) continue to progress with full vigour, with twenty six fresh students joining the doctoral programmes this year. Summer and internship programs have enabled many students from various colleges to get acquainted with the high end facilities at IGCAR.

BARC Training School AMD Campus, Hyderabad continued its activity wherein 15 Trainee Scientific Officers (TSO) of the 8th batch (OCES-2017) completed induction training on 31-07-2018. Seventeen TSO's of the 9th batch (OCES-2018) are undergoing induction training.

Human Resources Development activities at RRCAT revolve around imparting training to Trainee Scientific Officers, Ph. D. Scholars, and M. Tech. students from various Indian institutes.

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. 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.

The Administrative Training Institute (ATI) 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. ATI has been able to organize over 1000 programmes for over 27,300 participants, till date. Another major achievement of ATI is the "training at doorstep" of different units. 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.

SPONSORED RESEARCH

Promotion of Extra-mural Research in Nuclear Science

Board of Research in Nuclear Sciences (BRNS) continued to extend the financial & technical support to various universities and research institutes across the country in the form of sponsored projects. During the calendar year, 104 new research projects were sanctioned, and a total grant of ₹ 4835 Lakhs have been released for pursuing new and on-going research projects, supporting scientific publications/workshops and financing the Olympiad Programme of training the Indian student's contingent by Homi Bhabha Centre for Science Education (HBCSE). Besides funding research projects, BRNS also provided financial assistance for organising symposia/ conferences/ workshops on topics relevant to the programmes of DAE. Financial support to the tune of ₹ 224 Lakhs was extended for conducting 147 scientific events. Out of these, twenty 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 Graduate Fellowship Scheme (DGFS), the former being a post-doctoral and the latter a graduate research fellowship. During the current year, 19 new students were inducted under DGFS-Ph.D programme, bringing the total number of Ph.D. students enrolled under this scheme to 153. The Homi Bhabha Chair is instituted to avail the services of Scientists and Technologists who have distinguished themselves at national and international levels. Under the Raja Ramanna Fellowship scheme, a grant for 64 scientists was disbursed, besides supporting four Homi Bhabha Chair professors.

Promotion of Mathematics

The National Board for Higher Mathematics (NBHM) set up by the Government of India under the Department of Atomic Energy (DAE), in the year 1983 continued its activities 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 continued to provide M.Sc. Scholarship and Ph.D. Scholarships to students. NBHM also offered Postdoctoral Fellowships to selected young mathematicians who have completed their Ph.D. degree in Mathematics. NBHM extended financial support to the libraries of various Universities and Institutions. NBHM supplied selected books to Mathematics/ Statistics departments of universities/ institutes/ postgraduate centres. NBHM provided assistance for research projects. Assistance to mathematicians for attending conferences, symposia, summer schools etc. within the country or abroad was provided by NBHM. NBHM provided financial assistance for holding national and international conferences/ workshops/seminars. The Indian National Mathematical Olympiad (INMO), 2018 had 939 participants and the Madhava Mathematics Competition took place in 23 regions across the country.

In all 6701 students of undergraduate classes appeared for the competition. NBHM continued to support the Visitors programme, Conferences and Mini-workshops for the Indian Women in Mathematics (IWM).

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 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. These institutions are growing at a faster pace in terms of the projects undertaken by them.

Hon'ble Prime Minister of India inaugurated Mahamanna Pt. Madan Mohan Malaviya Cancer Centre in BHU Campus in Varanasi, Uttar Pradesh on 19.02.2019. The proposal of Tata Memorial Centre (TMC), Mumbai for 'Establishment of Homi Bhabha Cancer Hospital & Research at Muzzafferpur, Bihar has been approved by the Department on 31.07.2018. TIFR has started an ambitious new campus in Hyderabad, the capital of the newest member in the family of Indian states, Telangana. The site of the 200 acre campus, adjacent to the University of Hyderabad, has been generously made available by the state government, to nurture research and higher education in the region.

Grants to Cancer Hospitals

The Department extended financial assistance to Cancer hospitals located in other parts of the country. The grant released for the year 2018-19 for such partial financial assistance was of ₹2.65 crore.

Olympiad Programme

All the students selected and trained by HBCSE's Science and Mathematics Olympiad programme won awards (12 gold, 13 silver and 4 bronze medals, and 1 honourable mention) at the International Olympiads in Astronomy, Biology, Chemistry, Junior Science, Mathematics and Physics. In the International Physics Olympiad (IPhO) 2018, all 5 students bagged gold medals, enabling India to top the medals tally. This performance is the best by an Indian team in IPhO since participation began in 1998.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The Computer and Information Systems Division (CISD) of DAE has implemented the web-based portal rrf.dae.gov.in for online processing of applications. CISD has implemented an online system - Anusankalak for collecting the periodic reports online from all the constituent Units of DAE including PSU and Grant-in-aid Institutions. CISD has also implemented TaskPro - a web-based application for a periodic monitoring of progress of a task.

A new web portal has been deployed to conduct the online recruitment for various posts at VECC. The main web portal has been developed by computer division BARC. The original portal has been customized for VECC, and additional features were added as per the VECC requirement. A new E-mail infrastructure with 3 rack servers and 10 TB SAN storage has been installed and commissioned with proper security safeguards and updated version of e-mail server software. E-mail service has been migrated to new setup and deployed in production. It was decided to distribute all the critical IT services with redundancy among the Main building, C&I building and ANUNET building as a part of the disaster management plan for VECC IT infrastructure. High-speed fibre connectivity among the buildings have been established as an initial step for implementation of the plan. This fibre backbone will be used to extend the fibre connectivity to the other buildings of the VECC, Salt Lake Campus.

An IT security mock drill setup to be used for conducting mock security drill exercises has been

designed, developed and commissioned at RRCAT. An authenticated network services administration dashboard for monitoring complete status of RRCATNet, including critical network, internet DMZ security servers and security applications, has been developed and deployed. An IAAS based computing cloud setup has been commissioned to meet the short term computational requirements of users of RRCAT. The design, development and commissioning of a Short Messaging Service (SMS) gateway for sending SMS to employees, applicants etc. on their registered mobile numbers has been completed.

TECHNOLOGY TRANSFER

At BARC, a total of 37 technologies have been transferred to 64 parties. Eleven new technologies were introduced into public domain during the year. Licences for 2 technologies that were renewed during the period were On-line Domestic Water Purifier based on Ultrafiltration Polysulfone Membrane and Auto TLD Badge Rader. On the medical application front, a process to identify cancer cells using the extracellular acidity as a marker has been developed. Synthetic diamond thin film based sensor technology for detection of H_2S was transferred to M/s Innovative Material Technologies Pvt. Ltd., Jaipur. Ultrathin SnO_2 based resistive sensors were developed for toxic gas monitoring. A turbine blade health monitoring system has been developed in BARC. Technology for compact, low temperature alkaline water electrolyser capable of producing high purity hydrogen up to 10 Nm^3/hr and 5 Nm^3/hr oxygen has been developed. The technology was transferred to Industry. The technology for production of tungsten metal powder in kg scale batches was developed. The developed technologies were transferred to M/s. R. S. Enterprises, Pune. Technology for the 12 channel Tele-ECG (6 Vendors), Peripheral Pulse Analyzer (1 Vendor) & Body Composition Analyzer (2 vendors) was transferred. Growth of CsI:Tl crystals has been perfected by BARC and the technology for the growth of these crystals and fabrication of radiation detectors was transferred to M/s ANTS Innovations, Thane. Technology of Table Top Static Gas Sensing Unit was transferred to two private firms. The technology for Extra-Cellular Acidity Analyzer (ECAA), a portable electrochemical sensor developed to differentiate between cancer cells and normal cells was transferred to M/s Genuine Biosystems Pvt. Ltd., Chennai.

A technology knowhow on 'Metal oxide nano powder production technology' and license agreement was signed between IPR & RUBAMIN Ltd., Vadodara on 5th March 2019 at IPR. Since this technology will foster production of zinc oxide nano powders in India, this agreement contributes directly to the 'Make-in-India' programme of Government of India. MoU between IPR & Saurashtra University for development and supply of experimental plasma systems for academic purpose, signed in July 2018. MoU between IPR & VSSC for development of electro magnet module for structural analysis software package was signed in July 2018.

The technology transferred at VECC includes the RFID based embedded Issue/Return System for Library Management; RFID based Hand Held Reader for Attendance Recording; Digital Nano-ammeter and Digital Pico-ammeter.

COLLABORATIVE PROGRAMMES

BARC collaborated with industry under MoU for "Development of Radio-protector" technology; To Incorporate Segmental Impedance in Body Composition Analyzer along with Connectivity to Host PC; Incubation of production of nickel-cobalt-manganese based active cathode battery materials development and MoU of advance robotic prosthetic limbs. A Centre for Computational Engineering and Sciences (CCES) has been created under BRNS umbrella at IIT-Bombay to support development, maintenance and up-gradation of computational mechanics software packages and provide human resource development and education on a continuing basis. A turbine blade health monitoring system using non-intrusive technique is developed in BARC to measure the blade vibration from turbine casing. The system has been successfully used in Tata Power plant, Trombay, and Singareni Thermal Power Plant in Telangana.

SOCIETAL INITIATIVES

In order to promote technologies developed by BARC for rural populace, 6 DTDDF (DAE Technology

Display & Dissemination Facility) centres were established. A total of 11 awareness meetings were held in different places. Ten agreements were signed with different organizations and individuals to promote rural entrepreneurship using BARC technologies under Advanced Knowledge & RUral Technology Implementation (AKRUTI) Tech Pack.

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 2018-19, five DAE-IPR cell meetings were held, which reviewed twenty-four new patent proposals. DAE filed twenty nine new patent applications which includes; two applications under PCT (Patent Co-operation Treaty), thirteen in India, six in USA, five in Europe and one each in Germany, Japan & China. During this period, twelve of the previously filed patents were granted to the Department. These includes; two each in India & USA and one in Europe.

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 profit (Total Comprehensive Income) for the year 2018-19 is ₹ 2779 Cr.. The profit for previous FY 2017-18 was ₹ 3614 Cr. NPCIL bonds continued to be rated as AAA (Highest Safety) by CRISIL and CARE.

URANIUM CORPORATION OF INDIA LTD.

The total income of the Company during the year 2017-18 was ₹ 1791.95 Cr as against ₹ 1272.7 Cr in the previous year. In terms of performance of the Company for the year 2017-18, UCIL has been rated as "Excellent" by Department of Public Enterprises (DPE) as per Memorandum of Understanding (MoU) signed by the Company with Department of Atomic Energy. The MoU targets for production of U_3O_8 for FY 2018-19 has been successfully achieved.

INDIAN RARE EARTHS LTD.

During the financial year 2018-19, the Sales Turnover achieved is ₹ 762.65 crore (Provisional) against ₹ 573.88 crore of the corresponding period of previous year and Profit Before Tax (PBT) for the financial year 2018-19 is ₹ 203.96 crore (provisional) compared to PBT of ₹ 123.85 crore of corresponding previous year.

ELECTRONICS CORPORATION OF INDIA LTD.

Against the MoU target of Rs.1800 crore each for production and Net Sales, the Company achieved a production of ₹ 2751 crore and a net sale of ₹ 2728 crore upto March 2019.

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 2018, 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 62nd General Conference which was held at Vienna, Austria from 17-21 September 2018. Chairman, AEC had a number of bilateral meetings on the sidelines of the conference.

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. GCNEP Phase-II construction has been planned in four packages. While Phase II construction activities are in progress, GCNEP continues to deliver its commitment to promote safe, secure and sustainable nuclear energy by conducting specialized programs in the domain of Nuclear Safety, Security, Safeguard and societal applications. During the Year 2018 – 19, GCNEP conducted 10 International and 2 national programs, meeting similar mandate of more than 45 countries who participated in these programs.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and CANDU Owner's Group (COG) and participating in their programs for enhancing the safety and reliability of nuclear power plants. NPCIL is one of the founder members of WANO and its nuclear power plants are affiliated with two WANO regional centers located at Tokyo and Moscow. NPCIL participated in some of the COG meetings held through the audio conferences. In addition, COG representative visited NPCIL and discussed issues of mutual cooperation. NPCIL participated in various meetings, workshops, seminars organized by International Atomic Energy Agency (IAEA). NPCIL continued to provide information for IAEA Power Reactor Information System (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 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), carried out its 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. 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 2018-19, India participated in all the five IAEA conducted International Convention Exercises, known as “ConvEx”. 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. A new template for 'Off-site emergency preparedness and response plan' for nuclear power plant sites was developed jointly with NPCIL and AERB. The plan was tried with AERB concurrence for conducting off-site emergency exercise at Rawatbhata-Rajasthan site and found more 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 the DAE Secretariat. "Vigilance Awareness Week 2018" was observed in DAE during October 29th to November 03rd, 2018 on the theme of "Eradicate Corruption – Build a New India". As a preventive vigilance measure and to spread vigilance awareness, 8 Vigilance Awareness Seminars/Interactive sessions were held at NPCIL Head Quarter & sites. Vigilance Awareness Week was also observed in NPCIL.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC continued to manage the bi-lingual official website of BARC, Library Information Systems that includes IT infrastructure, Internet Cafe, Integrated Library Management System, Library RFID System, Digital Library (Saraswati), Retrospective Repository (D-space) Online Information Gateway (Lakshya), Remote Access Facility HOoA (Home Office or Anywhere) and Content Management System for creation & management of Information content. Publication of the bi-monthly BARC Newsletter was continued.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of public outreach 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 105th Indian Science Congress (ISC) –Pride of India Expo-2018 exhibition held at Manipur University, Imphal during March 16-20, 2018. 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 106th session of the Indian Science Congress (ISC) was held from 03-07 January, 2019 at Lovely Professional University, Phagwara, Punjab. The Hon'ble Prime Minister of India Shri Narendra Mody inaugurated the Indian Science Congress on 3rd January, 2019. The occasion was graced by Eminent Scientists, Nobel Laureates, Dignitaries, former ISCA General Presidents, Industry Leaders, Policy Makers, Innovators, Academicians and

105th Indian Science Congress at Manipur University, Imphal

106th Indian Science Congress at Phagwara

thousands of national/international delegates. Other units of DAE that included BARC, IGCAR, UCIL, ECIL, NFC, AMD, BRIT, IPR, HWB, RRCAT & NPCIL also participated along with DAE.

DAE organized the second series of Journalist's Workshop at IGCAR, Kalpakkam during March 26-28, 2018. 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 up and wherein Scientist-Journalist meet was also organized. The workshop ended with a Panel discussion and feedback from the journalists. DAE organized the third DAE-NUJ Journalists Workshop during August 27-30, 2018 at Kaiga, Karnataka. The event went a long way in changing the perception of the participants.

DAE-NUJ Journalist Workshop at Kaiga, Karwar, Karanataka

DAE organised the 30th DAE All India Essay Contest. The topics for the essay contest were: Evolution of Nuclear Power in India; Radioisotope Production and Radiation Technology Applications & Lasers and Their Impact on Mankind. Twelve students were selected for each of the three topics and they were invited to Mumbai to visit various facilities of DAE and to make an oral presentation of their essays. In order to generate a competitive spirit, selected students were being awarded with cash prizes.

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

NPCIL has been carrying out many public outreach activities in a structured manner through a multipronged communication approach. Many innovative public awareness campaigns have been conceived and implemented Pan India for different sections of the society. Use of films and multimedia in vernacular languages, creative publications, exhibitions, lectures and seminars, scientific meets, regular interaction with the public living in the vicinity of nuclear power plants and projects, visits of members of public to nuclear power plants, nationwide media facilitation and public relation activities along with various social media tools are some of them to enhance the public perception about nuclear power. NPCIL has also been partnering with many professional agencies to boost the various ongoing public awareness activities. NPCIL has set up Halls of Nuclear Power as permanent nuclear galleries at Science Centres in Mumbai, New Delhi and Chennai. In the smaller towns, miniature galleries are also planned in a phased manner to promote numerous aspects of nuclear energy. Semi-dynamic Nuclear Power Plant (NPP) models with synchronous commentary and LED animation are also being fabricated and donated to various Science Centres on regular basis.

Telecast of Special Documentary Film on Achievements of Rajasthan Atomic Power Station (RAPS), on DD National and other 13 Channels in association with Prasar Bharati

SOCIAL WELFARE

Corporate Social Responsibility

NPCIL is committed to economic and social development of the local communities around all its Sites. CSR programme is implemented at the 14 Sites of NPCIL, where either the operating stations or the projects under construction or the sanctioned projects 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 major categories in which CSR projects have been taken up are: education, healthcare, infrastructure development, skill development, sustainable development and other general projects.

Swachha Bharat Mission

The Department of Atomic Energy and its constituent units continued its activities for the "Swachha Bharat Mission". As per the directives of the Govt. of India, "Swachhta Pakhwada" was observed from Feb 16-28, 2019 at IGCAR, Kalpakkam. Cleaning of the office premises was carried out with special emphasis on e-waste. Competitions under various categories like slogan, essay and poster were conducted on the topic "clean and green environment" among employees / trainees of this Centre and prizes were distributed during the closing ceremony.

EMPLOYEE'S WELFARE

BARC continued to provide the health care facilities to entire Mumbai based CHSS beneficiaries through its 390 bedded hospital, 13 zonal dispensaries, 3 occupational health centers and 24 hr. casualty facility.

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. ECIL has received many awards during the year. SINP scientist has been awarded the "Excellence in Microscopy" by Electron Microscope Society of India (EMSI) for the year 2018.

CHAPTER

1

NUCLEAR POWER PROGRAMME STAGE-1

Bird's Eye View of Kakrapar Atomic Power Project (KAPP) Unit-3&4 main plant construction area

Main Construction area of
Rajasthan Atomic Power Project (RAPP) Unit-7&8

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. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. One of these operating reactors namely Kaiga Generating Station Unit-1 has registered world record of continuous operation by recording 962 days of continuous operation. Tarapur Atomic Power Station (TAPS)-1&2 reactors have registered 50 years of safe operation in May 2019. 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 LWRs at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Various pre-project activities are in progress for GHAVP-1&2 (2x700 MW PHWRs), KKNPP-5&6 (2x1000 MW LWRs) and for 10 PHWRs in fleet mode towards launching these projects. At GHAVP-1&2 excavation is completed, contract is awarded for Main plant civil works and site mobilization is in progress. At KKNPP 5&6, excavation is in progress. Various preparatory activities such as land acquisition and R&R, Environmental clearance, procurement of long delivery items and components, studies for regulatory clearance, site infrastructure development, public outreach, tendering for main plant civil works etc. are in various stages of progress in respect of 10 PHWRs in fleet mode. . 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 upgradation, continuous improvement in Quality Management, Quality Assurance/surveillance, Pre-Service Inspection/In-Service Inspection and interface with regulatory body.

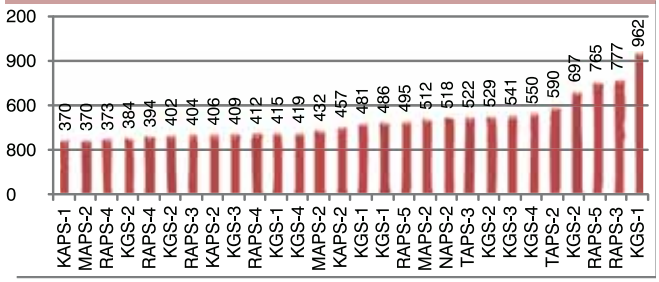
Operating Reactors

Out of 22 operating reactors, fourteen reactors of NPCIL viz. TAPS-1&2, RAPS-1&2, RAPS-3&4, RAPS-5&6, NAPS-1&2, KAPS-1&2 and KKNPP-1&2, with total installed capacity of 4380 MW, are fuelled with imported fuel and are under IAEA safeguards. Eight reactors viz. MAPS-1&2, KGS-1&2, KGS-3&4 and TAPS-3&4 with total installed capacity 2400 MW, are fuelled with domestic fuel.

Unit-1 of Kaiga Generating Station (KGS-1, 220MW) surpassed the earlier record of 940 days of continuous operation, held by Heysham-2 Unit-8 of the United Kingdom, on December 10, 2018. The unit was manually shutdown for planned maintenance activities and inspections on December 31, 2018, and thus completed 962 days of continuous operation registering higher than highest continuous operation record world over.

During the FY 2018-19, five reactors i.e. KGS-1 (962 days), KGS-2 (697 days), RAPS-3 (777 days), KGS-3 (541 days) and MAPS-2 (512 days) achieved continuous run for more than a year. So far, the continuous operation of more than a year has been achieved 28 times by various reactors operated by NPCIL.

Continuous operation for more than a year registered by NPCIL's Reactors as on March 31, 2019



TAPS-1&2 reactors have registered 50 years of safe operation in May 2019.

Nuclear power reactors in operation registered 500 reactor years of safe operation by the end of FY 2018-19. Various stations won several awards in areas of safety and performance.

During the Calendar Year (CY) 2018, NPCIL registered generation of 39051 Million Units (MUs) and the overall Plant Load Factor (PLF) and Availability

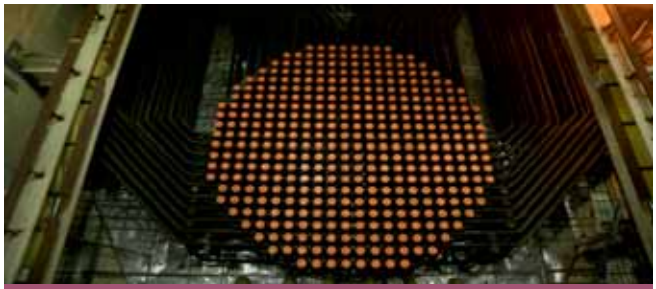
Factor (AF) for all the reactors in operation at 73% and 75% respectively. The actual generation in the Financial Year (FY) 2018-19 is 37813 MUs and with overall PLF and AF for all the reactors in operation at 70% and 73% respectively. In the previous CY 2017, the generation was 37180 MUs (in addition, there was an infirm power generation of 1427 MUs from KKNPP-2 during year 2017) and the overall PLF and AF for all the reactors in operation were 71% and 73% respectively. Actual generation during the previous FY 2017-18 was 38336 MUs and the overall PLF and AF for all the reactors in operation were 70% and 72% respectively.

In both units at Kakrapar Atomic Power Station (KAPS), major works relating to En-Masse Coolant Channels Replacement (EMCCR) and En-Masse Feeders Replacement (EMFR) were undertaken in project mode since August 1, 2016. KAPS-2 was re-started and synchronized to Grid at 12:50 Hrs on 22nd September-2018, three and half months ahead of schedule. KAPS-1 was re-started and synchronized to Grid at 06:44 Hrs on 25th May 2019, also completed over three months ahead of schedule.

Projects under Construction

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

Major equipment/components delivered during 2018-19 include 4 Shut-down Coolers, one Fuelling Machine Return & Recirculation Cooler, one Regenerative Cooler, one Bleed Cooler, 12 Oil Hydraulic Power Packs, 16 Local control panels, Scrubber Tank for Containment Filtered Venting System, 1951 valves, complete Stand-pipe thimble assembly, pipes, fittings, Electrical and C&I items etc. There are continued supply constraints to achieve required pace of physical progress.



Feeders erection work completion at KAPP-3

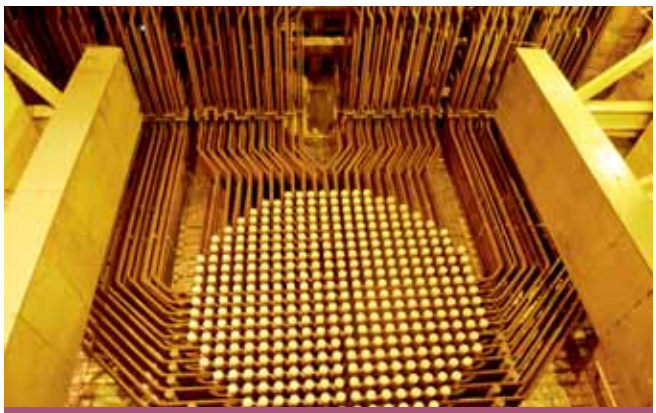
Unit-3 is in advanced stage of commissioning. After successful completion of Inner Containment (IC) pre-stressing activity, Outer Containment (OC) dome of unit-3 was completed and with this, all the major civil works of unit- 3 have been completed. Feeder erection work is completed. A major milestone of “Hydro test of Primary Heat Transport (PHT) system” was completed successfully. Main air Lock and Auxiliary Air Lock systems integrity test have been completed. Reactor Building Proof Test and Integrated Leak Rate test have been completed. All Primary Coolant Pumps (PCPs), Emergency Core Cooling System (ECCS) pumps have been installed and load tested. Active Process Water (APW) system is completed and hydro tested. Induced Draught Cooling Tower (IDCT) has already been completed and is in operation. Systems for reactivity monitoring and controlling which include Delay Neutron Monitoring system, Horizontal Flux units etc. have been completed. Reactivity Devices erection work also completed. All three low Pressure turbines (LP turbines) and High Pressure turbine have been boxed up and their instrumentation work is in progress. All three condensers have been made ready. All four Diesel Generators (DG) have been commissioned and two DG is loaded and synchronized with grid successfully. All the major equipment in Balance of Turbine Island Package (BOTIP) have been erected. Main steam line and Steam Generator blow down system which is required for Hot conditioning, have been completed. Natural Draught Cooling Tower (NDCT)-3A&3B internal structure has been completed. Plant water system main building has been completed and mechanical work of plant water system is in progress. Preparatory works for Hot Conditioning and Light Water Commissioning are in progress. The physical progress of the unit is about 94% as on end March 2019.

High Pressure and Low Pressure Turbine box-up at KAPP-3

In Unit-4, construction of IC dome completed and pre-stressing of IC containment is completed in April-2019. A major milestone of "Coolant channel installation" is completed. Construction of structure of Induced Draft Cooling Tower (IDCT)-4A & 4B is completed. Start Up Transformer (SUT) -4A&4B is charged and feeder fabrication work is in progress. The physical progress of the unit is about 83% as on end March 2019.

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

Major equipment / components delivered during 2018-19 include 2 Steam Generators, 7 Shut-Down Coolers, 2 Regenerative Coolers, one Inventory Addition Recovery System (IARS) Heat Exchanger, one Bleed Cooler, one Bleed Condenser, 2 Fuelling Machine Return and Recirculation Coolers, 6 Liquid Effluent Segregation System (LESS) tanks, 2 downgraded Heavy water storage tanks, 4 Passive Decay Heat Removal System Heat Exchangers , 1 Primary Pressurising Pump, 10 Steam Generator Blow Down (SGBD) Pumps & Motors, one Electric overhead traveling (EOT) crane, 2307 valves, pipes, fittings, Electrical and C&I items etc. There are continued supply constraints to achieve required pace of physical progress.



Feeder erection in RAPP-7

In Unit-7, construction of IC Dome has been completed and pre-stressing work is nearing completion. Civil works of Control Building and Station Auxiliary Building-7A & 7B is completed. Erection of all Steam Generators (SGs) is completed. Construction of Turbine Building-7 is nearing completion. Commissioning of Plant Water Pump House is completed. Charging of Start-Up Transformer (SUT) – 7A & 7B is completed. Erection of feeders is nearing completion. The physical progress of the unit is about 81% as on end March 2019.

In Unit-8, Construction of IC wall is completed and ring beam is nearing completion. Construction of SG vaults is completed. The physical progress of the unit is about 69% as on end March 2019.

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

Under the Russian Scope of Supply, six ship loads project cargo (about 36,000 Freight Ton) delivered at Tuticorin port/ Kudankulam site during the year, consisting of Reactor Pressure Vessel, Reactor Internals, Core Cavity Component, Core Melt Localizing Facility, Steam Generators, Turbines for Unit-3 and Turbo Generators, High Pressure Heaters, Moisture Separator-reheaters, De-aerator tank & column, Relief tank for both the Units. Under Indian Scope of Supply (indigenous supply), large diameter carbon steel buried pipeline (PAB) delivered in full scope for both the Units. Purchase Orders placed for EPC packages Electrical Switchyard; Common Services Systems; Main Plant Electrical Systems; Sea Water Systems and Diesel generators. Notice Inviting Tender (NIT) published for Automated radiation monitoring system package, Control and instrumentation package, Material handling equipment package and Procurement of Instrumentation Tubing package. Development of Working Documentation (WD) is in progress (53.78% completed).

Construction of Reactor Building-3 up to containment slab at +5.4 m elevation and Reactor Building-4 up to corium slab at +1.1 m elevation completed. Construction of Reactor Auxiliary Building, Emergency Power Supply Building, Turbine Building, Tunnels etc. is in progress for both the units. Subsequent to construction & dewatering of temporary dyke, excavation and geotechnical investigations completed for hydro-technical structures of both the units.

The physical progress of the unit-3 and Unit-4 are about 29% and 26% respectively as on end of March 2019.

Sanctioned Projects

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

Main Plant Excavation is completed. Ground Improvement in the Main Plant area has been completed and in the balance area, it is in progress. First Pour of Concrete (FPC) consent application submitted and is under review by AERB. Main Plant civil package is awarded. Purchase orders are placed for major equipment/components like Primary Coolant Pump, Steam Generators, Caldaria, End-shields, Reactor Headers, Moderator and D2O Heat Exchangers, etc. Process of tendering for other major packages like Primary Piping 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 DHBVN. Tests for pile validation at mock up soil-cement compacted area completed successfully. 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 of other infrastructure buildings like Main guard house, Construction warehouse is in progress. Award of work for Project Management Building is in the advanced stage.

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

In pursuance of Inter-Governmental Agreement (IGA) signed between the Governments of Russian Federation (RF) & Republic of India, Administrative approval and Financial Sanction has been obtained from Government of India in June-2017. General Framework Agreement (GFA) for setting up of KKNPP Units-5&6 has been signed between JSC Atomstroyexport (ASE) and Nuclear Power Corporation in June 2017.

All statutory clearances including clearances from Ministry of Environment, Forest and Climate Change (MoEFCC), Coastal Regulation Zone (CRZ), Tamil Nadu Pollution Control Board (TNPCB), Tamil Nadu Maritime Board (TNMB) and Siting Consent from AERB are in place.

Consent for excavation of main plant building pits has been obtained from AERB. Excavation work is in progress. Selection and Approval of Subcontractors is in progress for manufacturing equipment in Russian Federation. Purchase order has been issued for procurement of mechanical cleaning devices. Contract for delivery of equipment and materials (Balance of Plant-BOP) has been signed in December 2018. Tender for Main Plant Civil Works is in the advanced stage of finalization.

Ten 700 MWe PHWRs in Fleet Mode

Administrative Approval and Financial Sanction from GOI has been received in June 2017 for construction of ten indigenous 700 MW Pressurized Heavy Water Reactors (PHWRs) in Fleet Mode. Preparatory activities are in various stages towards launch of these units. Purchase Order is placed for Forgings for Steam Generators (6 units-24 Nos.), SS 304L Lattice Tubes and Plates for End Shields (4 Units) and further activities like raw material procurement and manufacturing are in progress. Procurement processes for Pressurizer & Bleed Condenser (BCD) and Steam Generator (SG) (28 Nos.), Reactor Headers (8 units-64 Nos.), Primary Coolant Pump (PCP) motor units, etc. are in progress. Other preparatory activities like land acquisition, environmental clearance related activities, site studies, etc. are in various stages of progress for commencement of construction of these units, at Chutka in Madhya Pradesh, Kaiga-5&6 in Karnataka, GHAVP-3&4 in Haryana and Mahi Banswara in Rajasthan.

New LWR Sites

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. In respect of Jaitapur, Land is acquired, Techno-commercial discussions with

Électricité de France (EDF), France are in progress and the "Industrial Way Forward Agreement (IWFA)" has been signed between NPCIL and EDF. At Kovvada, land acquisition process is in progress. Possession of part of the land is acquired and activities are in progress for taking possession of balance land. TOR is approved by MoEFCC. Studies related to the Environmental Impact Assessment (EIA) at site are in progress. Discussions with WEC is under progress. At Mithi Virdi site in Gujarat, land is to be acquired as per the new RFCTLARR Act, 2013, CRZ clearance available. MoEFCC would be approached again for obtaining the clearance based on the progress of land acquisition. At Haripur site in West Bengal, land acquisition is contingent to initiative by State Govt. and an alternate site is also under consideration by GOI.

Quality Assurance

NPCIL, in all its endeavors, is committed towards upgradation and continuous improvements in Quality Management, Quality Assurance, 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 / In-service Inspection (PSI/ISI) activities of Projects/ Stations has been completed successfully. Regulatory Interface on QA & PSI/ISI activities has been carried out on timely manner to meet the project and station schedule. Corporate Peer reviews of operating stations have been conducted based on World Association of Nuclear Operators (WANO) guidelines. Corporate QA audits & PSI audits of KAPP-3&4 have been completed in a planned way. NPCIL continued to provide QA consultancy services to Bhabha Atomic Research Centre (BARC) and Bharatiya Nabhikiya Vidyut Nigam (BHAVINI). Preparation, review and approval of Generic In-service Inspection document for PHWR type NPPs and for KAPP-3&4 In-service Inspection program document were 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. Quality Surveillance activities were performed for various equipment and components manufacturing for projects and those required for KAPS-1 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.

The Heavy Water Board has achieved 100.7% of overall targeted heavy water production. HWP, Hazira operated excellently, and with consistently high deuterium recovery, it has achieved 126.4% of targeted production. The plant has set record of lowest specific energy consumption for any Ammonia-Hydrogen Exchange process based plant, of 22.92 GJ/kg D_2O in 2018-19. HWP, Kota has also operated excellently producing 110.7% of the target. At HWP, Tuticorin, revamping jobs for targeted restart up of the plant is in full swing. Compressors were overhauled, safety valves calibration completed and DG set has been installed. Civil work related to solvent production plant is in an

advanced stage of completion. Engineering activities for solvent production plant are under progress.

Heavy Water Plant, Manuguru

Exchange Unit–II (XU-II) of HWP, Manuguru operated normally during the financial year. After getting clearance from AERB, rundown of H2S and decontamination of XU-I for Extended Major Turn Around (EMTA) was taken up on 05.11.2018.

Waste heat powered hot water Vapour Absorption-based Refrigeration (VAR) machines were successfully commissioned during the year. Among other planned activities completed were UT thickness scanning of all 5D radius bends in process liquid loops of XUs, pre-fabrication of secondary super heater coils of SG-1, chemical cleaning and passivation of SG-3 and overhauling of transformers GT-3, UAT-3 and ICT-1. For improving security at Plant Site & Colony, upgraded CCTV system has been installed and commissioned and peripheral road has been constructed for the colony.

Hot Water Vapour Absorption Refrigeration (VAR) machines commissioned at HWP, Manuguru

To mitigate the environmental issue related to fly ash generated from CPP, Vibro-Stone Columns were installed in Ash Pond-2 to increase the load bearing capacity and reducing liquefaction under seismic stress. Capacity of ash pond-2 being increased by raising the Ash Pond bund height. Attempts are in hand to achieve maximum disposal/ utilization of fly ash generated at CPP.

Auxiliary Steam Turbine (TG-4) operated efficiently to recover throttling energy losses in HP steam loop. The Solar Photo Voltaic Power Plant continued to operate satisfactorily generating 15.395 MU.

The targets of enriched Boron and B4C powder of IP B-10 $\geqslant$ 90% were achieved. The same was got micronized for further processing. CSR grade B4C pellets produced at HWP, Manuguru are confirmed as acceptable as per IGCAR requirements. Plant has also produced the Enriched Elemental Boron of B-10 $\geqslant$ 67% for production of B4C powder.

Heavy Water Plant, Kota

The plant operated excellently during the year 2018-19 achieving 110.7% of the targeted production. The production was achieved with energy consumption within the targeted specific energy consumption for the year.

Sodium Sulphate Crystallizer unit was operated surpassing the targeted operating hours by 20% and generated Na2SO4 crystals from the effluent Sodium sulphate solution.

Steam Turbo Generator was hooked up with Waste Stripper of Exchange Unit and trial runs were conducted successfully.

Chief Executive, HWB inaugurating test operation of Steam Turbine Generators (STG) at HWP, Kota

Heavy Water Plant, Hazira

The performance of HWP, Hazira was excellent during the year achieving 126.4% of targeted Heavy Water production. The plant has made a record of achieving lowest ever overall specific energy consumption in any ammonia based heavy water plant i.e. 22.92 GJ/kg D_2O. This could be achieved due to high on-stream factor as only short shut downs were taken up in April/May 2018 for replacement of heat exchangers E4104B, E4106 and E4101. Also with implementation of suitable modifications suggested by HWB in the Ammonia Plants of KRIBHCO, high average deuterium concentration was made available in feed synthesis gas.

Heavy Water Plant, Thal

Both streams A and B at HWP, Thal were under strained operating condition during this financial year. Loss of operating hours resulting in shortfall of production was mainly due to CO/CO_2 ingress from Ammonia Plants of RCF which affected Exchange Towers 12T1A/B. In August 2018, both streams were shut down for a month for cracker tube inspection and testing as specified in ISI manual.

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 was put under operation for fixing the operating parameters and developing / fine tuning the operating parameters and collect required data for scale up of the cell for industrial production facility of 600 MTPA Nuclear grade sodium. Actions have been initiated w.r.t fabrication of 24 kA cell along with its auxiliaries and setting up pilot scale purification system.

The plant has achieved synthesis of $CDCl_3$ using conventional method with Deuterium enrichment $\geqslant$ 99.80%. New synthesis procedure for $CDCl_3$ from hexa-chloro-acetone with Deuterium enrichment $\geqslant$ 99.80 is also established as targeted. Production of Deuterated Aceto-nitrile with Deuterium enrichment $\geqslant$ 99.80% was achieved.

D-labeled NMR solvents - Chloroform-d, DMSO-d6, Acetone-d6 & Acetonitrite-d3, Benzene-d6 and D_2SO_4 were synthesized using conventional and innovative methods as a part of developmental activities on alternate application of heavy water. 15 Kg $CDCl_3$, 2.0 Kg Acetone-d6, 6.0 Kg DMSO-d6, 2.0 Kg Acetonitrile-d3 and 50g Benzene-d6 was 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.

Inorganic products like KOD, NaOD, DCl, and D_2SO_4 were also produced. 1.0 Kg 40% w/w KOD solution in D_2O was sent to BARC, Vizag.

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, re-startup activities have been initiated. Two other projects are also being set up at HWP, Tuticorin viz. industrial scale Solvent Production Plant (SPP) and industrial scale Solvent Extraction Plant (SXP).

All the activities for re-startup of main plant are in full swing. Updating of operating manual, safety manual, Technical specification are in progress. HAZOP study for the various process loops of the plant was taken up. All compressors were overhauled. Maintenance & calibration of all safety valves work was completed. Compressors, pumps, vessels, panels, equipment & piping supports, cable tray are being tested / overhauled and painted as per planned schedule. Installation of cooling tower system has been started. Engineering for DCS/ PLC system is under progress.

An industrial scale Solvent Production Plant 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. Civil & structural work is nearing completion. Engineering activities for mechanical, electrical & instrumentation system is under progress. Utility & auxiliary piping work is in hand.

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 of SXP area work is under progress. Agreement with M/s GSFL for supply of phosphoric acid and utilities was signed on 14.09.2018.

Heavy Water Plant, Talcher

At HWP, Talcher, the production facilities for D2EHPA and TBP operated continuously to meet the targeted production. 10,000 kg of TBP was dispatched to KNRPC, Kalpakkam.

In the 50 lit. Glass ware set up at HWP, Talcher, Calix Crown-6 was synthesized for BARC as targeted.

The plant produced enriched BF_3 Di-ethyl Ether complex > 65% IP and > 90 % IP enriched KBF4 in KBF4 conversion Unit. Conversion of RCl into ROH from the RCl+ROH mixture was carried out in campaign mode in glassware setup.

Bf_3 Gas Generation and Bottling Facility at HWP, Talcher

Commissioning and 10 nos. of trial runs were completed for establishing the process of Boric Acid conversion and purification at Boric Acid Conversion and Purification Unit. BF_3 Gas Generation and Bottling Facility was dedicated to the Nation by Honorable President of India Shri Ramnath Kovind on 15th May 2018 through remote inauguration from BARC.

Technology Demonstration Plant

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. Characterization of rock phosphate samples collected at various locations such as Mussoorie (Uttarakhand), Hirapur & Mardeora (M.P), Kirauli & Udaipur (Rajasthan) has been carried out.

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

Gallium extraction facility at TDP, Mumbai

hydrometallurgical process developed by BARC involving leaching, solvent extraction, ion exchange, precipitation, thermal reduction for recovery of cobalt.

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 being commissioned at TDP site.

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 2017-18 (November 2017 to October 2018), integrated multi-disciplinary approach adopted for uranium exploration with substantial inputs of radiometric, geological, ground and 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 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 (6,902 sq km) and detailed (326 sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

Pratapgarh Formation, Delhi Supergroup, Mahendragarh district, Haryana: Quartzite at Sohla.

Hutti – Maski Schist Belt, Raichur district, Karnataka: Granite at Arkera.

Basement crystallines, Kadapa district, Andhra Pradesh: Granite at Pincha – Bhakrapeta (up to 0.133% U_3O_8) and Bayareddigaripalle-Eguvagattuvedu.

Chhotanagpur Granite Gneissic Complex (CGGC), Garhwa district, Jharkhand: Migmatites near Chundi.

Mahadek Basin, South West Khasi Hills district, Meghalaya: Lower Mahadek Sandstone at Mawthawpdah.

Dongargarh Kotri Belt, Rajnandgaon district, Chhattisgarh: Ferruginous quartz breccia at Khursitikhul-Padgondi Kalan.

CGGC, Balrampur district, Chhattisgarh: Brecciated ferruginous phyllite at Rakshakhand.

Aravalli Supergroup, Udaipur district, Rajasthan: Brecciated carbonaceous phyllite at Lakadwas.

Bhadesar Formation, Jaisalmer Basin, Jaisalmer district, Rajasthan: Ferruginous Sandstone at Mokal.

Kui-Chitrasani Shear zone, South Delhi Fold Belt, Sirohi district, Rajasthan: Breccia at Awal.

Basement crystallines, Kurnool district, Andhra Pradesh: Granite cataclasite at Lakkasagaram.

Basement crystallines, Wanaparthy district, Telangana: Leucogranite at Ammapuram – Guntapalle.

Geochemical Surveys

Geochemical surveys (4,521sq km) have delineated anomalous hydrogeochemical zones upto 23,600 ppb U along Kottamalapalle fracture zone in Pincha-Bhakrapeta sector, Kadapa district, Andhra Pradesh; up to 113 ppb U along Saraswati palaeochannel in Kolayat-Chandni sector Bikaner district, Rajasthan and up to 155 ppb U in Jhirna - Jhalikhera, Hoshanagabad district, Madhya Pradesh.

Ground Geophysical surveys

Ground geophysical surveys have been carried out in parts of Singhbhum Shear Zone, Jharkhand; North Delhi Fold Belt, Rajasthan & Haryana; Hanspani Shear Zone, Assam; Bhima Basin, Karnataka; Surguja Shear Zone, Madhya Pradesh & Chhattisgarh; Dongargarh-Kotri Belt, Chhattisgarh and Satpura Gondwana Basin, Madhya Pradesh. The geophysical surveys have delineated potential low magnetic zones in Jhanji-Jhapar-Tugwa sector, Singrauli district, Madhya Pradesh & Balrampur district, Chhattisgarh and high chargeability zones in Sohla-Nimbi tract, Mahendragarh district, Haryana and Imlikheda, Betul district, Madhya Pradesh.

Airborne Survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 42,056 line km in parts of Alwar Basin (North Delhi

Calibration of heliborne survey instruments at Milanpur helibase, Betul district, Madhya Pradesh before geophysical survey in Satpura Gondwana Basin

Fold Belt), Rajasthan; Satpura Gondwana Basin, Madhya Pradesh and Cuddapah Basin, Andhra Pradesh & Telangana.

Nine potential uranium mineralisation target areas for further ground study have been identified from processing and interpretation of heliborne geophysical data of Alwar Basin, Rajasthan. Similarly, twenty five target areas in Satpura Gondwana Basin and ten target areas in Cuddapah Basin were delineated for detailed studies.

Exploration by Drilling

A total of 2,50,808m (Departmental: 89,232m and Contract: 1,61,576m) drilling (reconnoitory, exploratory and evaluation) has been carried out to establish additional uranium resource in the known deposits and sub-surface continuity of mineralisation in the new promising areas.

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

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

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

Pinch and swell structure in Pegmatite Leucosome Mobilizate, Naktu area, Sonbhadra district, Uttar Pradesh

Uraniferous serpentinised peridotite outcrop at Kudada, East Singhbhum district, Jharkhand

Newly procured hydrostatic core drilling rig (KDR-600) in operation at Kudada area, East Singhbhum district, Jharkhand

Singhbhum Shear Zone, East Singhbhum and Seraikela-Kharswan districts, Jharkhand: Associated

with quartz-chlorite-sericite schist at Jaduguda (North), Singridungri-Banadungri, Narwapahar Deep, Bangurdih, Baglasai-Mechua and Galudih-Sankadih. Associated with altered peridotite in Kudada (Turamdih East extension).

Rohil and its extensions, Sikar & Jhunjhunu districts, Rajasthan: Albitite zones in NDFB along Rohil west, Narsinghpuri, Jahaz, Geratiyon ki Dhani and Ladi ka Bas.

Kanchankayi & Gogi West, 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.

Devri, Surajpur district, Chhattisgarh: Associated with brecciated granite, grey granite and granite-gneiss in Devri, which is situated in the east of Jajawal uranium deposit.

Dharangmau-Kachhar, Betul district, Madhya Pradesh: Associated with sandstone.

Kappatralla, Kurnool district, Andhra Pradesh: Associated with quartzite.

Rajpura, Una district, Himachal Pradesh: Associated with sandstone.

In addition to the above, the following potential/significant blocks have also been identified for sub-surface exploration at Loharkar, Hamirpur district, Himachal Pradesh; Kusumbarai, Mayurbhanj district, Odisha; Jhapar, Balrampur district, Chhattisgarh and Sarangapalli, Guntur district, Andhra Pradesh;

Rare Metal and Rare Earths Investigations

Reconnaissance (835 sq km) and detailed (4.25 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

Nb-Ta mineral and Beryl in pegmatite, Marlagalla-Allapatna area, Mandya district, Karnataka

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

A total of 14,073 m drilling has been carried out for RMRE in Siwana Ring Complex, Barmer district, Rajasthan and Ambadongar, Chhota Udepur district, Gujarat. Continuity of REE mineralisation in microgranite dykes has been established over 2 km strike length in Bhatikhera, Siwana Ring Complex, Rajasthan.

Additional resource of 1,019 kg of columbite-tantalite was estimated in pegmatites of Jangapara, Jharsuguda district, Odisha. About 3,46,462 tonne Rare Earth Oxide and 19,564 tonne Nb_2O_5 (Rare Metal Oxide) resource has been established at Ambadongar Carbonatite Complex, Chhota Udepur district, Gujarat.

Beach Sand and Offshore Investigations

Survey (Reconnaissance: 402 sq km and detailed: 13.75 sq 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 1,799 boreholes with a cumulative depth of 8,279 m and 5,588 samples have been generated.

The following potential heavy mineral zones have been delineated:

Mandapam Block & Atrankarai, Ramanathapuram district, Tamil Nadu with up to 20% and 10% THM concentration respectively.

Kottadindulu – Vadlavaripalem, West Godavari district, Andhra Pradesh with up to 20% THM concentration

Pedavanka – Metturu, Srikakulam district, Andhra Pradesh with up to 41% THM concentration.

Around Perumallapuram area in parts of Kakinada deposit, East Godavari district, Andhra Pradesh with up to 26% THM concentration.

Frontal dune complex with HM concentration, Kakinada deposit,East Godavari district, Andhra Pradesh

Resources

The country's total heavy mineral resource was updated to 1,173 mt which includes 648mt ilmenite, 34mt rutile, 12mt 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.

Jaduguda mine has been brought back to operation after receiving final clearance in September 2018 for renewal of forest land diversion of Jaduguda mine.

Reopening of Jaduguda Mine

Environmental Clearance for Uranium Recovery Plant from copper tailing at Mosabani for the capacity of 0.9 million TPA processing has been obtained. Pre project activities for setting up of the uranium recovery plant from copper tailings, such as transfer of land and obtaining consents for electricity and water supply are in progress.

UCIL has entered into 'Agreement' with M/s MECON Ltd. wherein M/s MECON shall undertake all procurement & work contract services and project related work of UCIL. This will help in better resource management of the Company. Pre-project activities for

Rohil Project - Rajasthan

Rohil Uranium Project, Jajawal Uranium Project, Gogi Uranium Project and Kanchankayi Uranium Project have been initiated.

Agreement on taking up Exploratory mining activities by UCIL on behalf of Atomic Mineral Directorate for Exploration and Research (AMD) at Rohil in Rajasthan has been signed with AMD.

A breakthrough in uranium extraction at Tummalapalle in alkali leaching conditions has been achieved through in-house research. It was found that generation of excess sodium bicarbonate during alkali pressure leaching is retarding uranium precipitation. By adding a small quantity of sodium hydroxide, conversion of excess sodium bicarbonate in recycle liquor to required sodium carbonate has been achieved, thereby increasing overall extraction (about 4%) and substantially reducing the consumption of Sodium Carbonate. It has a considerable effect on reduction in cost of extraction leading to saving of Rs. 30 Cr per year.

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.

The Indian Rare Earths Limited (IREL) received 'Excellent' MoU rating for its performance in the year 2017-18 after a gap of more than a decade.

Production of NGADU stood at 34.9 tons which is the highest production in last decade. Production of minerals increased by 6.7% (prov.) with respect to previous fiscal, which is also the highest production achieved since the last 7 years. Production of Mixed Rare Earth Chloride increased by about 55% compared to the previous fiscal.

1 kg of Hafnia with purity level of 99% was produced by IREL in laboratory scale. Samples have been sent to BARC for confirmation on the purity.

Hafnia with 99% purity produced by IREL

IREL has also produced yttria stabilized zirconia in laboratory scale, 1 kg of which was supplied to reactor Design & Development Group, BARC for use in PHWR application. The product was found suitable and IREL has been asked to supply additional quantities for further testing.

Environment Clearance for the much awaited Capacity Expansion Project of Mineral Separation Plant of OSCOM, Odisha received in January 2019. Request for Proposal (RFP) to appoint an Agency to implement the project on Engineering, Procurement, Construction (EPC) basis floated and site visit & pre-bid meeting completed.

Understanding between BARC and IREL (India) Limited for development and transfer of technology in the value chain of Rare Earths, to be demonstrated in the Rare Earth and Titanium Theme Park in Bhopal, Madhya Pradesh was inked in January 2019 in the presence of Chairman, AEC and Secretary, DAE. Activity of lease deed execution for taking over the land is in progress and will be completed by the 1st quarter of current fiscal. RFP has been floated for appointing an Architect to design the buildings.

Operations of Manavalakurichi (MK) Unit of the Company located in Tamil Nadu, which were in a standstill from January 2017 due to inadequacies in the CRZ Notification 2011, resumed from April 2018 after receiving Environment & CRZ clearance from MoEFCC.

Directorate General of Foreign Trade (DGFT) vide notification dated 21.08.2018 has designated IREL as State Trading Enterprise (STE) for canalization of export of beach sand minerals.

At BARC, an efficient process for recovery of hafnium from scrub raffinate of Zirconium Oxide Plant (ZOP) was demonstrated on pilot-scale using in-house synthesized Alkyl Phosphine Oxide (APO) solvent having higher separation factor and loading capacity compared to conventional TBP solvent. About 3.5 kg of hafnium oxide of purity more than 99% was produced.

99% pure hafnium oxide (HfO_2) produced in BARC

Bench-scale investigations are carried out on split-core bore hole ore samples from Kanchankayi, an extension of Gogi U ore deposit of Karnataka. The studies on split-core bore hole uranium ore from the Kanchankayi deposit indicated scope of about 88% overall recovery and the U_3O_8 assay of sodium diuranate product was about 76.5%.

The SBD (Singridungri-Banadungri (Singhbhum) contains about 6% of magnetite, which if recovered effectively economizes cost of uranium production. Micronized magnetite is used as suspension media during heavy media treatment of coal for removal of ash. The petro-mineralogical studies on SBD also indicated fully liberated magnetite at sizes finer than 74μm. Magnetite separation studies conducted on the neutralized leach residue of SBD ore using drum type Wet Low-Intensity Magnetic Separator (WLIMS) could successfully recover about 83% of magnetite in the magnetic fraction, under optimized processing conditions with magnetics assay of 72.3%.

Detailed process mineralogical studies have been carried out on rare earths and rare metal bearing split-core bore hole samples from Amba Dongar (AMB – 17; AMD Sample ID 131730320) in Gujarat state. Due to the very-fine grained nature of occurrence of REE phases, different fine gravity separation techniques and froth flotation with specific collector reagent are being examined for their beneficiability.

An "ore to yellow cake" large-scale processing facility (300 kg/batch) for demonstration of process flowsheet for U ores by sulfuric acid leaching was set-up at Jaduguda with AERB approval. A Hastelloy C 2000 make 850 liter capacity autoclave, capable of operating in both reducing and oxidizing conditions is commissioned.

Solvent extraction process flow-sheets have been developed and demonstrated to produce high purity (>99%) Y_2O_3, Dy_2O_3 and Tb_4O_7 from heavy rare earth concentrate of monazite mineral. The technical know-how and inventory of various chemicals including feed for production of 500 kg/year each of these rare earth oxides have been shared with Indian Rare Earths Limited for up-coming Rare Earths & Titanium Theme Park at Bhopal.

Under the MoU between BARC & NPCIL, first lot of 150 kg of nuclear pure gadolinium nitrate hexa-hydrate has been prepared and is ready for shipment. Balance 100kg will be delivered by February 2019. This material will be used as burnable poison for reactivity control & reactor shut down system for PHWR (KAPP-3).

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 1107 MT of PHWR fuel bundles from UO2 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 and supplied initial charge for KAPS-3 reactor.

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

Installation of Deflector Plate in Pan Filter Discharge Chute

The Ammonium Di-Uranate (ADU) slurry is filtered using a rotary horizontal vacuum pan filter. The filtered ADU cake being wet and sticky by nature gets accumulated in the pan filter discharge chute leading to unequal distribution and inconsistent feeding to subsequent equipment i.e. Turbo Dryer. To overcome this problem, a deflector plate has been fabricated in-house and installed in the discharge chute of the Pan Filter which has resulted in equal distribution of wet ADU Cake to the Turbo Dryer Feeder leading to improved quality.

Installation and commissioning of 2TR chiller in Stabilization Unit

Cooling water is normally used for removal of the exothermic heat generated during the stabilization process and helps in controlling the O/U ratio in the chemically reactive UO_2 powder. For efficient removal of exothermic heat generated due to the controlled oxidation during UO_2 powder stabilisation, a 2TR Chiller unit was installed and commissioned in the stabilization unit to replace the cooling water (40°C) with chilled water (11-12°C) . This has increased the LMTD of the system thereby resulting in more effective heat removal for a precise control on the O/U ratio of the final powder.

Installation and commissioning of 2TR chiller in Stabilization Unit

Modification of Turbo Scrubber spray system to reduce Air Activity

The exhaust gases from the Turbo Dryer passes through a Bag Filter and Scrubber System before being let out through the stack. In order to further reduce air activity in the discharge gas an additional water spray system is installed in the discharge line fan for trapping the fine radioactive particles if any which helps in controlling the air activity limits in the Turbo Exhaust. After this modification, a downward trend has been observed in the average air activity in the Turbo Exhaust.

Installation of NOx monitor

A new NOx monitoring system was installed in the dissolution area of UOP. This has helped in detecting any increased NOx level in the area, thereby improving the safety in the plant. As the dissolution section and the precipitation section are adjacent, the sensor of the NOx scrubber has been chosen to compensate the drift in measurement due to vapour ammonia thereby giving a more accurate reading.

Nox Monitor with Solid State Hooter System

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.

Developmental works

Qualification of Rotary compaction presses

Two advanced high capacity rotary presses were successfully installed and commissioned for fabrication of PHWR fuel pellets for the first time in India. The salient features of the press are Automated Boat Charging System; Precise dimension (L/D ratio) control of green pellets; Graphical User Interface with data archiving and trend analysis; Advanced safety interlocks for fail-safe operation and Online Density Measurement & Control. For the new presses, the works that were accomplished in house includes Development of Granulated Powder Transfer System; Highly durable PU belt conveyor design in place of metallic belt conveyor and Development of 3-D models for critical spares like take-off wheels, ejection cam base-plate, guides & scrapper blade as import substitute.

Industrial Granule

Rotary press transfer system

Installation & Commissioning of New High Capacity Ammonia Cracker Units

Existing low capacity ammonia cracker units of 35 Nm3/hr were replaced with advanced high capacity ammonia cracker units of 80 Nm3/hr to meet the cracked gas requirement of sintering furnaces. The units were specifically designed to suit the existing site conditions & layout. Installation & commissioning of both the cracker units were carried out within a span of 2 months without affecting the production schedules.

Ceramic Fuel Fabrication Plant –Assembly (CFFP – A)

Setting up of a new 37 element fuel bundle fabrication facility at CFFP-A

Many major works were carried out for setting up of 37-element fuel fabrication in the existing Block-A fuel plants without affecting the regular production of 19-element PHWR fuel. Following challenging activities were completed successfully.

Conversion & qualification of various resistance welding machines

Critical welding equipments like appendage welding machines and end plug welding machines were converted and qualified with new toolings and optimized parameters for production of 37-ele PHWR fuel. Total 7 nos. of end cap welding machines, 4 nos. of appendage welding machines, 2 nos. of Double Head turning machines and 2 nos. of end plate welding stations were re-qualified after conversion within a short span to enable full scale manufacturing of 37-element fuel bundles at Block-A.

Converted end cap welding machine

Converted appendage welding machine

New Robot and end plate welding machine

Interlink conveyor

Erection, commissioning and qualification of a new robotic end plate welding machine with integrated bundle conveyor system

An end plate welding station along with a new Robot was erected, commissioned and qualified for 37-element fuel bundle production. An interlink conveyor to transfer fuel bundle from end plate welding station to bundle inspection station was fabricated in-house and integrated to the system with various safety interlocks and in built-quality checks.

Establishment of appendage welding process with modified bearing pads

Extensive trials were conducted for checking impression settings and vacuum levels were suitably modified for welding of modified central and end

bearing pads on empty tubes and successfully qualified the process for mass production.

Establishment of pickling process parameters for modified bearing pads

Trials were conducted to establish pickling process parameters (pickling time and solution strength) for modified bearing pads and the same was optimised for regular production

Supply of initial core requirement of 700 MW PHWR

Successfully supplied 4980 (105.743 Mte) 37-ele bundles with modified bearing pad design to meet the initial charge of KAPS-3 700 MW PHWR.

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

Introduction of in-house designed NOx scrubbers for pellet dissolution tank

A dedicated arrangement of 2-stage packed column scrubber and condenser (shell and tube type) was in-house designed, fabricated, erected and commissioned for absorbing NOx fumes generated during dissolution of rejected pellets. This modification has greatly helped in increasing the batch size from 1.5 MT to 2.5 MT.

Introduction of high capacity vacuum conveying unit for charging raw material in batch dissolution tank

The old pneumatic conveying unit installed for raw material powder charging has been improvised by introduction of advance pneumatic conveying unit with additional features like multiple venturi ejector system, automatic filter cleaning system, selectable air purging technology etc. This has resulted in increased charging capacity from 500 kg/hr to 1100 kg/hr and hence significant reduction in the process time. This has also helped in reducing air-borne activity.

Modification in stripping unit for consistent Uranyl Nitrate Pure Solution (UNPS) quality

Stripping operation is carried out in a 10-stage air-agitated box type mixer settler unit. Organic entrainment in UNPS affects final ADU quality. Hence, the aqueous and organic port heights were increased, which increased the residence time for aqueous and organic separation by about 4 minutes. The improvement in phase separation led to better and consistent quality of UNPS.

Process modification in ADU precipitation process

UNPS generated after stripping operation was earlier precipitated using 10N Ammonium Hydroxide Solution. After meticulous lab scale trials and pilot scale optimization, NUOFP (O) turned to vapor ammonia precipitation. The switch-over has resulted in the advantages such as Reduction in precipitation time from 7.5 hours to 1.5 hours; Reduction in specific generation of liquid effluents and Elimination of Ammonium Hydroxide preparation process. Furthermore, for ensuring consistent ADU powder with desired size and morphology, various optimization trials were conducted by varying U concentration in UNPS, initial precipitation temperature and Free Acidity.

Introduction of modified baffle in Calcination & Reduction furnace

Heat transfer simulation studies were conducted for rotary furnaces being used for Calcination and Reduction operations at NFC. Subsequently, a systematically designed baffle with increased heat transfer area and lifting arrangement was fabricated and installed inside the furnaces. The modified baffle has increased the effective heat transfer area and has also lowered the furnace temperature profile by about 20°C. Additionally, it has increased the effectiveness of mixing, which has led to complete conversion of ADU to U_3O_8.

Introduction of chiller unit in reduction furnace discharge side

A chiller unit with feedback control was installed and commissioned in the reduction furnace discharge side for reducing powder ageing time and improving ease of powder handling.

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

Erection and commissioning of two High Temperature Sintering Furnaces

Two numbers of new high temperature (1700°C) sintering furnaces were made into regular production operation in a record shortest time of only five months. The erection and commissioning of such furnace consists of various multi-disciplinary activities such as shell alignments, hearth refractory brick lining, cold pushing of boats, heating elements installation, closing with graded insulation bricks, provision of leak-tight gases and cooling water pipe lines, electrical power connections, instruments panel, thermocouple provision, flow meters, RTD's etc. All the process and safety interlocks were checked during commissioning operation of the furnaces. Both the sintering furnaces are presently running in 'Auto' mode of operation.

Erection and commissioning of two High Temperature Sintering Furnaces

Commissioning of Gas Humidifier System in Sintering Furnaces

Commissioning of Gas Humidifier System in Sintering Furnaces

For the 1st time in NFC, a Humidifier unit is introduced in sintering furnace to supply moist hydrogen gas inside the furnace for easy removal of binder, thus less pick up of nitrogen in pellet, longer life of alumina refractory bricks and enhanced sintering of UO_2 pellet.

New 3D mixing machine modification to fit HDPE carboy and loading machine development in house

An In-house carboy loading machine is developed along with in-house designed mixing machine modification to suit HDPE container. Mixing machine designed and procured for loading SS containers is modified to load HDPE carboys for mixing UO_2 granules with powder lubricant. Mixing time is reduced to 4 minutes from 15 minutes earlier. The mechanized loading machine made in house to load HDPE carboys into mixing machine has greatly reduced operator's fatigue.

Natural Uranium Fuel Assembly Plant (NUFAP)

Fabrication of Documented Bundle with modified bearing pad

For the first time documented PHWR fuel bundles were made with "Modified Bearing Pad" and supplied to BARC for carrying out "out of pile test" before freezing the design of the bearing pads. After the study and design approval by NPCIL, NFC has put all the efforts in establishing the vendor for mass production of bearing pad through punching route and the same was introduced for making 37-element PHWR fuel bundles for 700 MW PHWR.

Equipment Development & Automation (ED&A)

Automatic Granule Transfer System – 2

An automatic system was needed to charge UO_2 granules from an SS container to a hopper mounted

Automatic Granule Transfer System-2

on the top of the rotary press. The rotary press produces green pellets out of the granules that are fed to it. The system is required to have capabilities to grip, tilt, raise, and swivel an SS container (with 100 kg of UO_2 granules) and transfer these granules into the hopper of the Rotary press. Design requires use of ball screw based drive shaft with an overhang and lifting the container up to a height of 3.5m. The system, fulfilling all the above functional objectives, has been manufactured in-house and commissioned by connecting to the Rotary press -2 at CFFP (P). A supporting structure was also designed, fabricated, and erected at site for providing lateral rigid support to the system. The support is given at an elevation of 4m. This system is currently working satisfactorily at CFFP (P).

Advanced Spacer Pad Welding Machine

For eliminating the manual loading &un-loading of empty tubes on to inflatable mandrel by the operator, the design of spacer welding machines has been thoroughly revised to bring it on par with tube feeding systems of the current version of ISBU (Integrated Spacer pad Bearing pad Unit).Introduction of this new design resulted in improvement in the product quality, and further improved the recovery & productivity of the spacer pad welding machines apart from greatly reducing the operator fatigue. Two units have been made and delivered during the previous year catering to

Advanced Spacer Pad Welding Machine

19-e configuration. Towards catering to 37-e configuration, suitable modifications in the design have been done. Three such units exclusively catering to 37-e configuration were designed, fabricated, assembled, demonstrated, delivered and commissioned successfully in the assembly plants of Fuel Group. These units since then have been deployed in production plants on a continuous basis with very good results.

Automatic Pickling System

Resistance welding is used to weld appendages onto empty Zircaloy fuel clad tubes. Resistance welding requires the components to be in cleaned condition devoid of any surface impurities. Hence, before welding the appendages on empty tubes, the components are pickled in acidic environment thus ensuring their surface cleanliness during welding. The pickling operation under acidic environment was being done manually. In order to minimize the risk of acid handling by operators' towards preparing the pickling bath and also to avoid the operators' exposure to acidic fumes while carrying out pickling operation, a mechanised system was designed and developed for pickling the spacer & Bearing pads.

Automatic Pickling System

The system carries out automatic component agitation inside acid bath and transfers the container with components from pickling tank to neutralisation tank. Instead of using conventional steels, most of the components of the mechanised system were made of Poly Propylene, PTFE and Teflon material owing to their acid resistant properties. After conducting sufficient number of operational trials, the system has been delivered to CFFP-A. After carrying out necessary changes in the component design based on operational feedback, the unit was commissioned successfully. Now, the operators' intervention is greatly reduced during pickling operation and gets necessitated only before and after pickling operation for loading and unloading the components respectively.

Fabrication of Fret Fixture component

The drawings were received from RED, BARC for fabrication of components required for assembly of fret fixture for testing of fretting corrosion of bearing pads. The drawings were finalised after detailed discussions with BARC. The components were fabricated, inspected, assembled and supplied to RED, BARC for conducting the fretting corrosion test.

Fabrication of components for flow induced vibration test facility

The drawings were received from RED, BARC for fabrication of components required for assembly of test facility for measurement of flow induced vibrations of PHWR fuel bundle. The drawings were reviewed and finalised after detailed discussions with BARC. The components were fabricated, inspected, assembled and supplied to RED, BARC for conducting flow induced vibration test.

Metallic Fuels

30.00 MT of nuclear grade uranium metal in the form of metal ingot (440-450Kgs/ batch) has been produced and supplied to AFD for fuel fabrication for research reactor during the year.

Uranium Metal Ingot Produced in UED

Sintered solgel UO_2 microspheres of different O/M ratios of 2.05, 2.15 and 2.20 were prepared and fully characterized. Around 100 g each of qualified sintered UO_2+x microspheres were given to AFD to irradiation studies.

New reaction vessel of boiler quality steel has been designed to accommodate the required quantity of charge material (UF_4 + Mg) and lining materials (MgF_2). The respective size of mould & graphite crucible have also been designed. After following the predetermined heating schedule, the Uranium Extraction Division (UED) has produced 2 large sized (850 kg /batch) nuclear grade Uranium metal ingots with a recovery of 98%.

The higher capacity ($50M^3$/hr) nitrogen generation plant was required to meet the present demand of various process equipment. Equipment has been procured after preparation of technical specification & following the various purchase procedure. The new Nitrogen generation plant has been installed at the site and commissioned and taken in regular operation. The Performance of the equipment is excellent.

UED has developed a process flow sheet for purification of SDU of Tummalapalle source. UED had already processed 5 Tons of SDU smoothly, and also produced 3 Tons of nuclear grade uranium metal first time in our country in the existing facility and supplied it to the fuel fabrication facility for fuel fabrication for Dhruva Research Reactor. UED has developed a chemical process to convert the metallic uranium chips in to Sodium Di Uranate (SDU) by commercial grade sodium hypochlorite solution without generation of hydrogen. This process will help for faster and safe conversion of uranium chips and metal to crude SDU for safe storage and further processing.

Extraction of uranium from aqueous stream by an organic solvent and subsequent direct precipitation of uranium from loaded organic by using ammonium hydroxide was demonstrated in microfluidic channels at 10 mL/min scale. The method combines stripping and precipitation steps in a single step and leads to process intensification. Reusability of the organic phase was checked. Smooth operation without chocking of microfluidic channel was observed despite of solid precipitation. The method is suitable for uranium recovery using a very compact setup for low throughput applications.

Thermal denitration of zirconium nitrate to zirconium oxide powder was demonstrated in a bench-scale fluidized bed reactor. ZrO_2 particles were used as initial bed material. The reactor was operated with zirconium nitrate solution (100 g/L) at a feed rate of 2 LPH. Continuous, smooth operation for 100 hours at 700^0C was completed without formation of agglomerates. The XRD analysis of the product confirmed product to be ZrO_2.

Structural Materials & Components

An indigenously developed hand-held real-time FPGA based eddy current thickness estimation system is developed and customized to inspect the thickness of Inconel-600 process vessels at Integrated Fuel Fabrication Facility (IF3), BARC. It has a specific advantage of reaching plant areas that are difficult to access due to its tiny and compact design. The system has a measurement resolution of 100 microns. The system can be calibrated to measure vessel thickness of other materials also, with an inbuilt library to load the calibration file of selected material.

The PLC-SCADA based automation system for manually operated three process labs at IF3 has been designed, installed and commissioned. The development includes design of a two layered system architecture handling around 300 I/O's, PLC configuration with field instrumentation, GUI involving 15 interfacing screens and implementation of MODBUS protocol. The top layer consists of workstation consoles with SCADA presenting the process plant layout in form of mimic diagram making it operator friendly. The second layer consists of ECIL PLCs with powerful processor, front end instrumentation that condition the output from the instruments. PLC program handles different interlocks to operate the process safely and reliably.

Zirconium activities

Zirconium Oxide Plant (ZOP)

An improved process for production of high purity HfO_2 powder from scrub raffinate intermediate stream is developed. This process facilitates operation of HfO_2 plant in-tandem with zirconium oxide plant, use of established and easily available TBP solvent for purification, generation of known and easily disposable liquid effluents requiring smaller size of process equipment. Implementation of control measures for reducing contamination of Aluminium in Zirconium oxide powder. Revamping of the old SCADA system with improved interface and process interlocks. Plant has reprocessed contaminated zirconium oxide material collected from exhaust pipe lines, aiming at recovery of valuable zirconium values of about 9MT.

Zirconium Sponge Plant (ZSP)

Successfully met the requirement of very high purity zirconium metal (oxygen $\leqslant$ 325ppm and all other elements $\leqslant$ 100ppm) for MSD, BARC in the form of discs and ingot. To meet the increased demand for processing of Zircaloy scrap, a bigger capacity Water Cooled Scrap Reactor for enhancing the Zircaloy scrap processing from 15 MT to 25 MT per month was designed and fabricated. Successful trials of low

pressure bleeds with higher frequency rate were carried out in Reduction operation resulting in 30% reduction in reaction time with improved yield. An additional Emergency forced air cooling provision is made for all the reduction units to handle any emergency requirement during the reduction process. Improvement in ventilation system of Incinerator furnace by effective sealing of the rotary tube & feeding head; effective capture of fumes through hood modification and improved settling of dust in dust collectors through baffles.

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 were carried out.

Development of New Process Route for Hot Working Operations of IN 617

Nickel based super alloys are potential materials for many critical applications due to specific properties of high strength and excellent corrosion resistance at very high temperatures. These alloys have very narrow hot working range. Super alloy IN 617 is proposed to be used in Advanced Ultra Supercritical (AUSC) boilers in thermal power plants. NFC is engaged in indigenous development and manufacturing of IN 617 seamless tubes in collaboration with MIDHANI & IGCAR. New process flow route has been successfully developed for hot working operations of this Super alloy at Extrusion & Piercing Plant (EPP). The new route consists of Hot Expansion, Solution Annealing & Hot Extrusion. Six billets of 212 mm diameter has been successfully expanded, solution annealed & extruded to 135mm X 20 mm blanks for further operations.

IN 617 Billets

IN 617 Extruded blanks

Extrusion of Ni based shape memory alloy

Ni-Ti-Fe shape memory alloy tubes and rods are being developed for strategic applications. Forged billets of size Ø 70 mm Outer Diameter have been successfully extruded to Ø 20 mm rods. 630T vertical extrusion press has been utilized for this specific product. Considering limited quantity of input material, extensive studies were carried out to finalize the parameters & specific lubricants. The extruded rods have been delivered to BARC for further processing.

Ni-Ti-Fe Shape Memory Alloy rods of Ø 20mm

Sintering of $SmCo_5$ powder compacts for Development of Permanent Magnets

$SmCo_5$ powder compacts are successfully sintered in Horizontal vacuum annealing furnace at EPP. The compacts needs to be sintered under high vacuum

Fixture containing $SmCo_5$ powder compacts rings for sintering

using specific temperature profile having two different temperature soaking levels. Two Step soaking durations have been attempted first time to get the desired results. The sintered product in ring form has been delivered to BARC for further analysis.

Extrusion of Aluminium alloys for defence application

Two different Al- alloys namely Al-4.75% Be and Al-4.75% Be- 4.75% Ag are under development by IIT-BHU for application in aero-space. Both alloys were melted into Ø 85mm billet and supplied to NFC. NFC carried out billet preparation by end cutting, skin machining and sizing before extrusions. Extrusion process development for the two Al-alloy grades

Machined Al-alloy billet of Ø 62 mm OD & 80 mm length

As extruded and coiled Al-alloy rods of Ø 10mm

included establishment of extrusion parameters such as extrusion temperature, strain rate, suitably designing the extrusion ratios. The extrusion was carried out on 630T vertical extrusion press using direct extrusion dies. Ø 60 mm has been extruded to Ø 10mm rods. Total 18.0mtrs of Al-Be alloy and 11.0mtrs of Al-Be-Ag alloy rods with excellent surface finish were produced and delivered to IIT, BHU, Varanasi in short span of 2 weeks.

Pilgering of smaller size (19.5 A/F x 0.4mm WT) Hexcan tubes from circular tubes for the first time

The pilger mills at NFC cannot be used for pilgering of hexcan of smaller size as the gears are designed for tube rotation of specific angles to produce perfect round tubes. The gear system of the pilger mill was suitably modified to achieve rotation angle of 60° ± 0.05°. Problems such as twisting and stalling of the tube were solved by proper link adjustment and optimized tool design. Hexcan tubes thus produced were found acceptable and the manufacturing process was established.

Erection of CNC Centerless bar Grinding Machine

Bar Operation Section has successfully completed erection of two CNC Centerless bar Grinding machines. Performance trials are under completion. The equipment will augment the production capacity.

Manufacture and Supply of 220 MWe Pressure Tubes for KAPS-I & II EMCCR (En-Masse Coolant Channel Replacement)

Zr-2.5% Nb pressure tubes are the most critical lifetime core components of a nuclear reactor and have

Pressure Tubes for KAPS-I & II EMCCR

to sustain extremely hostile working conditions of temperature, pressure, stress and neutron flux. Consequently their manufacturing is governed by very stringent specifications for Mechanical and Metallurgical properties, chemical composition, dimensions and NDT requirements. NFC has successfully developed and established the process for manufacture of 220 MWe Pressure Tubes by double radial forging - extrusion - single pilgering route and also supplied 2 charges of 220 MWe Pressure Tube EMCCR for KAPS-I & II.

Development of Zr-1%Nb tubes (60mm OD X 0.8mm WT)

STP has been involved in the development and manufacture of Zr-1% Nb tubes of 60mm OD X 0.8 mm WT for strategic applications for BARC. This involved several challenges from optimizing heat treatment to designing of pilgering pass schedule and finalizing the finishing procedure in order to meet all the stringent requirements of dimensions, microstructure and properties.

Design and development of fixture for autoclaving of Zr-1% Nb tubes

BARC has placed order on NFC for manufacture and supply of Zr-1%Nb tubes of size 20mm OD X 1.5mm WT in autoclaved condition. STP has designed and developed a fixture for autoclaving of Zr-1% Nb tubes.

Fixture for Autoclaving of Zr-1% Nb Tubes

Manufacture of fixture for Solution Annealing of Hexcans

There is a requirement of SS321 seamless hexagonal channel of 29.5mm (A/F) x 0.4mm (WT) for in-core component. The channels are to be supplied in solution annealed condition. Owing to thin wall tube heat-treatment of channel is a challenge. TRTP developed and manufactured a fixture to hold the channels in tension during the heat-treatment to prevent any distortion during heat treatment of hexcans. Hydrostatic Pressure Testing of Hexcan was developed and successful trial was carried out.

Manufacture of fuel compaction Punches for Rotary Press

Rotary presses are installed in NFC for compaction of fuel pellets. The punches required for these presses are characterized by very close geometrical and dimensional tolerances and very high surface finish. Further, due to very small holding length, the manufacturing of these tooling with stringent tolerances was a challenge. Tool-Room has developed and manufactured the punches to meet the requirement of natural UO2 pellet compaction.

Augmentation and modernization of Tool Room facility with Twin RAM CNC VTL

A CNC Vertical Turret Lathe (VTL) is successfully erected and commissioned at Tool Room for

A CNC Vertical Turret Lathe

manufacturing of Horizontal Extrusion Press (HEP) and Vertical Piercing Press (VPP) containers weighing up to 11 Tonne. The new VTL has advanced facilities like two rams, grinding attachment for catering the requirement of deep bore machining & grinding up to 143.5 mm diameter and 1000 mm long meeting stringent tolerances.

Other major activities that were taken place include production of 20.27 lakhs PHWR fuel tubes out of which, a record no. of 8.45 lakhs of 37 element fuel tubes are produced in a year; In-house automation of tube loading and unloading system in cut tube polishing machine. This has improved safety by reducing manual intervention and ensured consistent quality; Supply of Superni tubes of Φ6.3mm x 0.25mm thick, Φ6.9mm x 0.3mm thick and Φ13.5mm x 1.2mm thick; Production of Zr1%Nb tubes of Φ15.2 x 0.9mm thick; Production of Zr1%Nb guide tubes having flaring at one end and machining at other end; Manufacture of 12 nos. of Cobalt absorber assemblies for 220MWe PHWR; Manufacture of 4 Nos. of OFT assemblies for 220 MWe PHWR; Manufacture of 6 nos. of PIUs assemblies, 26 nos. of VFUs and 4 nos. of LZCs for 700MWe PHWRs RAPP-8, RAPP-7 and KAPP-4 reactors respectively; Manufacturing of 61 Nos. of assemblies consisting of 6 varieties of assemblies for CCTF project (BARC); Development of roll joint tool and successful demonstration of procedure for manufacturing of Zr-4 to SS roll joint for HFU & VFU Carrier Tube Assemblies; CNC Machining of Zircaloy and Niobium "Retraction Head" components using CAM software for EB melting furnace and Installation and commissioning of CNC Lathe with bar feeder system for precision manufacturing of RM components.

Special Materials

The plant produced highest ever production of 4230 kg of niobium metal granules during a year. Implementation of online density measurement in solvent extraction. Modifications in Solvent extraction process for reduction of Tungsten in niobium oxide. Preparation of 30 kg micron size Zr metal powder to meet critical requirement of Defence organizations and other agencies. EB evaporation coating on Inconel trays to improve corrosion resistance & purity of Niobium oxide during calcination of Niobium hydroxide. Supplied various high purity materials such as POCl3, Selenium, Tellurium, Ti powder, Titanium hydride, Zirconium hydride, Nb metal powder etc. to BARC, various industries and educational institutions as per their demand.

A collaborative programme was taken up by NFC & BARC for indigenous development and installation of 300kW electron beam melting furnace. This equipment was developed and installed for the first time in the country. India is the 4th nation in the world to develop high power EB gun technology. The facility has been inaugurated by Hon'ble President of India on 15th May 2018. Melting trials have been carried out for alloys such as Zr-2, Zr-4, Zr2.5Nb and Niobium metal.

Commercial activities

Stainless Steel Tube Plant (SSTP)

SSTP has successfully manufactured various critical products i.e. High corrosion resistance SS-304L pipes for Fast Reactor Fuel Cycle Facility (FRFCF), SS-D9 Fuel Clad tubes for Prototype Fast Breeder Reactor (PFBR), SS321,Titan-24 tubes for strategic defence Nuclear application & Nimonic-75 tubes for BARC, MDN-250 / 350 Maraging Steel tubes for Defence / strategic applications etc.

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 viz., RAPP 7&8 and Kakrapara 3&4.

Major Events/Milestones were as follows:

In-house preparation of Revised Detailed Project Report (DPR) by Project Team. Approval of revised DPR from Board, Vision sub-committee (VS1) and Project Appraisal Committee (PAC) is obtained. A meeting with Expenditure secretary was held for sanction of Man-power for NFC-Kota. Purchase orders

Inauguration of Fire Water Reservoir

Administrative Building

placed for Forge press, Extrusion press, Vertical Vacuum Annealing Furnace, CNC 4 Axis milling machine, VAR furnace, Hydraulic press 2000T, Hydraulic Cylindrical grinder, CNC centerless bar grinder, Horizontal Vacuum Annealing furnace etc. Site grading & Site infrastructure works has been completed. Construction power has been completed. Providing water supply to NFC Kota site from Heavy Water Plant Kota to Raw Water Reservoir has been completed.

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). Highest ever annual production of 287.6MT of Zirconium sponge and 573.4MT of Zirconium oxide powder was achieved.

First cycle of In-Service Inspection (ISI) of equipment as per the manual is completed. 12 No. of reduction retorts have been subjected to radiography as part of ISI and cleared for further use. Around 16,000 samples of raw material, chemicals, process and product samples have been analyzed. Plant has crossed 1002 days of operation without any reportable injury accident as on 31st March 2019. Zirconium Complex was certified for Quality Management System IS/ISO 9001:2015 by the certification body M/s Bureau of Indian Standards during June 2018.

Conversion of SS liner sheet shearing machine into zircaloy tube cutting and pressing machine

A SS liner shearing machine was modified to cut and press the rejected zircaloy fuel tubes for feeding the Water cooled Scrap Reactor. This conversion not only eliminated the procurement of costly nibbling machine, but also helped in transportation of the rejected fuel tubes from NFC, Hyderabad to Zirconium Complex in bulk lots and thereby increasing the zirconium sponge production.

Installation of Screw conveyor feeder for Hammer mill

Two hammer mills are in operation for grinding zirconium oxide in Oxide Production Facility. The hammers of these mills often got broken during operation. It was studied and found that the root cause of the failure was due to bulk entry of the feed material during manual feeding. A screw conveyor was introduced to regulate the feed flow in April 2018 and since then no failure has occurred.

Installation of hydraulic cutting presses and compaction press

A new 700T hydraulic cutting press has been installed to cut the 1.5 T batch zirconium sponge cakes.

700 T Hydraulic Cutting Press

250 T Hydraulic Cutting Press

A 250 T hydraulic cutting press was installed in addition to the existing cutting presses to process more number of batches. A 250 T chloride compaction press has also been installed & commissioned to compact zirconium tetrachloride for achieving higher bulk density and thereby enhancing zirconium sponge production.

Desalination Plant at Zirconium Complex

Desalination Plant with two streams each of capacity 30 cu.m per hour of product water is being set up at Zirconium Complex Sea water intake system is in regular operation. Both the RO streams have been commissioned and are under operation.

Desalination Plant at Zirconium Complex

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 equipments is in various stages of the process.

MRTDDF - Office Building

MRTDDF - Cell Building

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. Nine batches have been processed successfully.

Atomic Energy Central School at Pazhayakayal

AEC School has been functioning since April 2017 in the temporary infrastructure made at the stilt

AECS Building Foundation

floor of one of the blocks in township and two academic year sessions have been completed. Foundation stone for the new AEC school building was laid on 29th Sept 2018 and construction has commenced from October 2018.

BACK END FUEL CYCLE

Fuel Reprocessing

Forty samples of dissolver solution of irradiated fuel were analysed for Pu concentration by ID-TIMS for the input accountability of Pu in reprocessing plant. Concentrations of Pu were determined after chemical separation of fission products and bulk of uranium. In addition, one hundred and thirty three samples of reprocessed depleted Uranium were analysed for isotopic composition by TIMS.

CFD-PB (Computational Fluid Dynamics-Population Balance) model to estimate drop size distribution and dispersed phase holdup in Pulsed Disc and Doughnut Column (PDDC) was developed and validated with in-house experimental data. A CFD model to estimate Sherwood number for liquid-liquid mass transfer from a single drop was developed and validated with reported experimental data. The validated model was used to quantify the effect of the shape of drop on Sherwood number. The results from such CFD models will be used to replace empirical correlations in the CFD and mass transfer models of solvent extraction contactors such as air pulsed columns. A software with Graphical User Interface (GUI) was developed to simulate mass transfer in Annular Pulsed Disc and Doughnut Columns (APDDC). The software is based on axial dispersion model and reported correlations for estimating hydrodynamic variables such as drop size, dispersed phase holdup and axial dispersion coefficients. The software was validated with reported data of uranium extraction in an APDDC.

Rotary Screw Calciner was developed for continuous reconversion of heavy metal. A compact design was evolved, manufactured and tested with simulated feed for performance evaluation. The Rotary Screw Calciner will help in reducing the most intensive manual operations like long hours of filtration through vacuum assisted SS sintered frit, transfer of semi-dried cake to ignition boat and lengthy calcinations of the cake. The new system is being subjected to tests prior to introduction into the actual re-conversion setup for plant scale production.

In view of the advantages of a special glass composition with high Na_2O content, low B_2O_3 content, and ZnO, developed, industrial-scale demonstration of Cold Crucible Induction Skull Melter using high-temperature glass containing zinc oxide. The melter was operated at 1250°C and a maximum throughput of 30 LPH was achieved with a waste loading of 26%. Figure compares the skull thickness observed for two different glasses – with and without ZnO. The skull thickness observed in the case of glass with ZnO is significantly higher than that of glass without ZnO. This effect is because of the increase in glass viscosity due to ZnO addition. The enhanced skull thickness provides better protection to the stainless steel fingers of the cold crucible

The Induction Skull Melting (ISM) Facility was operated successfully and demonstrated consistent and reliable operations to produce different alloys which are of interest to DAE. During these trial operations, ISM technology was used for the production of boron-containing alloys. By virtue of strong electromagnetic stirring, boron gets uniformly distributed. ISM technology is also useful for producing alloys from their constituent metals having great differences in their densities and melting points. This was demonstrated by producing an alloy of Nickel, Chromium, Molybdenum, and Tungsten using the ISM Facility. Al-Si mother alloy was also successfully melted and homogenized in the ISM Facility to meet required levels of purity and homogeneity. The ISM Facility was under regular operation for the production of Aluminium-Silicon alloy in order to meet the requirements of NFG. Production of 400 kg of Aluminium-Silicon alloy was successfully completed and the consignments were shipped to NFG. BARC has also developed a Vacuum Induction Levitation Melter indigenously for producing high purity metallic samples for material characterization. Using this technology, small quantities of electrically conducting materials can be melted and levitated in a segmented, water-cooled copper crucible. This melter finds application in the preparation of experimental quantities of novel high purity materials and special purpose alloys.

After getting clearance from various safety committees, Waste Tank Farm of Power Reactor Thoria Reprocessing Facility (PRTRF) was commissioned.

High-Level radioactive Liquid Waste (HLLW) obtained from the recycling of spent fuel by PUREX process is a rich source of ^{90}Sr which is a pure β- emitter and decays to ^{90}Y, a very useful radionuclide in nuclear medicine for cancer therapy. The purity of clinical grade ^{90}Y (^{90}Sr <10-6Ci/Ci and gross α-activity <10-9Ci/Ci of ^{90}Y) is a most important requirement for such applications. In view of this, separation and purification of radio-strontium from HLLW was carried out in our laboratory using multi-step separation processes involving solvent extraction, extraction chromatography, radiochemical precipitation and membrane-based techniques to recover ^{90}Sr of ultra-pure quality for the generation of clinical grade ^{90}Y.

Alpha contaminated crucibles generated from metallurgical operations contain a significant quantity of Special Nuclear Materials (SNM). Attempts were made to recover SNM from such crucibles in FRD laboratory. Among the various methods, electrochemical method is found to be most suitable for SNM recovery from such crucibles. Based on extensive laboratory studies, a two-step recovery method was developed. Chemical leaching of SNM using 6M HNO_3 is the first step. This step removes SNM that is present in metallic form and a major amount of other soluble gamma emitting radionuclides resulting in significant dose reduction. Recovery of SNM by reductive dissolution is the second step using electrolysis. In this step crucible itself is used as a cathode and Pt-coated Ti as the anode (40A at 3.5V with a current density of 100mA/cm^2). Quantitative recovery of SNM is achieved in this step. The two-step process developed above was deployed to process three used crucibles received from metallurgical operations. More than 98% of SNM could be recovered from all the three crucibles. Recovered SNM in nitric acid solution was processed in MWPF, Trombay. Electrolytic cell and experimental set up inside the glove box are shown below. Separation and purification of radio-strontium were carried out using multi-step separation processes involving solvent extraction, extraction chromatography, radiochemical precipitation and membrane-based techniques to recover ^{90}Sr of ultra-pure quality for the generation of clinical grade ^{90}Y.

Recovered $^{90}Sr(NO_3)_2$ (specific activity 40Ci/L at pH 1-2) was used to generate carrier-free ^{90}Y- acetate using in-house developed two-stage Supported Liquid Membrane-based ^{90}Sr-^{90}Y generator system. Twelve lots of carrier-free ^{90}Y- acetate in the range of 130-140 mCi were separated and supplied to Radio Medicine Centre, BARC. Based on the quality control data with respect to ^{90}Sr, gross α and metallic impurities, the ^{90}Y-acetate product has got clearance from Radio-Pharmaceutical Committee.

Waste Management

Subsequent to the Hot commissioning of Alpha Demonstration Facility (ADF), Area-64, two drums of waste comprising of cellulose and rubber/plastics have been successfully treated. The Ag^{++} based electrochemical process has been successfully demonstrated for the treatment of cellulosic waste leading to the destruction of the cellulose and transfer of the alpha activity into the Ag^{++} solution. Recovery of alpha product from the silver solution has also been demonstrated. Ultrasound decontamination methods have been tested for alpha contaminated Plastic and rubber wastes and it has been found to be effective for fresh wastes. Process optimizations are being worked out for aged plastic and rubber wastes. The feedback of these trials is being used for the design of an alpha solid waste treatment facility being set up at Trombay.

An alpha solid waste treatment facility is being set up at BARC Trombay, based on the feedback of the alpha demonstration facility. In this regard, the architectural drawing/civil designs have been finalized based on process requirements and PSAR and other necessary documents for obtaining regulatory clearance for construction was prepared. The regulatory consenting procedures/reviews have been followed and the facility has received the regulatory consent for construction from the apex safety committee of BARC. Procurement action with regard to raw materials like SS 304 L plates, pipes etc have been initiated and NIT for civil works for this facility has been carried out.

The challenges of assaying very low amounts of alpha content in waste packages have been addressed by the use of specially identified detectors. In line with these developmental efforts, procurement action has been initiated for the NaI (Tl) detector and drum

handling system for demonstration of alpha waste drum assaying system.

Radioactive Waste management facilities (TL-7), BARCF, Vizag, is planned for the management of radioactive wastes generated from the operations of technological laboratories/facilities at BARCF, Vizag (Phase I). As a part of TL-07, BARC facility, Vizag, the Alpha Waste Transit Storage Facility is being set up for safe interim storage of alpha contaminated waste generated from the O&M activities of Technological Laboratories. The ASWTF-V facility has been designed in line with existing AWTSF at Trombay which is presently operational. PSAR and other necessary documents for regulatory clearance for construction were prepared and reviewed by the relevant safety committee. The facility has received regulatory consent from apex safety committee of BARC. Civil design of the facility has been finalized and the civil drawings have been issued to the site.

A process involving in-situ corrosion of mild steel under aerobic conditions has been developed for separation of low concentration of uranium (at ppb level) from aqueous solutions. The in situ generated corrosion product has been proven efficient at rapid U uptake from neutral aqueous solution. This developed process has been tested on engineering scale (100 lt batch), where it was found effective to remove uranium from 1000 ppb to about 30 ppb. The feasibility for U removal from tailing solution of Tummalapalle mines has been assessed. It is found that the process can be used after suitable pH adjustment of the tailing solution.

Preparation of ^{106}Ru bearing plaque source envisages isolation of ^{106}Ru from high-level waste, electrodeposition of the radioelement on silver foil and fabrication of the plaque. All steps have been developed and standardized. It has been confirmed that the separated ^{106}Ru is radio-chemically pure. The separated Ru was electrodeposited on silver foil. Two active foils containing ~70 μCi of ^{106}Ru has been prepared. On the other hand, plaque design in inactive scale has been completed. Four numbers of inactive plaque have been fabricated and being subjected to trial tests. In the next step, an actual plaque containing about 300 μCi of ^{106}Ru will be made.

Powder and composite of Crystalline Silico-Titanates Sorbents

Crystalline silico-titanate, an inorganic sorbent, is well known for its very high selectivity for both ^{137}Cs and ^{90}Sr, which are the two major radionuclides present in the low-level waste. The sorbent has been synthesized on a 5g scale by hydrothermal route and a composite of granular form has been prepared. Both the sorbent and composite have been characterized and found to have very high uptake for both Cs and Sr from Low Level Liquid Waste (LLW) streams. The utility of the composite has been demonstrated by conducting a fixed bed column run during which complete removal of Cs from 5000-bed volumes has been achieved.

Vitrification of high level nuclear waste in borosilicate glass matrix is the preferred process of waste disposal. Nickel-base superalloy Alloy 690 is the commonly used structural material for making vitrification equipment, such as melter pots, thermocouples, thermowells, electrodes, etc. Recent studies have shown that Alloy 693 exhibits better corrosion resistance than that of Alloy 690 in borosilicate glass melts. Detailed examination of the behaviour of Alloy 693 at elevated temperatures has been carried out and concluded that the alloy can be tailored to possess better mechanical properties than those of Alloy 690 in the vicinity of the vitrification temperature. Better mechanical properties, coupled with high corrosion resistance, makes Alloy 693 a superior structural material for the vitrification nuclear waste.

Two birnessite type phyllomanganates with Na^+ and K^+ ions have been prepared by oxidative reaction of freshly prepared $Mn(OH)_2$ and characterized for their compositions, structure, morphology. The efficient uptake behavior for Sr^{2+} ions have been observed by both Na and K-birnessite samples in the pH range 2 to 14. The clinical grade separation of ^{90}Y from ^{90}Sr-^{90}Y mixture solutions could be obtained using Na-Birnessite sample.

In order to develop glass for high gadolinium containing waste, solubility of Gd_2O_3 in barium borosilicate (BBS) glass matrix has been investigated in collaboration with Waste Management Division (WMD), BARC. Several glass compositions with different Gd_2O_3 contents were prepared and characterized by XRD, SEM, Thermal analysis techniques and photoluminescence studies. From XRD and photoluminescence studies, the solubility limit of Gd_2O_3 is found to be around 7.0 mol%. DTA studies revealed increasing trend of glass transition temperature with increasing Gd_2O_3content.

30,000 lit of High-level Rad-Waste was processed with the recovery of valuables. Sr-An bearing HLW Vitrified producing six nos. of vitrified product canisters. Production of Cesium-glass pencils of high specific activity (4.5 to 5 Ci/gm) was continued and it is being delivered to BRIT for societal applications. The Cs-specific solution was vitrified separately and resulting Cs-rich glass was used for the production of pencils of desired strength. More than 80 nos. of cesium-pencils produced safely.

Plasma pyrolysis based demonstration setup has been installed as a first of its kind facility in India for management of potentially radioactive all combustible Plant protective wears. About 350 kg of simulated waste was processed using both graphite and Cu-Hf based torches. The system was hot commissioned with actual radioactive waste using BARC developed Cu-Hf torch. Total 501 kg actual waste (a mixture of cellulose + rubber+ plastic) was processed safely achieving volume reduction factor of more than 30. Environmental discharges were monitored and were well within the prescribed limits.

Resin fixation system was operated for management of spent resins generated from 'SFSB pool water purification system' of Dhruva reactor. Three such hoppers were safely fluidized and cemented before its disposal in the Reinforced Concrete Trenches.

Towards effluents' management, receipt and collection (by pipeline, tanker, cask and carboy modes), treatment and discharge of Low-Level Radioactive Liquid Waste generated by various plants and laboratories in Trombay was continued safely to ensure uninterrupted operation of various laboratories and plants in Trombay. a hybrid plant comprising of ultra-filtration, reverse osmosis and ion exchange has been installed and cold-commissioned with an objective to reduce the discharges to As Low As Reasonably Achievable (ALARA). With encouraging results, the large-scale facility is planned for effective management of radioactive effluents. For solid radioactive waste collection and disposal from BARC and Mumbai facilities of DAE, volume reduction practices were employed like compaction, incineration etc. for amenable waste forms. Effective volume disposed of after due monitoring was 450 m^3; meeting authorized regulatory guideline by competent authorities.

Safety Performance of Reactors

NPCIL is responsible for deterministic and Probabilistic Safety Assessment (PSA) of nuclear power plants for siting, design, commissioning of new projects, safe operation, periodic safety review and extension of operating license/life management of operating plants, and also for obtaining regulatory clearance for the projects and operating stations. Deterministic Safety Analysis for KAPP-3&4 was revised as per final design and the revised preliminary safety analysis report was submitted to the regulatory body. Analysis was carried out in respect of different postulated accident scenarios including thermal hydraulic response, containment response and consequential radiological dose assessment for inclusion in the revised Technical Basis Document of Accident Management Guidelines of Indian PHWRs. Assessment of containment response and hydrogen distribution in containment following Loss of Coolant Accident (LOCA) initiated severe accident progressing to Ex-vessel scenario for standard 220MW PHWRs, revision of KAPP-3&4 PSA Level-1, comprehensive Level-1 PSA for “Shutdown & Low Power” state including human reliabilities for RAPS - 5&6, KGS-1&2, KGS-3&4 and TAPS-3&4, comprehensive Fire Hazard Analysis (FHA) of KAPP-3&4, Computational Fluid Dynamics (CFD) analyses for predicting flow and temperature distribution of moderator inside 700 MW Calandria under normal operating condition as well as under postulated accident condition (LOCA with ECCS failure), Radiological Impact Assessment (RIA) incorporating

the recommendations of Task Force on Radiological Impact Assessment (TF-RIA) for KAPP-3&4, GHAVP-1&2, Kaiga-5&6, MBRAPP-1&2& CMPAPP-1&2 demonstrating safety and robustness of plant design features, assessment & optimization of number of Environmental Radiation Monitors (ERMs) for Decision Support System (DSS) at Tarapur Maharashtra Site based on radiological impact analysis etc. were completed.

HEALTH, SAFETY AND ENVIRONMENT

Passive Catalytic Recombiner Devices (PCRD) housing along with Catalyst Bearing Panels (CBP) is used for PHWR projects. It was developed by BARC & NPCIL and fabricated by ECIL. Since the PCRD comes under seismic category-1, the structural integrity of the PCRD housing along with CBP has to be confirmed under design basis earthquake conditions. Now the device has undergone Seismic qualification for its installation at different Power Reactors of NPCIL and has been qualified based on shake table test and cleared for installation.

Vehicle Mountable Detection System (VeModS) is a complete transportable system for quickly determining whether raw or processed food has become contaminated with gamma emitting radionuclides during emergency scenarios at nuclear facilities, environmental surveying or in response to radiological event. During emergencies, radioactivity released into the environment can build up in food, as radionuclides get transferred through soil to crops or to animals. Uptake of radionuclides by fish and other seafood could also occur due to contaminated rivers, lakes and sea. Samples such as milk, meat, fish, grain, fruit, and vegetables, as well as air swipes, soil samples, and other materials can be placed inside the shielded counting chamber of VeMoDS and analysed. The computed activity can then be compared with the recommended Guideline Levels for further appropriate actions. This system is extremely useful for detection of gamma emitting radionuclides like ^{60}Co, ^{131}I, ^{134}Cs and ^{137}Cs at the site of incident or in-field assessment of radioactivity in environmental and biological samples.

A plastic scintillator based 4πβ-γ coincidence system is developed as an absolute standard for radioactivity measurements. 4πβ-γ coincidence technique is a powerful tool and widely recognised method to determine the absolute activity concentration of radioactive solutions. The system consists of Plastic Scintillator equivalent to NE 102 A, as a beta detector and NaI (Tl) for gamma detection.

One of the priorities in case of nuclear/radiological emergencies is to quickly identify internal contamination and also quantify internal dose (CED) receivable by the exposed individuals. Assessment of internal contamination requires knowledge of activity retained in different organs/whole body, daily urinary/faecal excretion and internal dose coefficients. Present study was taken up for generation of age-specific (new born, 1y, 5y, 10y, 15y and adult) parameters and dose coefficients for selected radionuclides useful for assessment of intake and internal dose during any emergency for members of the public. The excretion rates and retention fractions for these age groups following inhalation and ingestion intake of ^{60}Co (type M & S), ^{137}Cs, ^{90}Sr, ^{131}I, ^{238}Pu, ^{239}Pu, ^{241}Am, ^{252}Cf, ^{226}Ra, ^{210}Po and ^{192}Ir were computed by solving age dependent biokinetic models published by ICRP. The Specific Effective Energies (SEE) for these age groups along with transformations values were used to compute the internal dose coefficients (e50 Sv Bq^{-1}). The parameters are used as ready reckoner for the estimation of intake and CED for members of the public during any nuclear / radiological emergency for timely inputs for medical intervention, if necessary.

In vivo monitoring of radiation workers for high energy photon emitters is carried out using suitable whole-body counters which are calibrated using standard radioactive sources uniformly distributed in Bottle Mannequin Absorber (BOMAB) phantom. In case of inhalation intake of Type S compounds (oxides) radioactivity is retained in lungs for a long time, as a result its distribution in the body is non-uniform. Therefore, study was carried out to evaluate difference in activity estimate due to uniform distribution of radioactivity in whole-body and only in the lungs. HPGe detector based shadow shield bed whole-body counter was calibrated with known amount of ^{152}Eu uniformly distributed in the lungs of Lawrence Livermore National

Laboratory (LLNL) phantom. The multiple gamma energies of ^{152}Eu (121 keV to 1408 keV) were used to determine calibration curve for the activity deposited in the lungs. e.g. the calibration factor for insoluble ^{60}Co distributed in the lungs of worker is about $1.77x10^{-4}$ cps Bq^{-1} as against $1.45x10^{-4}$ cps Bq^{-1} used for uniform distribution of ^{60}Co throughout the body. Thus, the assumption of uniform distribution of Type S ^{60}Co compounds would overestimate the inhalation intake by ~20 %. The result of this work will be useful for better estimate of activity in case of inhalation of insoluble radionuclides.

The construction of Integrated Centre for Crisis Management (ICCM) in BARC was constructed to consolidate crisis management activities in BARC Trombay in an area of 500 sq. mtr. The ICCM facility was inaugurated by Honourable President of India on 15.05.2018. ICCM was established at Trombay for Prevention, Preparedness and Response to Chemical, Biological, Radiological & Nuclear (CBRN) and Security Threats/Emergencies. Online information on Meteorological & Radiological data of the site, Indian Environmental Radiation Monitoring Network (IERMON) data from more than 500 Countrywide Locations, output of Radiological Impact Prediction, Live Camera feed of all important locations in BARC is made available to ICCM. The centre is having a Personnel Decontamination Centre (PDC), Mobile Radiological Laboratory (MRL) and Emergency Ventilation System for 72 hours continuous operation.

Integrated Centre for Crisis Management (ICCM) in BARC

A stand-alone prototype light weight miniaturized, portable, wearable and in-built battery powered Personal Air Sampler (PAS) (10.5 X 7 X 14 cm.) has been indigenously developed. The sampler attached to a filter holder via a built-in air pump can be used for air sampling in the breathing zone of work place and continuously operated for 2 hours. This sampler will help in getting the representative air sample from the breathing zone of the worker. It will also provide an assessment of intake wherever applicable.

Occupational radiation protection and environmental safety surveillance in and around the front end nuclear fuel cycle was provided to all operating units of Uranium Corporation of India Ltd (Jharkhand & Andhra Pradesh), Indian Rare Earths Ltd. (Kerala, Tamil Nadu, Odisha) and Nuclear Fuel Complex (Hyderabad). A total of 8260 occupational workers were monitored for external and internal radiation exposure in the front end nuclear fuel cycle operations. In-plant radiological survey and radiation dose evaluations were carried out for all the units to ensure compliance with regulatory norms. The occupational radiation doses to workers in underground uranium mines and Thorium handling facilities were well within the regulatory limit of 20 mSv/year.

A comprehensive study of natural radionuclides, trace elements, anions and water quality parameters in Subarnarekha River and groundwater around adjoining areas was carried out to assess the possible impact of uranium mining activities, if any. Water samples were collected from the Subernarekha River, Garanalla, Jurianalla, Seemanalla, Karkai River, Sankanalla and Bagjurianalla. A stretch of about 400 km over the Subarnarekha River, from the origin, Piskanagari near Ranchi to estuary, Chandbali, Odisha, was covered for sampling. Water quality parameters such as pH, TDS, EC, ORP, Salinity, Temp., DO, alkalinity and hardness were measured in-situ. The uranium concentration was compared in upstream, mining area and downstream of the river. From the study, it was observed that the radiological parameters in upstream and downstream with respect to uranium mining activities are well within natural background variation.

National Uranium Project (NUP) was executed in collaborative project mode in phased manner (phase

1 to 4) and compilation of national database. Till 2018, 82 projects were sanctioned by BRNS, DAE, covering 403 districts out in 718 districts of India. As per the data reported till date, the total number of samples collected and analysed for uranium and associated water quality parameters are 24182 nos. The uranium concentration in drinking water in the samples collected from 17 states is found to vary from ≤ 0.2 – 4918 ppb. From the data, it was observed that 99.4% of samples were below the AERB prescribed limit of 60 ppb for drinking water on the basis of radiological toxicity and 96.1% of samples were lower than the WHO guideline value of 30 ppb.

BARC has carried out radiological survey around nine NTPC Thermal Power Plants in India based upon their request. The survey was carried out around three under construction thermal power plants (Kudgi in Karnataka, Solapur in Maharashtra and Gadarwara in M.P.) and six operating thermal power plants (Sipat, Chhattisgarh; Simhadri, Andhra Pradesh; Barh, Bihar; Singrauli, Uttar Pradesh; Bongaigaon, Assam, and Mouda in Maharashtra). The comprehensive survey includes gamma radiation, radon & thoron measurements, natural radionuclide levels (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb & ^{40}K) in coal, fly ash, bottom ash, soil, ground and surface water, locally grown vegetables, drinking water in and around the Thermal power plants as per the BARC standard procedure and protocol. From the present study, it was concluded that the radiological levels around the NTPC, sites is comparable with the national average values. The NORM levels in groundwater / surface water / drinking water samples was observed well below the AERB and World Health Organization (WHO) prescribed limit / guideline values.
On the request of Central Pollution Control Board (CPCB), Health Physics Division has carried out a comprehensive radiological characterization of water and sediment samples of Ganga River, stretching from Gangotri to Varanasi. Water and sediment samples collected from different locations were analysed for Gross alpha, Gross beta, Natural Uranium, ^{226}Ra, ^{210}Po and ^{40}K. Levels of naturally occurring radionuclides activity concentration in the water and sediment samples were reported to CPCB.Naturally occurring radionuclides activity concentration in the water and sediment samples collected from river Ganga were comparable to the national reported values.

UV-Visible spectroscopic technique has been applied for the dosimetric study using LR-115 SSNTD. The detectors were exposed to various high doses of alpha particles. The transmission spectrum under UV Visible spectrophotometer gave rise to a characteristic peak at the wavelength of about 380 nm and the variation in transmission at this wavelength was analyzed against the varying alpha exposure. The variation was observed to be linear with respect to the track density and these linear relations could be used for estimating track density for unknown exposure.

Monitoring of plutonium in ambient working atmosphere is mandatory as a regulatory requirement due to its high radiotoxicity. An indigenous plutonium-in-air monitor has been designed and developed for quick detection of long lived alpha air borne activity in the working atmosphere. This system is based on alpha spectrometric principle and the system is capable of measuring 10^{-2} Bq/m^3 of plutonium air borne activity for 30 minutes of sampling period.

An indigenous system has been developed for detection of long lived alpha emitting radionuclides in air based alpha to beta activity ratio technique. This ratio is found to be empirically constant in a well-ventilated laboratory condition. This ratio has been theoretically established and experimentally validated. The detector used in this system comprises of a composite ZnS (Ag) and a thin plastic scintillator for simultaneous detection of α and β radioactivity deposited on a filter paper. The long-lived alpha activity in air can be evaluated using 'technique based on α to β disintegration ratio'. Presence of any long-lived alpha activity in the laboratory atmosphere will increase this ratio thereby enabling detection of airborne activity. The Minimum Detectable Activity (MDA) of the system is dependent on the radon and its daughter's concentration in laboratory. For a typical laboratory condition, the estimated MDA is 2.5 Bq.h /m^3. The system has cleared lab trials and is ready for deployment in various laboratories.

In continuation with the efforts for densification of Indian Environmental Radiation Monitoring Network (IERMON), Environmental Radiation Monitoring (ERM) systems were installed at various police stations in Chennai under Chennai MetroNet. With these IERMON

systems are installed at 505 important locations distributed all over the country.

The radiological safety of general public around Nuclear Power Plants (NPPs) is considered as one of the top priorities of DAE during design, construction and operation. To ensure this Environmental Survey Laboratories (ESLs) are established at each NPP site for periodic monitoring of environmental matrices. These ESLs are equipped with highly sensitive instruments to analyse extremely low levels of radioactivity in environmental samples. Samples of soil, sediment, air particulate matter, water, milk, food items, sea food, grass etc., upto 30 km radial distance from the plant are collected, processed and analysed for activity content using various radiometric techniques. The results of the environmental surveillance carried out around nuclear power plants clearly indicate that the dose to the member of public at fence post (1.6 km) is only a small fraction of regulatory limit of 1000 μSv/year stipulated by Atomic Energy Regulatory Board (AERB) and negligible compared to the dose received by the public from natural sources. At larger distances from the plant, the doses are much lower. Carbon-14 (C-14) and tritium are released to the environment during routine operation of nuclear power plants. Monitoring of C-14 and Organically Bound Tritium (OBT) assumes importance as they get incorporated into biological matrices in the vicinity of nuclear power plants. Methodology has been standardized for determination of C-14 and OBT in environmental matrices using pyrolizer and Liquid Scintillation Analyser.

Radiation monitoring in the environs of all the facilities constitutes an integral part of the activities of Department of Atomic Energy. Environmental gamma radiation monitoring, using thermoluminescent dosimeters (TLDs) placed around all the nuclear installations in India are being carried out by BARC. The TLD-recorded radiation profiles reflect the environmental gamma radioactivity distribution pattern and seasonal variations in the radiation levels. In addition to DAE facilities, radiation monitoring programme has been extended to generate national database on natural background radiation levels. Establishment of levels of natural environmental background radiation for Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Jammu and Kashmir, Maharashtra, West Bengal and Assam states has been carried out using TLDs.

Other studies and Radiological Impact Assessment carried out by BARC includes Radiological Impact Assessment of Fuel Fabrication Facility - Integrated Nuclear Recycle Plant (FFF-INRP) Tarapur; Radiological Impact Assessment for Heavy Water Polishing Facility, Rawatbhata Rajasthan (RR) site; Study of natural radioactivity and water quality parameters in Periyar River in the state of Kerala after 2018 floods; Generation of Baseline and Meteorological data around BARC, Vizag facility; Automatic Air Moisture Sampler for Tritium Analysis; Nanomaterials as a probe for detection of toxic ions and Indian Network for Detecting Radon Anomaly (INDRA) across Indian Tectonic Plate Boundary towards Earthquake Precursory Research.

BARC conducted IAEA/RCA Regional Training Course on Analysis of Sr-90 and H-3 in Seawater during March 12-23, 2018, in Mumbai as part of ongoing IAEA/RCA Project on Enhancing Regional Capabilities for Marine Radioactivity Monitoring and Assessment of the Potential Impact of Radioactive Releases from Nuclear Facilities in Asia-Pacific Marine Ecosystem (RAS7028). The programme included lectures, practical sessions and field sampling. The training course was attended by 19 foreign participants including three international experts.

NPCIL has recorded about 500 reactor years of safe operation of reactors by the end of financial year 2018-19. 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 AERB 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.

MoEFCC accorded Environmental Clearance (EC) for Chutka Atomic Power Project (CMPAPP) (2x 700 MWe, PHWR). For Environmental Clearances (ECs) for Atomic Power Project at Mahi Banswara (4x700 MWe, PHWR) and Kaiga Atomic Power Project Unit 5 & 6 (2x 700 MWe, PHWR), Public Hearings were organized successfully. Final EIA reports for these projects after incorporating the Public Hearing Proceedings were submitted to MoEFCC for appraisal by Expert Appraisal Committee (EAC), MoEFCC. NPCIL submitted Form-1 & other documents to MoEFCC for extension of validity of EC and CRZ Clearance for KKNPP-3&4. Following NPCIL submissions and review/ discussions thereupon, MoEFCC granted extension of validity of EC for KKNPP-3 to 6. For Nuclear Power Project (NPP) at Kovvada (6x1208 MW, LWR), draft EIA report based on three seasons data is under preparation. For Environmental Clearance of AFR for KKNPP-1&2, the EIA report (based on one season) is prepared and is planned to be submitted to State Pollution Control Board (PCB) for organization of the Public Hearing. Following NPCIL submissions, MoEFCC accorded approval of TOR for EIA/EC for AAFR for RR Site.

The Management Team is strongly committed to convey NPCIL's safety culture and values to employees. Industrial and Fire Safety aspects is being ensured through comprehensive Oversight and Support Function and implementation of Safety Management System at work locations of NPCIL. NPCIL takes responsibility for maintaining a safe workplace in every part of the Company by minimizing the risk of fire, injury and exposure to ill health for all employees and contractors. Operating Plants and Construction Projects of NPCIL received various National and State level recognitions from National Safety Council of India, AERB, Ministry of Labour & Employment and State chapter of National Safety Council.

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.

Bird marathons were organized 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). The Nature club of Narora Atomic Power Station began a turtle conservation program in year 2014 and built turtle hatching and breeding facility in collaboration with an NGO, Turtle Survival Alliance. The neonates after desired development are released in river Ganga. The turtles and Ghariyals are also rescued and relocated time to time from the lower Ganga canal near our plant site at NAPS with the expert helps from Wildlife Institute of India (WII) and Uttar Pradesh (UP) Forest Department. Along with carrying out various other conservation a knowledge center on conservation activities related to Namami Ganga Project is under establishment at NAPS. NPCIL has published various coffee table books in the past on birds, butterflies and flowers found within and around all the Indian NPPs. Recently another coffee table book is published with title “100 lives around us”.

RESEARCH & DEVELOPMENT

NPCIL's Directorate of Technology Development (DTD) 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 required/ being taken up for achieving continual enhancement of nuclear & radiation safety, reliable operation, vendor base broadening, product development and cost reduction of Nuclear Power Plants.

For the financial year 2018-19, major achievements/ progress derived from the four verticals

under DTD viz. R&D Facilities, Remote Tooling, Indigenization and Construction Time Minimization are as follows.

R&D Facilities

Primary Coolant Pump Test Facility (PCPTF)

Design/ detailing of the test facility is completed. Civil construction is in progress. Several mechanical orders are placed and under execution. Processes for procurement of C&I, electrical package, vessels etc. are in various stages of progress.

Construction Civil Work at R&D Centre

Hydrogen Recombiner Test Facility (HRTF)

Performance evaluation of samples of Passive Catalytic Hydrogen Recombiner Device (PCRD) units were carried out at HRTF for bulk supply of PCRD units required for various PHWR units.

Iodine Scrubbing through Containment Spray System

Detailed scrubbing experiments were conducted with different aerosols along with removal rate measurements in support for implementation of CSS in 700 MWe PHWRs.

NPCIL Thermal Hydraulic Test Facility (NTTF)

Full Power Rectifier commissioning has been carried out with available load. New Motors for the Primary Coolant Pumps and modified Seal Cooling System are erected. Integral commissioning of NTTF loop with Variable Frequency Drive and indirectly heated fuel element simulators are in process.

Fuelling Machine Test Facility (FMTF) for 700 MW PHWR

Erection and commissioning of modified loop are in advanced stage for carrying out high pressure & high flow test of Fuelling Machine Head at cold condition. Control System Logic for hot loop operation of FMTF has been developed, installed and commissioned. Erection of high pressure piping between NTTF and FMTF is completed.

Shut-off Rod Drive Mechanism Limit Switch

Moderator Pump Motor Stator Assembly after EQ Tests

Environmental Qualification (EQ) Activities

EQ of equipment/ components for projects (viz. Inflatable 700 MW Air Lock Seal, Differential Pressure Transmitters for severe accident conditions etc.) and large number of components/ equipment from Operating Stations for re-qualification and residual life assessment was carried out.

Development & qualification of 19 element fuel bundle simulator

Design detailing and preparation of Technical Specification have been completed. Development order is placed. Manufacturing is initiated.

General

Experimental works related to pressure tubes were continued further with dedicated test facilities to support En-Masse Coolant Channel Replacement of KAPS-1&2. Full scale operation trials of Special Handling & Operation Tools and Flask of 700 MWe Cobalt Adjuster Rods was completed.

Remote Tooling

Channel Health related activities of NPCIL's Operating PHWR fleet

Pressure Tube In-Service Inspection (ISI) campaigns using BARCIS for 220/ 540 MW PHWRs (NAPS-2, RAPS-2&5, KGS-1&3, MAPS-1, TAPS-3&4) were carried out successfully. These ISI campaigns included volumetric inspection of Pressure Tubes, Sag measurement and material sampling. Successfully demonstrated cutting of End Fitting and Bellows by LASER during full scale mock up as well as at site for 540 MWe Pressure Tube inspection, cutting and removal. The same was deployed successfully for TAPS-4 Pressure Tube. Designed and successfully developed single Calandria Tube removal scheme for KAPS-1, in association with BARC. Full scale mock up facility erected for Pre-Service Inspection qualification of 700MWe Pressure Tubes. Automatic Lip Welding Tool for Annulus Gas System Bellows of 220 MWe reactors was developed.

Moderator Heat Exchanger (HX) Remote Tooling

Design, Specification and drawings completed for development of tooling system for remote operation of eddy current inspection system for 540 MW moderator Heat Exchangers.

Steam Generator Tube Cleaning System

Design and development for automated Steam Generator Tube Cleaning System is completed. The System, consisting of high speed pneumatic Cleaning Head, Mounting & Adaptor Plate assemblies, Pusher-Puller Unit, Sludge Collection & Disposal Unit and Control Module, is ready for SG tube cleaning deployment. Specification is made for DRDO based manipulator for NAPS SG In-service Inspection system after receipt of Technology transfer drawings/ documents. Detailed design and specification made for automated remote Cutting & Beveling Unit for RAPS-2 Hairpin HX and development order is placed. Prototype qualification in progress. Design and detailing for technology & remote tooling development for removal of eroded ligament segment from Steam Generator feed water box and its repair is in progress.

Cobalt Adjustor Rods (AR) Dismantling System

To support the processing of Cobalt material irradiated in NPCIL PHWR Stations by Board of Radiation Isotope Technology (BRIT) and to meet the country's requirements for radiation source for medical and industrial applications, NPCIL is developing following remote tools.

Cobalt Adjuster Rod Dismantling System: Based on detailed design, purchase order is placed and Quality

Cobalt Adjuster Rod Dismantling System

Assurance Plan, fabrication drawings and other manufacturing documents have been approved. The work is under execution.

Cobalt Adjuster Rod Bundle Opening Tools: Full scale version of these tools for Pellet type and Slug type Cobalt Bundles are in advanced stage of manufacturing and operation trials.

End Shield and Calandria Vault Inspection and Maintenance

Special remote tooling developed for MAPS End Shield remote inspection and successfully deployed. Design, detailing and specification completed and tendering made for development of remote tools for Calandria Vault Top Hatch Beam Openings Sealing System. Development order is under process.

Extended Reach Manipulator

Extended Reach Manipulator (ERM) is a mechanical handling system used in pairs in radioactive hot cells for incell material and process handling operations. ERM has two mechanically interconnected arms, five manual motions and three electrically actuated motions and can handle a maximum of 10 kg payload. Five pairs of ERMs has been developed by BARC.

Extended Reach Manipulator

Indigenization

Shutdown Cooling Pump for 700 MW PHWR

The alternate vendor development for Shutdown Cooling Pump (SDCP) covering type & performance tests at a dedicated high pressure and high temperature loop is completed. After successful development, the SDCP is delivered to RAPP-7&8, thus ensuring availability of alternate Vendor for fleet mode 700 MW projects.

700 MWe Shutdown Cooling Pump and Test Loop erected for Endurance Test

PCP Rotor Assembly & Stator Assembly

PCP Motor Brake Assembly and Thrust & Journal Bearing Assembly

PCP Motor Assembly

6 MW Primary Coolant Pump (PCP) Motor

The alternate vendor development for 6.6 kV, 6 MW vertical squirrel cage induction motor for PCP required for 700 MWe PHWR projects has been completed. The motor was successfully tested and delivered.

End Shield Tube Sheet balance SS Plates for 700MW PHWRs

Subsequent to indigenous development of End Shield Tube Sheet Plates manufacturing process, optimization of process parameters and methodology continued with manufacture of six more plates. Technology adopted for fleet mode 700 MWe PHWRs.

Steam Line Venturi Forging

Development of full scale Steam Line Venturi for calibration of steam flow measurement, required for reactor power measurement from secondary side has been carried out.

Steam Line Venturi under Forging and Steam Line Venturi

Portable PCRD Plate Testing Unit

NPCIL is in the process of installing Passive Catalytic Hydrogen Recombiner Devices (PCRDs) in all Operating PHWRs and new projects. Development of portable PCRD Plate Testing Unit is completed for in-situ performance evaluation of the PCRD plates.

Portable PCRD Plate Testing Unit

Development of 700 MW Pressurizer Heaters

Prototype full scale Pressurizer Heater development trials has been completed successfully as a part of indigenous vendor development for 700 MWe reactors.

Development of Plasma Nitriding Technology for SS Materials

Plasma Nitriding Technology

Development of Plasma Nitriding completed for Fuel Handling System components, in collaboration with Institute of Plasma Research.

Boiler Feed Pumps for 700 MW reactors

Indigenous development of Boiler Feed Pumps for 700 MW reactors by two vendors is in progress. Casting of first Pump Casing carried out and non-destructive examination is in progress.

700 MW Primary Coolant Pump

First set of documents review and approval completed for Indigenous Development of Primary Coolant Pump (PCP) for fleet mode 700 MW reactors after finalizing design & manufacturing inputs with vendor.

Lattice Tube development

Successfully produced the low cobalt ingots, forging carried out and indigenously manufactured twelve numbers of Lattice Tubes for End Shields of 700 MW reactors.

700 MWe End Shield Lattice Tube Forgings

Hardness Testing of Forging

Implementation of Electrical Penetration Assemblies in ongoing 700 MW Projects

Subsequent to the successful indigenous development of factory built Electrical Penetration Assemblies (EPAs) for Control & Instrumentation Cables and low tension electrical cables, the EPAs were installed and commissioned in the first 700 MW project at KAPP-3. Same is being adopted for all 700 MW PHWRs.

Construction Time Minimization

Tools/ techniques for construction time and cost minimization has been identified as thrust areas for future NPPs. Progress on technological advancements in this field are as follows:

Single Pass Laser Welding Setup with Rotating Laser Welding Head (LWH) inside the Prototype Assembly

Single Pass Laser Welding of Lattice Tubes

Laser Welding Head development and qualification carried out successfully for single pass Laser Welding of Lattice Tube to Calandria Side Tube Sheet joint of End Shields. This development will result in substantial reduction in fabrication time and ensure consistent quality of this critical weld joint (392 numbers each for both End Shields) of 700 MW reactors.

Auto Narrow Groove TIG Welding Unit

Development of automated narrow groove TIG welding machine carried out for adoption in primary piping. It is proposed to adopt same for en-masse replacement of Hairpin type Heat Exchangers of steam boilers.

R&D-Electronic System (ES)

For ongoing PHWR projects, Software was developed in-house and deployed enabling completion of PHT hydro test at KAPP-3. Hardware documents have been revised and qualified. Fuel Handling Control System (FHCS) software has also been installed at site. IV&V of common embedded software module has been completed (CSPI/CSMI). For Operating stations, ECCS Test Facility (ETF) software has been modified for some reactors, RAPS-5 RRS software has been modified to address specific events/ issues. RAPS-2 Digital

Recording System (DRS) and Plant Information System (PIS) have been up-graded.

Engineering

Engineering activities performed in areas of projects, operating units, C&I, simulator and information technologies are as given under

Projects

Commissioning procedures were finalized for KAPP-3. Primary Heat Transport (PHT) system hydro test in KAPP-3 was completed successfully. Seismic qualification methodology of First of a Kind (FOAK) air cooled Diesel Generator (DG) (a part of post Fukushima Safety enhancement) was finalized and equipment was qualified successfully. Regulatory acceptance was obtained for Leak Before Break (LBB) methodology and leak detection system for PHT system. Commissioning and validation of real time full scope simulator for KAPP-3&4 is in advanced stage of completion. Hot conditioning application for KAPP-3 has been submitted to AERB and is under review. Electrical Penetration Assemblies (EPAs) which are First of a Kind (FOAK) equipment have been successfully installed and tested in KAPP-3. In respect of GHAVP-1&2, standardized design & detailed engineering is progressing in 3D modelling engineering platform. Process & Instrumentation diagrams of all in-house engineered process systems have been completed. Detailed engineering, including 3D modelling, stress analysis, supports and Embedded Parts (EPs) up to El. 100 meters has been completed. Civil construction drawing up to EL 100 meters have been issued. Plant water system engineering has been completed. Technical Specifications and tender drawings for Main Plant Electrical and Switchyard Package have been issued. Application for First Pour of Concrete (FPC) consent for GHAVP-1&2 has been submitted to AERB and is under review. In respect of 700 MW PHWRs in Fleet Mode, considering that the initial activities of the Fleet Mode Projects are in multiple domains and by different agencies, the mechanism has been strengthened to integrate these activities for better effectiveness. Applicat ion for siting consent along with site evaluation report for Kaiga-5&6 has been submitted to AERB and is under review.

Operating reactors

Design support to the operating stations were provided. Root cause was established for pressure tube leak incidents in KAPS-1&2, by carrying out extensive analytical & experimental studies in coordination with various facilities of DAE units. The Calandria Tube cutting, removal and reinstallation activity was done for the first time in India in KAPS-1. Calandria Tube removal technique by thermal cycling induction method developed by BARC was successfully employed after exhaustive developmental works, full scale mockup trial and qualifications. Re-installation of a new calandria tube was successfully carried out. Time Limited Ageing Assessment (TLAA) studies have been carried out for the Reactor Pressure Vessel (RPV) and recirculation piping system of TAPS-1&2 in order to evaluate the effects of the environment on the fatigue resistance of the material to preclude fatigue crack initiation in RPV and recirculation piping up to 40 Effective Full Power Years of reactor operation. For up-gradation of Fire Protection System (FPS), a standardized scheme/ methodology has been finalized to take care of the obsolescence of the existing equipment and addition of new items with forward and backward compatibility.

Safety Enhancement

Post Fukushima, more importance is being given to enhance design provisions and demonstrate margins with respect to Beyond Design Basis (BDB) conditions. To this end, various advanced safety features are incorporated in the new projects and being implemented in operating stations. Also, Seismic Margin Assessment (SMA) is being carried out to demonstrate margins w.r.t. Beyond Design Basis Earthquake for the operating stations.

Control & Instrumentation

The design of C&I has been completed for KAPP-3&4. The 3-D modeling related activities for Instrumentation & Control systems in different buildings have been completed in GHAVP-1&2.

Information Technology

Software application has been developed for standardizing plant performance reporting from nuclear

power stations to Head Quarter including monthly reporting to regulator, critical plant parameter trend analysis and exception reporting. For further strengthening of Plant Maintenance, generic Scheduler software module has been developed as part of Corrective Action Management System. This software takes care of auto generation of schedules, work completion reporting and monitoring for compliances related to various programs like Preventive Maintenance, Condition Based Monitoring, Technical Specification Surveillance, Station Document revision and management, etc.

Simulator

The first 700 MW Full Scope Replica Operator Training Simulator (FSTS) with KAPP-3 as the reference plant has been made available for operator training as per regulatory requirement ahead of plant criticality. This version which includes simulation of all plant systems operable from the Main Control Room (MCR) has been validated by an independent team for various normal and postulated off-normal operating conditions before release of the simulator for a two-phased operator training programme and WANO Crew Performance Evaluation. For GHAVP-1&2, Simulator Facility layout and related civil drawings have been finalized.

R&D relating to PHWR

Burn-up of the UO_2 based fuel irradiated in KAPS-I was determined using isotope-dilution thermal ionization mass spectrometry (ID-TIMS). The burn-up data for the samples from Central pin, Intermediate pin and Outer pin were found to be 1.91±0.04, 2.13±0.04 and 2.63±0.05 atom%.

Packing module fabrication, surface activation & performance testing of high efficiency structured packing for heavy water upgrading column sections have been successfully completed to meet the pressing demands of upcoming PHWR sites of NPCIL. The column sections are performing well by providing good separation and hydrodynamics.

A vertical scanning system was developed and used for fine scanning and accurate characterisation. The system allows controlled fine movement in axial and circumferential directions to enable scanning of the spool samples. Pressure Tube spools were inspected for any pre-existing defects. Then they were loaded with fuel bundles and subjected to vibration on shake table. The spools were again inspected after vibration for detection and characterisation of any defects.

Vertical Scanning System

Mini BARCIS Drive

Calandria Tube of Q15 channel of KAPS-1 was inspected before its removal. A compact Mini-BARCIS drive with a stroke of 1m was developed for this activity. The inspection involved Ultrasound Testing (UT) for detection of defects & nodular corrosion and dimensional measurement. In addition to UT, ECT inspection and sag measurement was also carried out.

PRESAM 220 tool-head

WEST 540 tool-head

Linear Variable Differential Transformer (LVDT) based PRESAM (PREssure tube SAg Measurement) inspection system is developed. It consists of a tool head, data acquisition system and signal processing algorithms. The local curvature of pressure tube is measured using a radiation-resistant under-water service-able tool head. The tool head traverses along the length of the pressure tube. PRESAM 220 and PRESAM 540 were deployed for sag measurements of 49 channels at six PHWRs.

Wet scraping Technique (WEST 540) technique is used for collection of sliver sample from pressure tube of 540 MWe PHWRs, remotely for estimation of hydrogen concentration. WEST 540 tool head was used for the first time in Indian PHWR, TAPS Unit 4 for sampling in L08 channel in November, 2018. Four sliver samples were collected. Sizes of all the samples were satisfactory.

Calandria tube is an important component of coolant channel assembly of Pressurised Heavy Water Reactor (PHWR) which separates hot pressure tube from cold moderator in the reactor. It is joined to the end shield tube sheets through sandwiched type rolled joints at both ends where it is sandwiched between tube sheet and SS410 insert. For removal of calandria tube from 220MWe PHWR, induction heating followed by fast cooling based Calandria Tube Rolled Joint Detachment (CTRJD) system has been developed in BARC. The CTRJD system was used first time in Indian PHWR in Dec, 2018, for removal of calandria tube from Q-15 lattice position of KAPS, unit-1.

Tool head of calandria tube rolled-joint detachment (CTRJD) system

Formation of partially constrained precipitates such as hydride blisters and oxide nodules have been reported on surfaces of Zr-alloy components of pressurized heavy water reactors and is associated with a large increase in volume. Such a change in volume imposes large stresses in the material surrounding the precipitate and may facilitate stable crack growth through delayed hydride cracking. In this work, the stress field of the partially constrained precipitates with different depth and aspect ratio has been computed using a finite element method by considering autocatalytic growth of precipitates. The computed stress field is used to predict the region in the matrix in which radial hydride is likely to form and fracture, by taking into consideration grain-size, texture and multi-axial state of stress. For a hypothetical crack just below the precipitate, stress intensity factors are estimated using material properties for both un-irradiated and irradiated pressure tube materials. The results are used to determine the critical size of precipitates that can initiate crack growth due to delayed hydride cracking.

Presently, Zr-2.5Nb alloy is being used as a pressure tube material for Indian PHWR. The thickness of Zr-2.5Nb pressure tube material for 220MWe, 540MWe and 700MWe Indian PHWR are 3.5, 4.5 and 4.5mm respectively. Also during the service life of PHWR thickness of the pressure tube is reduced to corrosion of the pressure tube with the heavy water. It is well reported that thickness has an effect of the specimen thickness when thickness is lower than the critical thickness for valid JIC test. So for the correct comparison of fracture toughness of 220MWe pressure tube material with that of 540MWe or 700MWe pressure tube material it is required to know that if there is any effect of thickness on fracture toughness between 3.5 and 4.5mm. It is also required to know if there is any effect on fracture toughness because of reduced thickness due to corrosion. The Curved Compact Tension (CCT) specimens of different thicknesses between 0.5 to 4.5mm were machined from 540MWe pressure tube. For samples thickness between 2 and 4.5mm, practically there is no effect of specimen thickness on fracture toughness. Below 2 mm thickness, fracture toughness was observed to decrease drastically with decrease in specimen thickness.

Test set up of full scale dissimilar metal pipe

Dissimilar Metal Welds (DMW) are widely used to connect pressure vessel nozzle of low alloy steel to piping of stainless steel in nuclear power plants. These are pressure retaining components and hence their integrity is of utmost importance from safety considerations. Integrity assessments of these components with DMW joints require accurate prediction of fatigue crack growth rate of different zones of weld. As a part of this, fatigue crack growth rate test on full scale dissimilar metal pipe weld with part through crack in the centre of the weld under normal cyclic loading has been carried out. The good matching between test results and theoretical predictions provides confidence for the accurate estimate of the fatigue life of the components with flawed DMW joints.

Weld residual stresses have a significant effect on the fracture assessment of the welded components with flaw because it affects the crack driving forces and leakage-flow (when crack becomes throughwall). Presently, average residual stress is assumed for fracture assessment whereas actual residual stresses vary across the thickness of the components. Therefore, an improved methodology based on finite element analysis has been developed to estimate the growth of a crack subjected to actual residual stress profile and operating load (due to pressure). The developed methodology has been used to quantify the effect of residual stress on Crack Opening Displacement (COD) below for austenitic stainless steel pipe having 90° through-wall crack in center of weld. This will help in accurate fracture assessment of components with weld and reduce conservatism in design of AHWR/PHWR/IPWR.

As part of research activities to address direct contact condensation and water hammer behaviour, a Water and Steam Interaction Facility (WASIF) has been set up at SRI, Kalpakkam. An indigenous numerical code based on six-equation, two-fluid model has also been developed for simulating Condensation Induced Water Hammer (CIWH). The developed code has been benchmarked against results of the international code WAHA available in open literature. This code will be further validated against in-house experiments being conducted at WASIF.

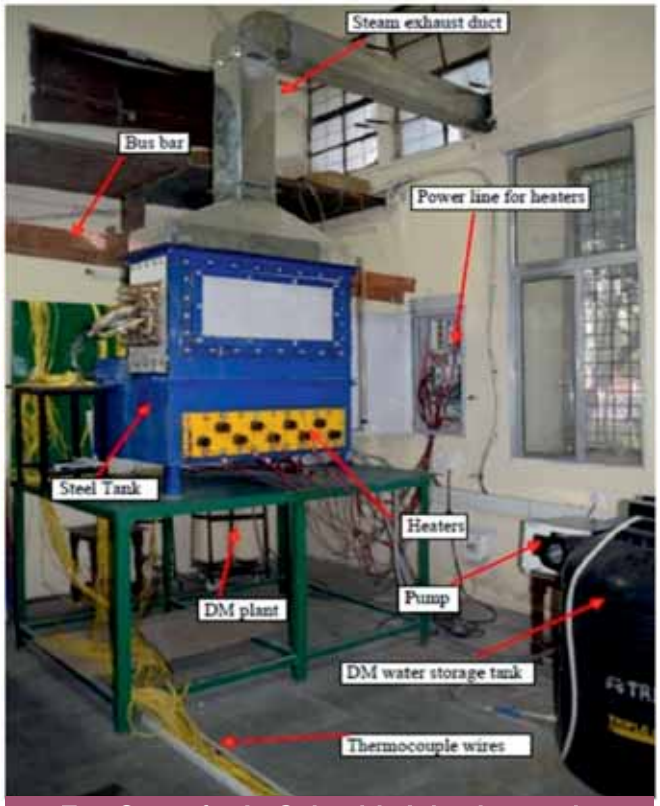
Water and Steam Interaction Facility (WASIF) at SRI, Kalpakkam

The containment structure of a nuclear reactor is the final barrier to release of activity into the public domain. The behaviour of hydrogen in the post-accident atmospheres of the containment of PHWRs is important to devise hydrogen management strategies and thus protect potential hydrogen-induced damage to the containment. Experimental studies have been completed in the multi-compartment geometry of CSF with an aim to characterize the stratification and distribution behaviour of lighter gas (using Helium as simulant for hydrogen). The analytical capabilities of the department have been enhanced and validated by performing CFD-based inter-code benchmarking

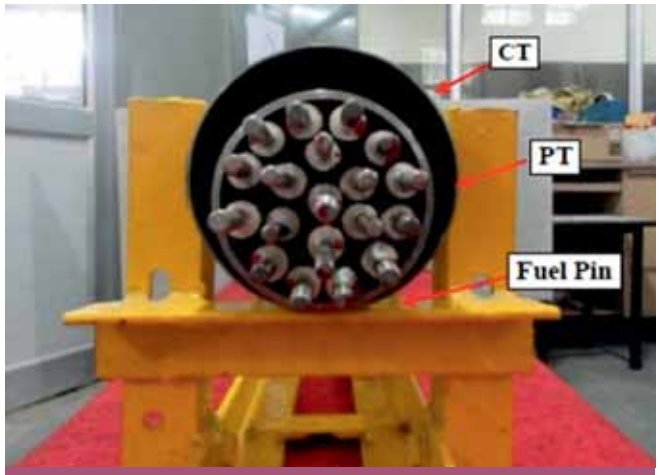
Containment Study Facility at Hall-7, BARC (Schematic and Actual)

exercises for the experiments conducted at CSF. This has helped to evolve the methodology and a numerical framework for application to hydrogen distribution and management behaviour in actual PHWR containments.

Injection of Fire Fighting Water (FFW) into the PHWR Calandria constitutes a part of Severe Accident Management Guidelines (SAMG). The purpose of the injection is to remove residual heat from exposed reactor channels which forms a suspended debris bed. As a part of SAMG verification activities, the adequacy of FFW flow rate on residual heat removal is assessed. A scaled down experimental model is fabricated. Fuel channel simulator of 1.5m length is fabricated with 19 fuel pin simulators, pressure tube and calandria tube. The rise in Calandria level from FFW injection and the decay power of the channel are simulated. The experimentation shows successful residual heat removal with designed FFW flow rate for 1% decay power. Further experimental study shows that residual heat removal corresponding to 1.25% decay power is achievable with lower flooding velocity (0.8 cm/min) and higher injection temperature (90°C). Thus the designed FFW flow rate for In-Calandria injection is verified.



Test Setup for In-Calandria Injection study for verification of Severe Accident Management Guidelines for suspended debris



View of Fuel Channel Simulator

Reactor design and analysis required high fidelity computer codes which can model the geometries and the physics phenomenon more accurately. There has been significant development with regards development of a Monte Carlo based multi-group code PATMOC and a method-of-Characteristics based solver DAIMOND. The 3D space-time kinetics code ARCH has been rigorously updated with simplified thermal hydraulic modules to model high temperature reactor transients.

Performed seismic requalification of DHRUVA structures, piping systems & components, Seismic retrofitting of HWPK structures with elasto-plastic dampers. Entrance porch structure of Heavy Water Plant, Kota is not meeting the seismic demand as per the current design basis. SSES and HWB engineers

designed elasto-plastic dampers and were manufactured and installed at HWP, Kota.

R&D relating to LWR

Integrated Reference control system of Compact LWR for Project 1& 2 has been setup at Ship Building Centre (SBC), Visakhapatnam for regular operation, training & regulatory certification tests of Compact LWR control system. This facility constitutes of 40 Control Systems racks, 10 nos. of Simulators comprising of field I/O simulators, plant simulator, Control Rod Drive Mechanism (CRDM) simulators and actual CRDMs. The facility was titled "DRISHTI" and was handed over to SBC for regular operation & testing.

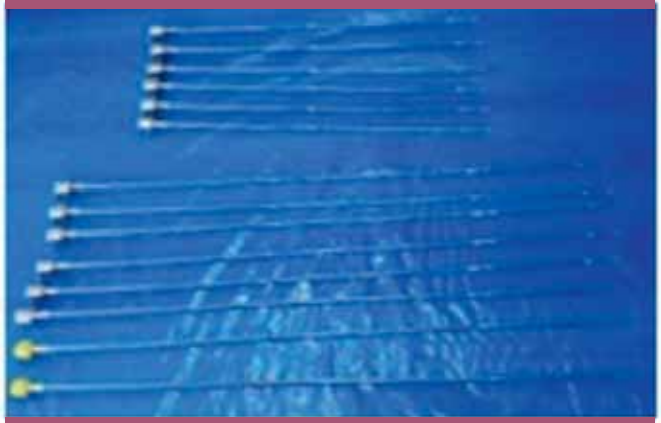
IPWR is a PWR being developed indigenously. The envisaged cycle length of the core is 410 Full Power Days at the rate of 900 MWe (2700MWth) with a three batch refuelling scheme. The physics design of Indian Pressurised Water Reactor [IPWR] has been evolved to obtain a better fuel utilisation. With this aim a first core loading has been worked out and the cycle characteristics have been estimated.

Process sensors for Steam Generating Plant and Reactor of Project-2 namely – LOCA qualified

Absolute Pressure Sensors

Multipoint Ultrasonic Level Sensor Assemblies

Bulk Head Adaptors



Thermocouple Assemblies

Absolute pressure sensors for measurement of pressure in primary systems of SGP, Multipoint Ultrasonic Level Sensor assemblies for measurement of water level in high pressure vessels of Steam Generating Plant, Primary and electronic converters for Single Point Ultrasonic Level Signalizers for water level measurement in tanks and vessels, Thermocouple assemblies for reactor coolant inlet and outlet temperature measurements and Bulk Head Adaptors for leak tight passage of sensor cables from reactor compartment; have been fabricated and delivered to project after completing the qualification tests.

The hot deformation, continuous cooling transformation and irradiation damage behavior of 20MnMoNi55 reactor pressure vessel steel were characterized. The optimum hot working conditions were determined using a thermo-mechanical simulator. Strain rate sensitivity map showed the optimum hot working condition to be from 1000°C to 1200°C and 10^{-1} to 1 s^{-1}. The prior austenite grains size increased with increasing temperature and decreasing strain rate. Deformation at 700 °C showed elongated grains,

whereas at 900°C equiaxed grains were formed. Two Continuous Cooling transformation curves of 20MnMoNi55 were generated using austenitization temperatures of 870°C and 1000°C. Higher austenitization temperature shifted the ferrite formation nose to lower cooling rates. A study on the effect of irradiation on defect and hardness was carried out on this steel. 20MnMoNi55 was irradiated to 10, 25 and 50 displacements per atom (dpa) at 300°C with 1.76 MeV Fe^{+} ions using the 1.7 MV Tandetron accelerator at IGCAR at dose rate of 4.4×10-3dpa/s. Samples were examined by Electron Backscatter Diffraction, Grazing Incidence X-Ray Diffraction, depth dependent Doppler Broadening Spectroscopy and nanoindentation before and after irradiation. The dislocation and point defect density increased resulting in increase in hardness.

Towards infrastructure for design & development of Light water Reactors including IPWR, the construction of New Engineering Hall 11 with associated service building has been completed. Engineering Hall 11 also includes facilities like Shake Table, Thrust wall & Strong Floor of RSD, RDDG for seismic testing of structural components and reactor components.

BARC is providing off-site fuel management services for TAPS units #1 and 2. The main goal of reactor fuel management is to utilize as much fissile material as practicable to generate energy over the cycle. In TAPS BWR, three batch refuelling scheme is used where approximately one third of the burnt fuel is replaced by the fresh fuel bundles. An optimum loading pattern was provided wherein the cycle energy outputs of unit-1&2 are 5.8 GWD/ST and 6.0 GWD/ST.

As part of ongoing research program on development of sacrificial core-catcher materials Red-mud from NALCO, India was processed to obtain sintered ensembles by adding suitable additives and their melting behaviour have been studied. Further to correlate the behaviour of reactivity of the red-mud with corium, investigations on relevant components systems, like Fe_2O_3-Al_2O_3, Fe_2O_3-Al_2O_3-CeO_2/Pr_2O_3, Fe_2O_3-U_3O_8-ZrO_2 systems were undertaken.

CHAPTER

2

NUCLEAR POWER PROGRAMME STAGE-II

West Side view of PFBR

Mobile Purification Loop

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

PFBR is a liquid sodium cooled, pool type reactor using mixed oxide of uranium and plutonium as fuel. The plant is located south of the existing Madras Atomic Power Station. After completion of construction, manufacture & erection of all the systems / compononts of PFBR, commissioning of various systems are in progress.

East side view of PFBR

West Side view of PFBR

The major activities that have been completed during the report period Jan 2018 to Mar 2019 are as follows:

Various commissioning activities pertaining to secondary sodium loops have been carried out. Initially all the circuits in loop-1&2 were preheated and sodium flow was established in purification circuits. Subsequently sodium was filled and purified in both the loops to the desired plugging temperature and trial runs of Secondary Sodium Pump (SSP) -1 & 2 were made.

During the commissioning trials of the secondary loops, there were a few consecutive commissioning related problems associated with electro-magnetic pumps, which could be effectively resolved after carrying out appropriate modifications and marginal design changes of the electromagnetic pump.

During the commissioning trials and characterization of the SSP-1 & 2, certain deviations were noted in the performance of one of the pumps, which was replaced with a spare Pump Internal Assembly (PIA). Subsequent to replacement of Pump Internal Assembly of SSP-2 and modifying the existing supports & adding one additional restraint support at suction line, both the SSPs were started and the speed was increased in steps upto 520 rpm and later to 700 rpm for data collection. Required data collection was done and the pumps speed was reduced to 380 rpm for stable operation. Presently both the secondary loops are operational and performing satisfactorily.

The initial commissioning trials of the various fuel handling system equipment, viz., Large Rotatable Plug, Small Rotatable Plug, Transfer Arm and Inclined Fuel Transfer Machine, were completed. Also, the Verification & Validation (V&V) of the computer based system for operating all the fuel handling equipment from handling control room were completed. However, subsequent trials of the Transfer Arm, at high temperature, indicated certain deviations in performance, for which the component was taken out and necessary modifications were carried out and presently it is ready for installation on pile and normalization. Performance testing of Transfer Arm is planned to be carried out shortly.

During commissioning, bearing in Large Rotatable Plug (LRP) which is used for positioning & approaching various fuelling positions, has developed a snag and the same is being attended in consultation with the design team.

Commissioning trials and plans for V&V are in progress for the cell transfer machines. Preparations are underway for commissioning the primary system, which will be taken-up, after completion of LRP bearing rectification works.

With respect to tertiary system, Performance guarantee tests of auxiliary sea water pumps and condenser cooling water pumps were successfully completed. Two streams of electro chlorination plant were commissioned and the performance was checked at full capacity. The steam generator tube side preheating with hot water circulation by operating Auxiliary boiler and Motor Driven Boiler Feed Pump was carried out successfully.

Commissioning of sodium systems is in advanced stage and secondary sodium is in circulation. Work is in progress for filling of primary sodium in Main vessel and commissioning of the Primary Sodium Pumps. After filling primary sodium and completing the Initial Test Programme, fuel loading will commence towards approaching first criticality.

To contribute to the supply of first and second core sub-assemblies and special sub-assemblies required for PFBR were manufactured for the first time in the country and supplied by NFC.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

Fast Breeder Test Reactor (FBTR)

FBTR crossed another milestone in its history when reactor power was raised for the first time to 30 MWt. Turbo Generator (TG) synchronized to the grid with the newly installed Automatic Voltage Regulator generating power of around 6.5 MWe, Reactor was shut down by ordering manual LOR since one of the Control Rod Drive Mechanisms (CRDMs) became in-operable. Reactor was restarted after replacing the faulty motor. Reactor was shut down to discharge the special subassembly containing grid plate material specimens after it attained 7 dpa for carrying out post irradiation examination to re-estimate the residual life of the grid plate. Subsequently, during changeover of the main boiler feed pump, reactor underwent LOR on high SG pressure. After identifying the root cause and taking necessary corrective action, reactor was re-started.

After effecting necessary core changes, the 27th irradiation campaign was started on 29th September 2018. The reactor core had 56 fuel subassemblies (47 Mark I + 1 Mark II +8 MOX) for this campaign. The estimated reactor power when the peak rated Mark I fuel SA operated at 400 W/cm LHR was 32.0 MWt and total duration of the campaign was 40 days. Major missions of 27th irradiation campaign were; irradiation of sodium bonded ternary metallic fuel pins (23% Pu+ 19.8%EU+6% Zr), yttria capsule for strontium production and tungsten carbide specimen (a potential axial shield material for FBTR fuel SA) in addition to the continuation of irradiation of other sodium bonded metallic fuel pins and structural materials.

After completing the low power physics experiments, reactor power was raised to 32.0 MWt, on 8th October; another milestone in the history of FBTR, with TG generating 7.0 MWe., Reactor underwent LOR on primary sodium pump. The pump underwent fast retardation due to EMI noise pickup due to lightning in the over current monitoring signal cable of the pump. After taking the remedial measure of replacing the cable with EMI resistant cable, reactor was re-started. Towards

the end of the campaign, there was an increase in primary cover gas activity on three occasions due to gas puff release. Since the stack activity release and radiation levels in RCB were within the limits, reactor operation was not affected. After completing the 27th irradiation campaign, the gas leaker subassembly was identified using a special procedure in January.

As part of post Fukushima safety up-gradation of FBTR, a Seismic Instrumentation System (SIS) has been installed and commissioned. The SIS notifies and alerts the plant regarding any seismic induced ground motion in and around the plant premises. Earthquakes predominantly affect the plant civil & mechanical structures resulting in abnormal operating condition or leading to conditions affecting safety of plant and personnel. The system consists of a set of ground motion sensors (accelerometers) located in and around the plant along with alarm and recording units which will help the operator to initiate appropriate action. The >24 hour autonomy of the unit ensures availability of operator alarm and motion recording even in the event of a station blackout of duration 24 h.

A Supplementary Control Panel (SCP) was installed and commissioned in turbine building with provision to shut down the reactor, monitor decay heat removal & radiation level in the plant in case the main control room is inhabitable due to any reason.

By successful commissioning of the seismic instrumentation system and SCP, FBTR has completed all the post Fukushima recommendations stipulated by AERB and this has strengthened the safety of FBTR. Regulatory clearance for commencing 28th irradiation campaign has been obtained. Reactor power will be 32 MWt and the campaign duration will be around 54 days during which turbo generator will be synchronized with the grid generating power of around 7 Mwe.

R&D relating to PFBR

Technical Support to PFBR Commissioning

Calibration of Actuator Rod Position in Transfer Arm

Tolerance on the positioning of actuator rod with respect to the fingers affects the performance of the gripper actuation in transfer arm. Estimation of error band due to control system, relative thermal expansion and frictional forces were carried out for various positions of the fingers. The above estimates were also validated by suitable experiments. Final finger calibration at room temperature and confirmations of smooth operation of fingers of transfer arm from handling control room was completed.

Root Cause Analysis on Transfer Arm Gripper Finger

Difficulty was experienced in the actuation of gripping fingers during qualification trials in hot nitrogen. In order to identify the root cause for this issue and arrive at an optimum design solution, systematic examination of the mechanism parts after removal from the pile; re-examination of the archived data on qualification tests done before installation in reactor; detailed analysis of joint clearances/tolerances and series of tests after removing the mechanism from reactor have been carried out. Also, contact stress analysis has been carried out for the guide rail of transfer arm gripper assembly to estimate the contact stresses under normal operating and stuck condition and thereby decide the required surface hardening for the sliding surfaces. Three different orientations of guide with respect to the rail were analysed with/without fillet for guide in guide rail assembly. It was found that the contact stresses are higher than the yield stress, suggesting local surface hardening is essential. Based on this study, the required surface hardening for the sliding surfaces, optimum curvatures for the sliding joints have been finalized. These modifications were implemented in the plant.

Horizontality Measurement of Control Plug

The horizontality of control plug top plate, on which the shutdown mechanisms, failed fuel location modules etc. are supported, has been measured in-site found to be ± 0.25 mm. Acceptability of this value is established after a detailed study of its effect on functionality of absorber rod drive mechanisms.

In-Pile Testing of Failed Fuel Location Module (FFLM)

Based on detailed investigations, the reason for increased torque in FFLM was traced to be due to eccentric loading by DC conduction pump and resultant reactive force between guide sleeve & selector plug. Suitable design modifications have been incorporated in one FFLM and the same was erected back in the reactor. Subsequent in-pile tests in 150 C nitrogen indicated a very low torque of 6 Nm which is acceptable.

Thermal Hydraulic Analysis of Reactor Assembly Preheating

As per the direction of AERB, temperature evolution in roof slab and reactor internals during pre-heating was predicted with the flow achieved in the plant. The predicted data were compared with plant measurements and the validity of the thermal hydraulic model was established.

Thermal Analysis for Restarting Secondary Circuits

The duration of preheating for IHX tube sheet structures covered by thermal shields (13 d), locations of cold spots in IHX in the top shield region which are not exposed to hot nitrogen and electrical heating, temperature of IHX after sodium filling (141°C), time available for safety action in case of pump trip & loss of heating to IHX etc. were determined by a detailed thermal analysis. The secondary loops were commissioned based on these studies.

Estimation of Sodium Plugging Temperature and Purification Time after Main Vessel Filling

Initially primary sodium is charged into the main vessel at 150°C. The sodium absorbs the impurities present in structural surfaces and as a result, its plugging temperature increases. Knowledge of quantity of impurities that will get dissolved at this temperature and the resulting plugging temperature are essential to understand the primary sodium purification time. Based on a computational model, the impurity at the end of filling is estimated to be 15.8 ppm which corresponds to a plugging temperature of 211°C. The purification time is also estimated based on the evolution of secondary sodium plugging temperature during purification. It is seen that the primary sodium purification takes 40 days to achieve a plugging temperature of 120°C.

Study of Undulation of Top Shield

Deflection of roof slab and rotatable plugs under combined mechanical and thermal loads, arising during one secondary loop operation, has been determined by 3-D structural analysis. Permissible circumferential variation in temperature of the components for smooth operation of the bearing has been arrived at. Further, to support commissioning of components mounted over top shield, structural analysis of top shield for different combination of mechanical and thermal loading has been carried out for as built data. Slope of critical locations of top shield under various conditions during preheating of reactor assembly has been estimated to decide the commissioning approach for various mechanisms mounted on the top shield.

Design of Mechanical Arrangement for Unloading / Reloading of LRP from Bearing and Contact Analysis

The Large & Small rotatable plugs (LRP & SRP) are supported on large diameter bearing measuring 6.9 m / 4.6 m, respectively to facilitate their rotation for enabling fuel handling operation. To examine the bearing a weight of 400 t needs to be unloaded from the bearing and lowered to rest on roof slab, directly. Towards this, a mechanical arrangement has been designed. The arrangement consists of 90 numbers of connecting rods with trapezoidal threads at one end for temporarily transferring the plug load to a large diameter circular ring, which is supported at the top of bearing. Detailed structural analysis of the arrangement has been performed to confirm that the stresses at various parts are within allowable limits and manufacturing drawings for the arrangement has been prepared. Also contact stress analysis of LRP bearing was carried out for full complimentary balls / roller-spacer ball arrangements at various contact angles (90°, 60° and 75°). Contact parameters, viz., deformation, contact stress, contact area and peak von-mises stress were determined. It was found that contact angle of 60° is the critical one which has to be used for design check. The

maximum contact stress is found to be 1948 MPa (for roller-spacer arrangement) which is less than the permissible value of 3000 MPa and is acceptable.

Thermo-mechanical Analyses for Secondary Sodium Pump (SSP) Commissioning after Refurbishment

Temperature distribution at labyrinth location of SSP during preheating and sodium filled conditions, have been determined by transient and 3-D computational fluid dynamic studies. It is found that the soaking time for preheating is 3 days. Further, an assessment of reaction forces induced in the secondary sodium main piping due to pressure loss and turning of flow in bends / T-joints was carried out. The net unbalanced force on the piping and its effect on possible tilting of the SSP assembly were quantified. Subsequently, free vibration analysis of cold leg of secondary sodium main circuit along with SSP was carried out to understand the dynamic behaviour of the coupled system. Based on the analysis, additional restraints were found essential for the pump suction line to increase the natural frequency of the coupled system. Following these, 3-D contact stress analysis of SSP assembly was carried out, considering the reaction forces obtained from piping analysis, to understand the possibility of interaction between the static and moving parts of the SSP. Displacement at critical locations, where there is limited clearance between outer shell and inner pump assembly, were determined. It is established that the displacement is very small and there is no risk of interaction between the various parts.

Vibration Monitoring and Support Modifications in EM Pump

Detailed field measurements were carried out in the Secondary Sodium Fill and Drain Circuit (SSFDC), which indicated piping vibration with low frequencies when EM pump is in operation. To avoid resonance, the bottom spring support in discharge line (between frozen seal valve and flow meter) was modified to a rigid support and an additional lateral support was provided to the valve. These modifications increased the natural frequency of the piping from 7 Hz to 16.5 Hz. Thermal stress in EM pump was computed based on an integrated model. It is seen that stress in EM pump nozzle is acceptable for all temperature 350°C.

Finalization of Core Flow Monitoring Strategy

Before criticality, it is essential to measure the primary sodium flow through various types of subassemblies for design validation. Since flow measurement is a time consuming activity, there is a need to optimize the number of subassemblies where flow measurement have to be carried out, (i.e) in the dummy core and in the first core. The strategy for this activity has been finalized and as per this, in the dummy core, flow measurement will be carried out by sampling method. In the first core, flow in all the un-monitored blanket subassemblies and fuel subassemblies where dummy core data has been collected, will be measured. To enhance the accuracy of the measurement in the present version of the devise, the core flow has been increased from 20% to 40% of the nominal value, paying critical attention to eccentric position of control plug w.r.t. core, low hot pool sodium level and flow induced vibration of control plug parts. This is arrived at based on 3-D CFD analysis of hot pool.

Finalization of Calibration Strategy for Bulk DND System & Design of Dry-Rupture Localization System

Calibration of bulk Delayed Neutron Detector (DND) system is to be carried out during commissioning. For this purpose, a special subassembly with bare metallic fuel pin will be mounted in various locations in core. These locations, the corresponding concentration of delay neutron precursors, and the procedure for DND calibration were finalized based on coupled reactor physics and thermal hydraulics analyses. Conceptual design of a new gas stripping device which separates gaseous fission products from sampled sodium for identifying dry rupture of fuel pin is completed. Hydraulic design of system and the feasibility study for accommodating the device in the FFLM are also completed.

Estimation of Additional shield Requirements for Spent Subassembly Washing Facility (SSWF) and Rad Waste Building (RWB)

The spent subassemblies are washed in SSWF located in fuel building. Additional local shields have been designed to enable easy maintenance of pumps circulating the liquid effluents. The activity contribution

is found to be mainly from Na-24, Mn-54 and Co-58. Along with the existing shields to the radioactive effluent tank, additional lead shields of thickness 1.5 cm at the top and 4 cm for side walls are found essential to bring down the dose rate under permissible limit. The in-vessel components undergo chemical decontamination process in RWB, where a thin layer of activated steel from the surface is removed by acidic leaching. The sources of activity considered include, activated corrosion products Mn-54, Co-58, Co-60 and Fe-59. Lead shield of thicknesses 3.0 cm and 7.0 cm are found required for the top and side walls respectively, separating the accessible areas, to meet the dose limits.

Estimation of Shield Requirements for Additional Spent Subassembly Storage Bay (ASSSB) and Criticality Analysis

The proposed ASSSB contains 232 fuel subassemblies, which are stored in a triangular pitch with pitch distance 320 mm. From detailed shielding calculations it is found that 105 cm thick normal concrete is required on the sides and 90 cm thick normal concrete is required at the top and bottom of the bay to meet the design limit of 10 Sv/h. Criticality analysis indicates that the value of k-eff in air and water flooded conditions are 0.51 and 0.6 respectively indicating the acceptability of 320 mm pitch.

External Flood Hazard Analysis for Kalpakkam Site

Hazard Analysis is one of the important steps in External Flood PSA. In this study different hazard analyses carried out for Kalpakkam site were compared. The hazards considered are rainfall, storm surge and tsunami. The recommended hazard curve for Kalpakkam site is arrived at. The total frequency of different flood levels were estimated from single hazard and combination of storm surge and tsunami hazards, for the purpose of Core Damage Frequency quantification. The estimated Core Damage Frequency due to external flood is determined to be 2.1E-08 /ry, which is acceptable.

Impact of Snubber Malfunctioning on Thermal and Seismic Response Characteristics of Sodium Piping

Hydraulic snubbers of various capacities are used in high temperature sodium piping systems. As per the regulatory requirements, the impact of malfunctioning of a few critical snubbers, on the performance of the piping system was analyzed. It is established that the stresses in the piping system is less than the ultimate stress.

Acceptability of Hot Pool Temperature during UTOPA Event & Decay Heat Removal Following Simultaneous Leak in Main and Safety Vessels

As per AERB stipulation, detailed 3-D transient CFD analyses of hot pool has been carried out for the event of Unprotected Transient Over Power Accident (UTOPA). Based on this study, the peak temperatures experienced by hot pool components, viz., control plug, IHX and inner vessel were determined to be 832°C, 745°C and 736°C respectively. The properties of SS-316 for this high temperature have been extrapolated. Then, the creep damages to these components were determined and found to be < 0.5, which is acceptable. In a postulated scenario of leakage in safety vessel after a main vessel, decay heat has to be removed only by steam-water system. By 3-D coupled CFD analyses of hot and cold pools, it is established that the decay heat can be safely removed from the core, if safety vessel fails 5 h after main vessel failure.

Design of Future FBR

Design Safety Limits for Bulk Temperature of Hot and Cold Pools

Creep-fatigue damage assessment of hot and cold pool components viz., Inner Vessel, Main Vessel, Control Plug and Intermediate Heat Exchanger (IHX)) was completed, using the latest design code (RCC-MRx, 2012) considering stress relaxation phenomenon. IHX is found to be the governing component. Based on this study, Design Safety Limits for hot and cold pools were finalized.

DYANA- P Code Modification and Events Analysis

DYANA-P code which is used for carrying out plant dynamics studies for PFBR has been modified for

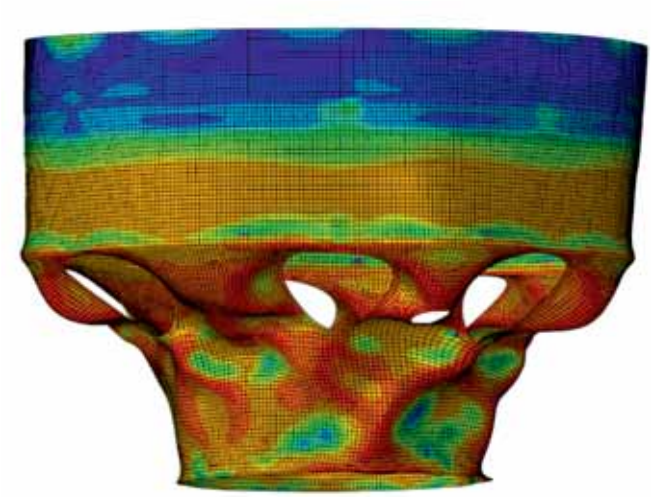
its application to FBR1&2. Code modification has become essential due to the increased number of primary sodium pumps and reduced number of steam generator modules. Following this, thermal hydraulic analysis of enveloping design basis events at full power conditions have been completed using the modified plant dynamics code (DYANA-P V2.0). It is observed that the maximum temperatures reached during the various events with SCRAM by the second trip parameter are well within the design safety limits specified for the category to which event belongs. Hence, safety of the reactor is ensured against the various enveloping DBEs. Events analysis during plant with two out of three primary sodium pumps in operation has also been completed and the permissible response times for various SCRAM instruments have been arrived at. Also, the number of SCRAM parameters has been reduced by 2 from that for PFBR. Evolution of flow and temperature fields in hot & cold pools and transient thermal loads on primary system components during various transients have been determined by 3-D transient CFD analyses.

Structural & Thermal Analysis of Main Vessel

Stress analysis of Main Vessel bottom, with redundant support for core support structure, was carried out for mechanical loads to determine thicknesses of various parts. To keep the stress intensities on different parts of the main vessel below the allowable limits, the curvature of the dished end has been modified and its thickness near triple point has been increased to 60 mm. With these modifications, both the supports can transfer the loads to main vessel individually. To maintain the main vessel below the creep regime, a cooling system is provided. The number and size of cooling flow outlet holes in the baffle plays an important role in deciding the free fall height of sodium and the associated concerns of weir instability as well as argon gas entrainment. Estimation of the required number of outlet holes and their size has been finalized along with tolerances on geometrical parameters.

Thermal Hydraulic and Structural Analyses of Inner Vessel

Steady state 2-D conjugate thermal hydraulic analysis of hot / cold pools was carried out and temperature field in inner vessel and heat loss from hot pool to cold pool were determined. Based on the temperature field, thermo-mechanical analysis of inner vessel was carried out. To reduce the stresses due to mechanical loadings at the inner vessel - standpipe junction, addition of flanges around the standpipes, is found to meet the permissible stress limits. Subsequently, buckling analysis of inner vessel under mechanical and thermal loads was completed for 3 imperfect shapes. It is established that the collapse load multiplier due to buckling is 4.4, which is more than the minimum limit of 2.64, indicating that inner vessel meets the imposed buckling strength limits with adequate margin.



Deformed shape at collapse load for a particular imperfection

Buckling Analysis of Core Support Structure (CSS)

Buckling analysis of core support structure has been carried out and the conceived design is seen to meet the buckling design criterion.

Conceptual Design of Redundant Support for Reactor Assembly

In line with the evolving safety philosophy, it is proposed to have a redundant support to roof slab integrated with main vessel. Structural and thermal analyses were completed to check the feasibility of the proposed concept. It is finalized to connect the redundant conical support to roof slab at an elevation matching with that of the top plate of roof slab. Stress analysis of roof slab for the revised box-type structure

(with redundant supports) has been completed for mechanical loads. The various stress limits are checked by considering one support taking load at a time. It established that both the supports are able to meet the design requirements in terms of stress with sufficient margin.

Gripper Design of Hydraulically Suspended Absorber Rod (HSAR) Drive Mechanism

HSAR is a part of passive shut down system, which protects the core in case of Loss of Flow Accident. The gripper holds HSAR during normal operation and pushes HSAR into the core during SCRAM. A snap-fit type design is completed for the gripper, taking into account of the larger holding forces in bowed subassemblies.

Design of Single Failure-Proof Hoist for Subassembly Transfer Flask

Design of subassembly transfer flask, which transfers core subassemblies from in-vessel to ex-vessel and vice-versa, has been completed. It consists of a hoist including dual wire rope, rope drum, pulleys, drum-shaft, gear box, holding brakes, drive motor and tension sensing mechanism.

Conceptual Design of Floor Valve

Fuel handling scheme requires several ports over to enable the handling of core components from the respective work posts. Floor valves are fitted over various ports to provide sealing as well as shielding during subassembly / transfer pot transfer at various phases of refuelling operation. Floor valve concept based on a rotating cylinder with eccentric hole has been finalized based on the merits / demerits in various options.

Safety Analysis

Unprotected loss of flow accident analysis was carried out assuming failure of hydraulically suspended absorber rods to drop. With the current core design with low positive sodium void, it is found that the transient does not lead to fuel slumping or Core Disruptive Accident (CDA). In spite of this favourable result, thermal analysis of containment following CDA has been carried out for two different design concepts, viz., single wall containment and double wall containment. It is seen that the maximum temperature seen by the outermost layer of the outer containment is 10 K less than that of maximum temperature of concrete surface in contact with air in single wall containment. Also, maximum pressure developed in double wall containment is less than that in single wall structure, suggesting double wall containment has significant benefits.

Design and Analysis Support to FBTR

Admissible Steam Outlet Temperature Difference in Steam Header

An increase in temperature difference between steam outlets of same module was observed during the operation of the reactor, when one Steam Generator (SG) module was replaced by a spare SG made of mod. 9Cr-1Mo. Hence, it was required to determine the admissible steam temperature difference. A detailed 3-D finite element analysis of the module was completed and it is established that the current steam outlet ΔT of 46°C meets the code limits with sufficient margin.

Effect of Change in Gripper Spring Design on Loading/ Unloading Force of Fuel Subassemblies

Gripper spring is provided in subassemblies, which holds the SA in its grid plate sleeve. Due to manufacturing constraints, the change in the design of spring is envisaged. Analytical methods and FEM analysis were carried out to quantify changes in the design based on stiffness change, stress concentration and change in loading-unloading forces. It was found that no appreciable change in stiffness occurs with this design change. As the design change has no significant effect on functionality of the gripper spring, the proposed changes to meet the manufacturing constraints are accepted.

Stress Analysis of Sodium Flooding Line

Weight, flexibility and seismic analyses of the existing sodium flooding line was carried out with the new valve added to the line. The existing supports were found to be adequate to meet limits of B31.1 piping code.

Blockage Analysis of Metal Fuel Test Subassembly

Analysis of sodium flow blockage through metal fuel test subassembly was carried out considering inter-subassembly heat transfer, to understand the temperature distribution in fuel, clad and sodium. It is established that even under 60% flow blocked condition, all the temperatures are well within the permissible levels.

Safety Analysis

As per the AERB stipulation, Hypothetical Core Disruptive Accident (HCDA) analysis for the 26th campaign core was completed with improved equation of state. The energy release from HCDA is found to be < 1 MJ which is very small compared to the reactor vessel design value of 39 MJ. This ensures complete safety of FBTR against HCDA.

Structural Mechanics and Reactor Physics R & D

Development of Creep-Fatigue Damage Assessment Diagram

In the case of Sodium cooled Fast Reactor (SFR), due to higher operating temperature and longer life, creep-fatigue damage is a major life limiting factor. Realistic life prediction of SFR components calls for nonlinear computational procedure to estimate creep-fatigue damage. Detailed computational analysis, including creep relaxation, creep-fatigue interaction and cyclic secondary stresses along with the creep relaxation effect has been carried out. As an outcome, a creep-fatigue damage assessment diagram specific to FBR 1&2 operating temperature and loading cycles has been developed for component design / qualification.

Fatigue Crack Growth Studies

Towards validating numerical simulation of Fatigue crack growth (FCG) behaviour, a plate specimen and a full-scale representative pipe bend were studied using the Franc3D software. The stress intensity variations for the plate specimen and pipe bend are found to be different, suggesting that for accurate simulation of FCG, full-scale piping component has to be modelled and it cannot be approximated by a plate specimen.

Neutron Attenuation Experiments with Concrete Blocks in KAMINI Reactor

In the south beam end of KAMINI reactor, neutron attenuation experiments were conducted with concrete blocks of density 2.4 g/cc and were compared with other hydrogenous materials. Four blocks each of dimension 30x30x10 cm were used and were arranged in the south pit using a stand. The overall thickness of the shield model was 42.4 cm. The measurement shows that the epithermal and fast attenuation pattern of concrete blocks are less than that of water & paraffin and it is almost comparable to polyethylene blocks.

Measurement of Neutron Flux and Dose Rate from Am-Be Neutron Source

Neutron spectrum, flux and dose were measured for the existing Am-Be neutron sources using the Nested neutron spectrometer. Measured data were also compared with computer simulations and a maximum deviation of 16 % was observed, validating the computer models.

Computational Model for Fission Gas Release and Swelling in Metallic Fuel

A mechanistic model of the swelling and fission gas release for U-Pu-Zr metallic fuel in a fast reactor was developed and validated against irradiation test results reported in open literature. For a fuel temperature of 550°C, the fission gas release is 73% and the fission gas pressure is 4.85 MPa at the end of 100 GWd/t burn-up. Hence, gas plenum length for metal fuel pin can be reduced by 23%.

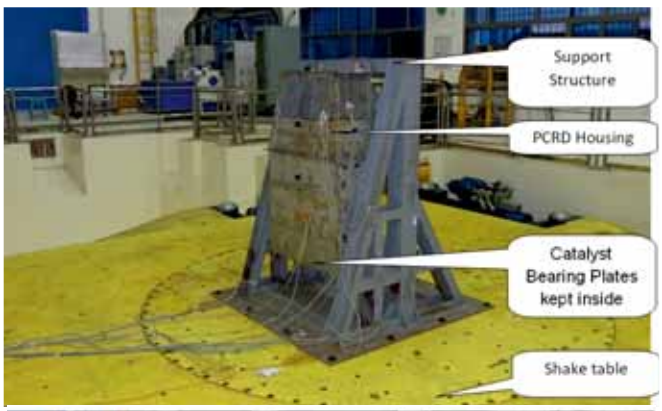
Revised Design of RISHI Loop along with Sodium Leak Monitoring System Loop

The heat exchange zone, specimen chamber and actuator mechanism are re-designed based on the requirement of increased heat removal from specimen chamber. Actuator mechanism, used for oscillating sodium in U-tubes is also modified to meet the requirement of longer oscillation height by introducing

dummy volumes in bellows. Further, a dedicated sodium leak detection system using argon has been designed. This system has an inherent advantage of sodium leak detection in the whole loop including space between loop and thimble. It also provides thermal insulation to loop from the reactor environment. This arrangement also relaxes the leak tightness requirement at the passage for the thermocouple in specimen chamber which otherwise is extremely challenging to manufacture. This system ensures a continuous flow of argon in all the zones of the loop before finally passing through the sodium leak detection system located outside the reactor vessel.

Seismic Qualification Tests using 100 t Shake Table Facility

A new type of Passive Catalytic Re-combiner Device (PCRD, Type–B1) housing along with Catalytic Bearing Plate (CBP) developed jointly by BARC & NPCIL for thermal reactors, and fabricated by ECIL has been tested successfully as per NPCIL test procedure. Based on the test results, it is proposed to provide locknuts for the PCRD mounting bolts in order to qualify the device for seismic condition. Seismic qualification tests have been completed for controller panel used in primary argon cover gas circuit heaters of PFBR. Based on pre-test, intermediate-test & post-test inspections carried out by IGCAR & BHAVINI, it was established that panel meets the seismic criteria. The function of Supplementary Control Panel (SCP) in FBTR is to facilitate necessary controls for safe shutdown of reactor, ensure decay heat removal and monitor integrity of the containment in case of Main Control Room becomes uninhabitable. As per AERB stipulations, seismic qualification tests on SCP were conducted and it was demonstrated that SCP along with its junction box meets the required seismic criteria. Seismic qualification of limit switches, micro switches, solenoid valves, transmitters and pressure switches for thermal reactors plants of NPCIL was completed.



Seismic qualification tests on Passive Catalytic Re-combiner Device (Type–B1) housing along with catalytic bearing plate (above) and Seismic qualification tests on supplementary control panel along with junction box for FBTR (below)

Functional Testing of Large Diameter Bearing Qualification Rig

A test facility for testing of 4.6m bearing under simulated operating conditions, viz., load, temperature and temperature difference across the races, as in the reactor has been constructed and commissioned. Functional tests at 50-230 t loads and the torques required to rotate the bearing were continuously monitored and found to be within the acceptable range.

Testing of large diameter bearing at IGCAR

R&D on FBRs

Commissioning and Operation of Mobile Purification Loop for Purification of FBTR Flooding Circuit Sodium

The Flooding circuit of FBTR consists of two sodium tanks containing total sodium inventory of 64

m3. A separate purification system is planned to be installed for purifying this sodium. For this purpose, a Mobile Purification Loop (MPL) was made ready and the loop was commissioned successfully. The loop was operated at 250 °C and purification of 0.6 m3 sodium in dump tank was carried out. The oxygen concentration was brought down to < 2 ppm. The loop was shifted to FBTR for purification of flooding circuit sodium.

Mobile Purification Loop

Development of Out-of-pile Version of Fuel Instrumented Capsule

Out-of-pile version of fuel instrumented capsule to measure the centre-line temperature of metal slug and the outside surface temperature of clad tube of dummy fuel pin using thermocouples has been developed. The out-of-pile test has been designed to simulate the main features of fuel instrumented irradiation capsule and to demonstrate the technology development. Sodium was filled in the dummy fuel pin around the metallic rod representing the metal fuel slug. This capsule was tested in a vertical furnace up to 700 °C and the performance was found to be good.

Out-of-pile version of fuel instrumented capsule (left) Testing in Electrical Furnace (right)

Development of 2 t Hoist for Remote Disassembly & Material Handling within Argon Containment in the Engineering Scale Pyro Facility

Photograph of 2 t Hoist (left) Silicon Oil Test Setup of ultrasonic transducer showing pulse echo at 250ºC (right)

Pyro Chemical Processing is normally carried out in leak-tight containment box in high purity argon atmosphere. It is essential to minimise the penetrations and maximize the inert gas containment duration for maintenance operations. In order to facilitate break-down maintenance of the power manipulator and in-cell crane within the inert containment, an ante-chamber with a special-purpose hoist has been developed in the process containment box. The hoist has been successfully installed and commissioned inside the containment box in Pyro-Processing R&D Facility. The remote handling trials are underway inside the facility.

High Temperature Testing of Indigenously Developed 2MHz Ultrasonic Transducer

Under Sodium Ultrasonic Scanner (USUSS) has been developed to detect protrusion of fuel sub-assemblies in PFBR. To improve the capability of the scanner for use upto 250°C of sodium temperature, a new method of bonding the PZT crystal to diaphragm called Diffusion bonding technique has been developed. 2 MHz transducers have been fabricated by the new technique for use in place of 5 MHz downward viewing transducers. Its performance has been qualified by testing in water and in- sodium testing is planned.

Design and Development of a High Speed Data Acquisition System for PFBR SG Tube Inspection

Prototype Fast Breeder Reactor (PFBR) Steam Generator (SG) Inspection System (PSGIS) is indigenously designed and developed by IGCAR for the remote inspection of SG tubes. As a part of Pre Service Inspection (PSI) campaign, eight SGs were inspected at PFBR site. Based on the calibration tests, the speed of inspection using Remote Field Eddy Current (RFEC) testing probe was set at 20mm/s. It was observed that in

HSDAQ - HMI control panel

the total duration of inspection of SG tube, significant time is consumed by the RFEC probe during its insertion and withdrawal, and travel of the probe over the entire length of 23m of SG tube. As an effort to reduce the inspection time, it was proposed to increase the speed of inspection by the RFEC probe. A High Speed Data Acquisition System (HS-DAQ) has been designed and developed with high speed pushing mechanism, data acquisition and data storage features. Based on various qualification tests, it is proved that the data obtained from the HS-DAQ at higher speeds are consistent with the data collected at 20 mm/s. The system with high speed was deployed in the Steam Generator Test Facility (SGTF) with 23m long tube and the performance of the system was validated.

Development of Sodium Resistance Geo Polymer Concrete (GPC)

Geo polymer based sodium resistant concrete is being developed at IGCAR as protective floor liner for future Fast Breeder Reactors. Qualification tests were carried out on GPC test specimens by subjecting to sodium at 500°C in air. Pre and post-test chemical analysis and destructive/ non-destructive tests revealed that sodium penetration depth is below 20 mm and reduction in compressive strength is below 10% confirming better sodium resistance capability of GPC compared to limestone concrete. Further experiments are planned with variable compositions.

GPC Concrete Specimens; Testing in sodium fire

Performance Evaluation of DCCP and PMFM of FFLM

Sodium testing of 0.36 m3/h DC conduction pump used in Failed Fuel Localisation Module (FFLM) for sampling the sodium coming out of fuel subassemblies was carried out. Sensitivity evaluation of the Permanent Magnet flow meter used in FFLM to monitor sodium flow was also carried out. Performance of both the equipments are found to be satisfactory.

Photograph of FFLM PM Flow meter

Development of Indigenous Control Rod Gripper Bellows for FBTR

Gripper bellows for FBTR Control Rod Drive Mechanism were indigenously developed. The bellows are tested in sodium in Test Vessel-2 of Large Component Test Rig. The bellows are found healthy after 230 cycles of operation and 100 hrs of hold at 530°C and hence qualified for their use in FBTR.

Design, Development and Testing of sodium submersible miniature size Annular Linear Induction Pump (ALIP)

A prototype sodium submersible miniature size Annular Linear Induction Pump (ALIP) of flow rate 0.36 m^3/h and 1.45 kg/cm^2 head capacity has been designed,

manufactured and tested in sodium loop at 560°C. Overall diameter and length of ALIP are 108 mm and 980 mm respectively. This development has potential to replace bulky DC conduction Pump.

Fabrication of Irradiation capsule containing W & WC specimens

One of the life-limiting factors for FBTR is the degradation of the grid plate structure due to neutron irradiation. Research and development of alternative shielding materials have lead us to identify tungsten and tungsten carbide as a better effective shielding material. Irradiation Capsule containing tungsten (W) and tungsten carbide (WC) specimens has been fabricated and delivered to FBTR for irradiation in the core. The irradiation capsule has three partitions each containing W & WC samples in pellet and thin disc forms. The partitions are filled & sealed with helium gas at a pressure of around 2 kg/cm^2. Tungsten carbide would be used as lower axial shield material in the future fuel sub-assemblies to extend the life of grid plate which determines the life of FBTR.

Irradiation capsule containing W & WC specimens and the steel carrier subassembly required to load the capsule in FBTR

Endurance testing of Transfer Arm gripper central guide in sodium

Transfer arm (TA) is an offset arm type in-vessel fuel handling machine of PFBR. An additional central guide-rail arrangement was provided between the offset link and the connecting piece of the TA gripper for centering and better alignment of actuator rod during finger operation. The central guide design was experimentally validated for catering to the initial core loading by endurance testing it in sodium. The testing was carried out with simulated reaction load on the central guide of Mark-II transfer arm gripper with similar modifications carried out in PFBR TA. The testing and qualification were carried out in three stages, in air, hot argon and finally for 6000 cycles in sodium at 200°C. The performance of the machine was satisfactory and the load cell reading for raising and lowering of inner tube assembly in gripper was well within limits.

Modified central rail – guide arrangement

Control systems & sensors

Development of Molten Salt Level Measurement Probe for Pyroprocessing Plant

Molten LiCl, KCl eutectic salt is used as the electrolyte in pyro chemical method for reprocessing of spent fuel from metallic fuel reactors. The operating temperature of the electrolyte is 500°C and the salt is hygroscopic in nature. At present commercial instruments are not available in the market to measure the molten salt level. A level probe was successfully developed for measurement of the molten salt level. A level probe of range 0 to1000 mm is fabricated and it is shown in the figure.

A level probe of range 0 to 1000 mm

Porting and Development of Simulator Development Platform on x64 hardware

Porting and development of Simulator Development Platform on x64 hardware was taken up, to replace DEC Alpha servers with Intel x64 based commodity hardware as Alpha servers were becoming obsolete. This work involved creating a simulator runtime environment above CentOS and porting of all the simulator components like Process modeler, Logic

modeler, Instructor, external modules etc. It also involved development of new libraries using GTK/ Cairo for drawing directly to the GUI windows and string libraries along with migration of the database. Further, the commercial library used for virtual panel development was replaced with Genlogic tools by developing new template widgets to emulate the functionality of analog and digital meters, switches, pushbuttons etc.The functionality testing and performance evaluation of ported version of Simulation tool was carried out and found to be satisfactory.

Implementation and integration of Digital Signature based authentication for in-house developed web applications

A digital signature based authentication scheme has been developed for in-house developed web applications. To implement this scheme, a public key infrastructure (PKI) has been deployed with Certifying Authority (CA), Online Certificate Status Portal (OCSP) and Time Stamping servers for creation, administration, distribution and revocation of digital certificates of users. A digital signing client software has been developed to interact with web application and PKI server to digitally sign the PDF document from user desktops. Also a web based user interface has been developed to facilitate creation of certificate signing request (CSR), changing of certificate passphrase (PIN) and creation of certificate store either in PKCS12 or hardware token. The PKI and digital signing software has been integrated with online APAR portals of IGCAR, GSO and DPS.

Development of Network Diagnostic Data Visualization and Analysis Software for WSN

To diagnose deployed WSN behaviour in real time, a data analytic software framework for WSN data has been developed. This framework assess the performance of deployed WSN in real time and derive performance and behaviour matrices. In this project, in-house developed Wireless Channel Monitors (WCM) has been used to capture network data from Large Scale Test Bed (LSTB). Parsed, classified and tagged data from WCM were then sent to centralized server to classify link quality and assess the WSN behaviour. Web based Wireless Network Management station (WNMS) has been developed to display dynamic network topology based on derived information.

Deployment of Virtual Desktop Infrastructure (VDI) and High Definition (HD) Graphics enabled virtualized workstations

In order to meet the desktop computing requirements of IGCAR, a high quality, secured, low-cost, low-maintenance virtual desktop infrastructure solution has been deployed with a centralized data centre and ultra-thin clients. The VDI setup consists of 22 numbers of high-end servers, a unified storage of 185 TB usable space to support 1000 virtual user desktops. A pilot HD Graphics virtualized thin-client based solution was developed and deployed. These virtual graphics workstations are designed for delivering professional 3D graphics applications (CAD/CAE) from data centre to distributed user desktops through thin-clients.

Virtual Desktop Infrastructure Facility at IGCAR

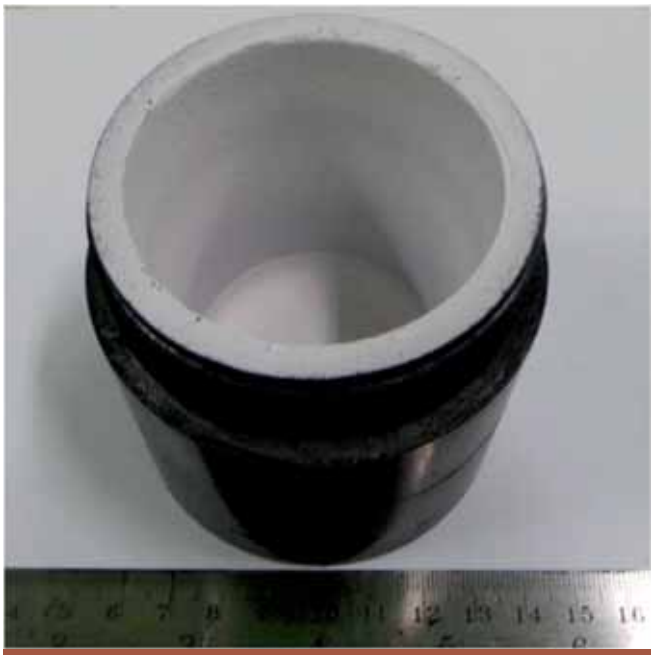
3D modeling & Animation

Modeling of Block 1 and 2 of Fuel Reprocessing Plant of FRFCF consisting of civil structure and process equipment was done with animation of process-workflow.

STUDIES ON MATERIALS FOR FBRs

Yttria coating on Graphite crucibles used in pyro-chemical reprocessing

Large capacity high density Graphite crucible, used in salt distillation, melting and consolidation of



Yttria coated Graphite crucibles used in pyro-chemical reprocessing

uranium dendrites during cathode processing step in pyro-chemical reprocessing, has been successfully coated with yttria of 200-250 μm thickness using Atmospheric Plasma Spray technique. An optimized spray power of 20 kW was used for the coating, after thorough alumina grit blasting (100 mesh angular alumina with 1.5-2 bar pressure) to achieve better mechanical interlocking and adhesion. The coated crucible is found to be suitable for operation up to 1400 °C and can handle molten salts and U/Pu/Zr.

Yttria-coated High density graphite (HDG) crucible with SiC as an interlayer

A novel pack cementation method was used to develop SiC interlayer followed by top yttria coating on HDG crucibles. Thermal cycling of the sample at 1450 to 1550°C performed in the high-temperature tubular furnace and induction melting of uranium was carried out in an inert argon environment. The formation of β-SiC with cubic crystal structure after pack cementation is confirmed by XRD studies. SiC coating of thickness 150 μm was achieved by pack cementation with 200 μm top yttia coating. The coating with SiC interlayer withstood more than 25 cycles while without SiC interlayer the coating cracks/delaminates in less than few cycles at 1550 °C. Five uranium melting cycles are carried out in yttria-coated HDG crucible with SiC as an interlayer.

Nano layer copper coating inside the Ti condenser tubes using electroless technique

To control bio-fouling Ti condenser tubes, nanoscale copper film is deposited on them using electroless plating. Microbiological studies showed two orders reduction in bacterial counts on the copper coated tubes, as compared to tubes without coating. The 3-dimensional confocal images of biofilms on uncoated and coated tubes showed a lower biofilm thickness on copper coated surface after two month exposure in seawater, owing to the presence of copper ions with antimicrobial property on the surface.

Development of Super-Hydrophobic Coating on Copper

A simple and economic method of Super-Hydrophobic (SHP) surface modification of copper surfaces with a water contact angle of 147°C and a roll-off angle of 5°C have been developed. Electrochemical studies in aqueous chloride environments demonstrated the corrosion resistance of super-hydrophobic copper surface.

Corrosion analysis of FBR components

Corrosion analysis of failed thermo-syphon evaporator used for acid killing of intermediate level waste streams of Kalpakkam Atomic Reprocessing Plant (KARP) has been completed and measures to mitigate such failures have been recommended. Intergranular corrosion failure was found to be due to transpassive dissolution of 304L SS, caused by prevailing high redox potential in the heat affected zone (HAZ), and the accelerated corrosion due to autocatalytic reduction of nitric acid vapours in the presence of formaldehyde. The corrosion of BIS markings on the main vessel and safety vessel due to impurities in nitrogen has been simulated at 600°C. It is found that the degradation of the markings will be insignificant if the oxygen and moisture content in nitrogen is maintained below 476 and 165 volume ppm, respectively.

High-temperature molten salt corrosion in pyro-chemical reprocessing environment

The corrosion behaviour of 9Cr-1Mo steel in

molten LiCl-KCl salt exhibited the formation of intermittent oxide film. Elemental analysis showed that the mode of corrosion is due to segregation and enrichment of alloying elements Cr and Mo. The corrosion resistance in the high-temperature LiCl-KCl molten salt is found to be strongly related to the nature of oxides, the materials composition and the molten melt composition.

High Performance Green Concrete (HPGC) with improved strength and chloride ion penetration resistance

A novel high performance green concrete has been fabricated by incorporating fly ash, nanoparticles and corrosion inhibiting admixture into conventional M45 grade concrete. The new concrete showed a homogeneous distribution of hydration products over the surface with gel pores at the nanoscale, which enhanced the compressive strength, flexural strength and split tensile strength. The chloride ion penetration resistance, carbonation, water permeability and water adsorptivity of new concrete were also found to be superior as compared to conventional concrete.

Production of Phase Pure Tungsten Carbide (WC) pellets by spark plasma sintering (SPS) for FBTR irradiation experiments

In order to extend the life span of FBTR grid plate, attempts are being made to provide adequate axial shielding against fast neutron irradiation by introducing sub-assemblies incorporating tungsten carbide (WC) as shield in place of stainless steel. To produce high density pellets of WC, without making use of any additives such as Co or Ni, Spark Plasma Sintering (SPS) technique has been employed. Optimized SPS process parameters were identified after extensive experimentation and characterization studies. Using these process conditions, regular production of phase pure WC is being carried out at 1750°C/14kN force, employing a vacuum of 10^{-3} Pa.

Spark Plasma Sintering Facility at IGCAR used for WC pellet fabrication

Plasma Nitriding of model FBR components: a feasibility study

Plasma Nitriding (PN) is considered a viable alternate, clean low temperature process for controlled hard-facing of various FBR components that experience wear and fatigue. The process enables highly reactive nascent nitrogen ions to diffuse into the subsurface of a component and thereby produce a hard nitride layer with high hardness. Based on key experiments conducted at IGCAR, the process capability to nitride austenitic stainless steel and 9Cr-1Mo ferritic steel components were established, and appropriate technical process specifications have been drawn.

Plasma Nitrided Casing ring of PFBR secondary sodium pump

Deloro-50 hardface alloy deposits on austenitic steel by laser rapid manufacturing– Characterization and thermodynamic modelling

A feasibility study has been initiated in collaboration with RRCAT, Indore to fabricate Ni-based hard-face alloy deposits on austenitic stainless steel by

employing laser rapid manufacturing technique. After optimizing the process parameters, deposits of Deloro 50 hard-facing alloy were made and these were characterized using a variety of techniques.

Generation of Thermophysical Property data on indigenously developed FBR Materials

Comprehensive material property database comprising information about thermal stability and high temperature thermophysical properties has been generated for soft magnetic iron, pure Mo and 51Ni-36Fe-13Co (wt%) alloy which are used in various parts of temperature sensitive electromagnetic switch of DSRDM. In a similar fashion, the high temperature thermophysical properties of WC pellets were fabricated by spark plasma sintering have also been measured.

Experimental and theoretical study of microstructure characteristics and phase stability in Equiatomic CrFeMoV alloy

Phase stability in equiatomic CrFeMoV alloy prepared by casting is studied through experimental and theoretical analysis. Microstructural analysis showed a dendritic microstructure with a micro segregation of Mo and Fe to dendrites and interdendrites respectively. BCC structure of dendritic and inter-dendritic regions with lattice parameters of 0.299 ± 0.02 nm and 0.297 ± 0.02 nm were identified by XRD and TEM analysis. Detailed first principles calculations predicted the energetically stable crystal structure of the CrFeMoV alloy to be cubic F-43m with lattice parameter of 0.57594 nm, where the enthalpy of formation of the alloy is computed to be -10.543 eV/atom. The analysis suggests that it is possible to obtain a stable BCC solid solution in this equiatomic Cr-Fe-Mo-V alloy, suggesting its suitability of being a good candidate core structural material for nuclear applications.

Quantitative HRTEM Analysis of Strain Assessment along the Defect Cores in Cryo-rolled CP Ti

A quantitative estimation of strain has been carried out along the defect cores of severely cryo-rolled CP Ti from the aberration corrected atomic resolution TEM micrographs. Image aberration corrected phase contrast micrographs, which are already well analysed in terms of structural information, are subjected to Geometrical Phase Analysis (GPA) to generate the strain map. The map has been normalized with respect to the minimum strain region. Relative variations of strain across the defect cores have been generated. However in the atomic resolution images several linear contrasts can be observed which are postulated to be originated from the accumulation of the localized strain during rolling. Quantitative electron microscopy analyses using the GPA methods are employed to confirm the generation of these linear contrasts due to the localized strains.

Mechanical Property Evaluation of FBTR Grid Plate SS 316 Material Irradiated to 6.75 dpa

Neutron irradiation damage to the grid plate (type 316 stainless steel) which supports the core sub-assemblies is one of the major factors considered for life extension of Fast Breeder Test Reactor (FBTR). Towards assessing the ductility exhaustion of grid plate material due to low dose neutron irradiation and facilitating life extension of FBTR, an accelerated irradiation experiment was conducted in FBTR. Tensile and disc specimens of SS316 grid plate archival material stacked in an experimental capsule and housed in an experimental carrier sub-assembly was irradiated in IV ring of FBTR core to neutron damage in the range of 2.3 - 6.75 dpa (displacements per atom). Tensile testing of grid plate grade SS316 samples carried out remotely in the hot cells indicated progressive increase in yield and ultimate tensile strengths (hardening) and a corresponding reduction in elongation (ductility loss) with increasing radiation dose. The uniform elongation of FBTR grid plate SS316 specimens subjected to 6.58 to 6.75 dpa and tested at 380°C was in the range of 12-15%. Considering an operational limit of 10% residual ductility, it is inferred that FBTR grid plate can safely operate from the present neutron damage level of 2.1 dpa to 6.75 dpa.

Microstructural and Phase analysis of irradiated FeB shielding material

Ferroboron is a prospective material which can replace stainless steel and boron carbide as in–vessel

neutron shielding in Fast Breeder Reactors which can result in significant cost savings. An accelerated test irradiation of a capsule with ferroboron filled stack was carried out in FBTR with the aim of establishing its in-reactor performance over a target life-time of 60 years. Microstructural analysis using optical microscopy followed by SEM and phase analysis using XRD was carried out to evaluate chemical interaction between the ferroboron and SS304L clad. Optical microscopy studies indicated that the cladding of the sub-capsule corresponding to the axial location of maximum neutron fluence has undergone wall thinning due to chemical interaction with ferroboron. Detailed analysis using SEM indicated that the interaction phase extend up to 200 μm, from the clad inner surface. The phase analysis using XRD also confirmed the formation of the Lithium rich interaction phase of "Fe0.5Li0.217" at the interface due to (n,A) reaction.

Lead cell commissioning activities for PIE of metal fuel pins

Phase-I lead cell is being commissioned for the characterisation of irradiated metallic fuels under high-purity nitrogen atmosphere. As a part of the commissioning, remote optical microscopy system with a compact motorised X, Y, Z stage has been designed, fabricated and installed. A modular type crane of 50kg capacity has been designed for installation in the lead cell which consists of a stepper motor driven long travel having a travel range of 3960 mm, manually operated cross travel motion and hoist motion. The crane is of rugged construction such that it is failure proof. Three glove boxes with compensatory shielding have also been designed and fabricated for interfacing with the lead cell containment box to allow for maintenance of in-cell equipment and other operations.

Establishment of a new transfer device for irradiated FBTR sub-assemblies

A new 28-ton lead shielded cask with an internal mechanism called Pot Transfer Device (PTD) has been devised for the transfer of irradiated FBTR Fuel Sub-Assemblies (FSAs). The PTD has provisions for remote operations such as locking of the pot containing the FSA lifted into the cask, translation of the pot out of the cask and rotation of the pot for leak-proof transfer of FSA into hot-cell for further operations. Fabrication and testing of PTD has been completed.

Commissioning of 100 kN capacity Advanced Tensile Testing Machine 3-Directional Laser-Video extensometer system

A 100 kN capacity screw driven tensile testing machine with 3-directional laser-video extensometry for measurement of full-field strain and necking measurements at ambient and high temperature up to 1000°C has been established. Tensile properties of Mod.9Cr-1Mo steel and SS 304LN with specimens extracted from base, weld and heat affected zone, have been evaluated. During the tests, local strain fields have been assessed using Digital Image Correlation technique (DIC).

100 kN capacity screw driven tensile testing Machine with 3-directional laser-video extensometry

100kN capacity servo-hydraulic FCG test system

Commissioning of 100 kN Fatigue Crack Growth (FCG) Study Units

Two servo-hydraulic test systems are commissioned recently for characterization of fatigue crack growth properties of high temperature materials like Mod.9Cr-1Mo steel, SS 316L(N) base and weld, Alloy 617M etc. The test systems are attached with high temperature furnaces and online crack growth (DCPD) monitoring devices.

Development of In-Situ Deformation and Fracture Characterization Facility

A facility for in-situ deformation and fracture characterization of high temperature materials has been commissioned. This system enables tensile and fracture testing experiments in the vacuum chamber of scanning electron microscope (SEM), using a mechanical stage with loading up to 5 kN. The test system also allows interrupted stops to observe the possible crack initiation and growth. This system would help to interpret the influence of the local microstructure and texture on the deformation and fracture properties at smaller length scales (less than 1 mm). Figure shows the mechanical stage and the short and long crack growth data SS316LN.

Mechanical stage for the in- situ deformation and fracture characterization

Development of Thermo-mechanical Treatment (TMT) methodology to enhance Tensile and Creep properties of RAFM Steel

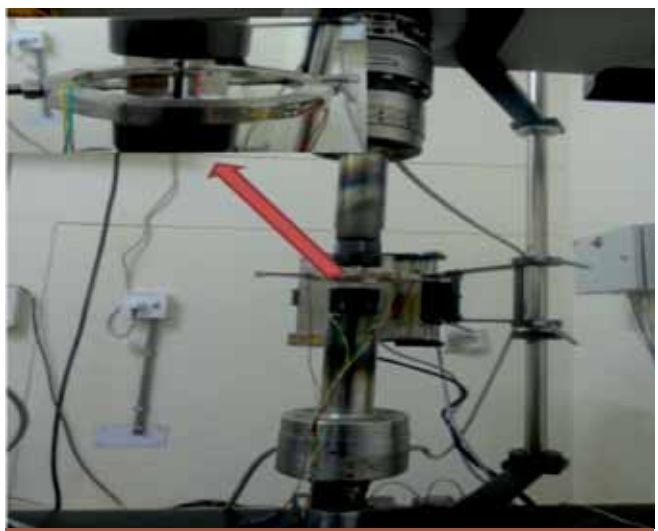
Reduced Activation Ferritic–Martensitic (RAFM) steel is being considered as the candidate material for the test blanket module of Fusion Reactor. One of the methods of improving microstructural stability of these steels, to enhance strength properties, is by Thermo-mechanical treatment (TMT) methodology. Substantial improvement in creep properties and rupture behaviour are observed after subjecting the steel to TMT (i.e. warm working before final tempering heat treatment) and is credited to the refinement in material microstructural features (such as lath width, M23C6 and MX precipitates) compared to the steel in conventional Normalised and Tempered (N+T) condition.

Development of Improved Continuum Creep Damage Model for Long-term Creep Behaviour of Grade 91 Steel

Improvement has been made into a continuum creep damage model by incorporating the influence of individual precipitates in Grade 91 steel on its long-term creep behavior. The creep law is modified to incorporate the various changes in the material microstructure (such as precipitate coarsening, formation of new phases, etc.). The model has been able to predict the creep strength of the steel for the creep rupture lifetimes of 40 years.

Commissioning of Fretting Fatigue Test System

Fretting fatigue occurs when two components are in contact and one of them is subjected to cyclic loading. The fretting fatigue specimen and fretting pad have been fabricated adhering JSME S 015 – 2009 guidelines. Data logging instrumentation for the strain gauge output to measure the contact pressure on the



Fretting Fatigue test set-up

specimen has been developed in-house. Fretting action introduces stress concentration and reduces the fatigue life.

Digital Image Correlation (DIC) to Characterize and Analyze Deformation Behaviour in 316L(N) Weld Joint

Digital image correlation (DIC) technique was employed towards understanding the strain incompatibility between the weld and the base metal zones of 316 LN SS weld joint in both as-welded and thermally aged (873 K, 1000 h) conditions under tensile deformation (which were carried out at 298 K with a strain rate of 1×10-4 s-1). In the as-welded condition, the base metal takes most of the applied strain in the low strength region during tensile deformation due to metallurgical notch effect. However, thermal ageing imparted a softening effect on the weld metal and considerable reduction in the severity of the metallurgical notch, leading to an increase in the ductility of the weld joint.

Towards Setting up of In-Situ Irradiation Creep Facility at IGCAR

Design of in-situ Irradiation Creep Facility (ICF) has been finalized and is in the final stage of procurement. Generating precise irradiation creep data in a nuclear reactor is cumbersome, time consuming and challenging, apart from the restriction in experimental conditions. ICF in a linear accelerator using proton beam is a unique facility and is being developed first time in India. Thermal creep and swelling compensated irradiation creep curve can be generated in ICF. Temperature of sample can be maintained well within +1° through manipulating proton beam current, heater current and liquid indium cooling. Thus, it is possible to carry out dose rate change and temperature change experiments in a single irradiation creep experiment and generate thermal and swelling compensated irradiation creep equation.

Design and Development of Miniature Setup for Performing Hot Extrusion of Rods and Tubes

A miniature hot extrusion setup was designed and developed for parametric studies on hot extrusion of rods and tubes at laboratory-scale as well as to optimize extrusion process parameters, so that cost, time and material expenditure during industrial extrusion processes could be reduced. The miniature modular extrusion setup, shown in is attached to a 10-ton high temperature compression testing machine. The setup can perform extrusion at temperatures ranging from room temperature to 1200°C at variable speeds up to 1.5 m/s. Successful extrusion of 20 mm outer diameter rods as well as tubes have been carried out, some products of which are shown in Fig. 50(b). These extrusion trials are being used to assess the effect of workpiece-die friction and its impact on extrusion load and product quality.

Miniature hot extrusion setup mounted on 10-ton compression testing machine (left) Expanded view of miniature extrusion setup and extruded forms (right)

Development of Quenching and Partitioning Heat Treatment to Overcome Temper Embrittlement Induced Cracking in AISI 410 SS Used as a Sprocket in PFBR

AISI 410 SS is used as a sprocket in PFBR in the normalised and tempered (N&T) condition followed by nitriding. This steel reveals cracking due to temper embrittlement on tempering at 550°C. A quenching and partitioning (Q&P) heat treatment process is developed which improves the toughness of the steel from 5 – 20 J to 35 J leading to a change from intergranular to typical dimpled ductile fracture. Modified heat treatment ensures that components are free from cracking and mechanical properties are improved.

Establishment of Automated Orbital-TIG welding facility

Orbital-TIG (Tungsten Inert Gas) welding machine is an automated welding facility installed at MJS / MDTD. Procedure qualification for similar weld joints of Alloy 617M and 304H Cu SS tubes and

dissimilar weld joints of Alloy 617M / 304H Cu SS tubes are being carried out. These weld joints are to be employed as super heater/reheater tubing in Advanced Ultra Super Critical (AUSC) coal fired power.

FBR - FRONT END FUEL CYCLE

At BARC, for the quality assurance of FBTR fuel, 51 (U, Pu)C samples were analysed by electrochemical method for uranium and plutonium content. Isotopic composition of Pu was analysed by Thermal Ionization Mass Spectrometry (TIMS) complemented with alpha spectrometry for ^{238} Pu and ^{241}Am determination. As a part of the chemical quality control of FBTR fuel and Pu bearing nuclear materials, about 140 samples including (U-Pu)C,(U-Pu)O_2, BeO, Pu-Ga, U-Pu-Zr and Th-U-Nb alloy samples were analysed for 22 trace metallic impurities using DC arc-AES and ICP-AES methods. Analytical methods were developed using EDXRF and AES techniques for advanced ternary alloy fuels such as U-Pu-Zr and Th-U-Nb and technical/nuclear grade BeO. The analytical methods were validated using suitable interference free analytical lines and synthetic samples.

Boron based refractory materials like borides of Zr, La, Ce, Ti and Ti-Cr as well as boron carbide are neutron absorbers which have applications as control/shut-off rod and/or shielding materials in nuclear reactors. Total boron concentration and its Isotopic Composition (IC) of these materials were determined by Particle Induced Gamma-ray Emission (PIGE) using 4MeV proton beam from Folded Tandem Ion Accelerator as a part of the Chemical Quality Control. For total boron concentration, an in-situ current normalized PIGE method with Fluorine as the current normalizer was used. As a part of quality assurance, IC of boron was determined by TIMS and total boron mass fraction was determined by conventional analytical methods.

A system for combined gamma-ray spectrometry and calorimetry has been set-up for non-destructive assay of plutonium. The set-up consists of a low energy photon spectrometer (2 cc planar HPGe detector) and a radiometric calorimeter. The quantity of plutonium in a sample assay of SNMs is obtained from gamma-ray measurement using low energy photon spectrometry for determination of isotopic composition of plutonium and 241Am, and calorimetric measurement of the total power output from the sample. The present measurement set-up is well suited for the assay of non-standard geometry samples with different chemical forms most common in radiological facilities.

A miniature Spectrophotometer was developed for monitoring U (VI) concentration at a higher range in aqueous stream. The setup is capable of monitoring U concentrations in different stages of extraction simultaneously using fibre optic probes and LED light source (λmax=471.5 nm). Uranyl (VI) ions exhibit five absorption peaks at 403, 415, 426, 467 and 485 nm having different molar extinction coefficients. The setup was tested for continuous production of U (IV) from the reduction of U (VI) by monitoring 665 nm absorbance peak using a LED light source having 665 nm emission wavelength.

To reduce radiation exposure to operators and to increase the throughput, BARC has developed various automation technologies for implementation in the fuel fabrication stage in PFBR. Automation technologies have been developed for powder handling, pellet sorting, pellet stacking, pellet loading into fuel pin, fuel pin number identification and storing by imaging technique and pin loading into transport magazine. The technologies developed will be deployed in the fuel fabrication line in AFFF, Tarapur.

Commissioning of a Characterization Laboratory for Metal Fuel Programme

Metal fuel slugs are produced by injection casting process and the slugs have to be qualified by physical, chemical & metallurgical characterisation methods. The characterisation laboratory has five Glove Boxes (GB) housed with equipments for preparing sample and evaluating the metal fuel slugs. The physical characterization setup has equipments comprising low speed cutting machine for sample cutting, hydraulically operated mounting press for mounting the sample and inverted microscope for metallography. The chemical characterization setup has equipments for measuring non-metal impurities using C-S, O-N analyser, EDXRF machine and plenum gas analyser.

Specimen mounts were prepared & tested to validate pressure, time and temperature cycle, mould

assembly quick ram return mechanism, water cooling arrangements, good finish of embedded sample etc. Percentage level measurements of sulphur, carbon, oxygen and nitrogen in U-Zr samples were carried out. Plenum gas analyser with pin puncturing device measures plenum gas pressure and purity filled inside the sodium bonded metal fuel pin. The plenum gas was extracted, measured for pressure/volume and analysed for purity, composition by gas chromatography. The results were found matching with filled gas mixture compositions. EDXRF spectra of calibrated samples for the determination of uranium were obtained. Glove box-with equipment and instruments was leak tested, commissioned and connected to argon recirculation & exhaust system.

Characterisation laboratory where glove boxes with instruments are housed

FBR- BACK END FUEL CYCLE

Pyro Chemical Reprocessing

Development of pyrochemical technique based on molten salt electrorefining is being pursued at IGCAR for reprocessing of spent fuel from future metal fuel fast reactors. An engineering scale facility called Pyro Process R&D Facility (PPRDF) is being set up for scaled up pyroprocessing studies. Alloys of natural U (10 kg per batch) containing simulants for Pu and typical fission products will be used to simulate spent metal fuel. The experience gained from this facility will be helpful for designing future pyroprocess plants. An engineering scale facility called Pyro Process R&D Facility (PPRDF) is being set up for scaled up pyroprocessing studies. Alloys of natural U (10 kg per batch) containing stimulants for Pu and typical fission

Process equipments erected inside containment Box of PPRDF

products will be used to simulate spent metal fuel. Construction of the facility is completed and all systems/equipment have been erected. These include a 500 m3 containment box, process equipments for electrorefining and cathode processing steps of the pyroprocess flowsheet, inert gas systems, utilities, etc. Pre-commissioning activities of these systems are in progress. Also, a 9 m^3 glove box required for preparation and vacuum drying of LiCl-KCl eutectic mixture, to be used as electrolyte in the electrorefining process, has also been commissioned.

Reprocessing of mixed carbide spent fuel of FBTR

Compact Reprocessing of Advanced Fuel in Lead cell (CORAL) has successfully completed its initial mandate of reprocessing of FBTR spent fuel and closing the fast reactor fuel cycle. The facility has been re-licensed by the regulatory body upto 2023 and further reprocessing campaigns are under progress. Demonstration Fast reactor fuel Reprocessing Plant (DFRP), built with the objective of regular processing of spent fuel from FBTR and demonstration of reprocessing of PFBR fuel, has progressed to the second stage of commissioning, namely Acid-TBP runs, after obtaining consent from the regulatory body.

R&D on Fast Reactor Fuel Reprocessing

Kinetics of Interphase Transfer of Zirconium between Nitric Acid and Tri-n-butyl phosphate Solutions

Zirconium (95Zr) is one of the troublesome fission products in the aqueous reprocessing of nuclear

fuels because it is one of the most readily extractable species which frequently contaminates uranium and plutonium products. Removal of zirconium from the product stream assumes importance in order to achieve the required decontamination factor. The knowledge of the mass transfer characteristics, intrinsic kinetics and the extent of axial mixing are essential for the design of extraction equipment such as mixer-settler, pulsed column and annular centrifugal extractor., an attempt has been made to understand the mechanisms of extraction accompanied by chemical reactions and hence determination of intrinsic kinetics by developing a suitable mathematical model.

The extraction kinetics experiments were carried out in a constant interfacial area stirred cell. Experiments were conducted by varying different parameters like nitric acid concentration, aqueous phase concentration of zirconium, organic phase concentration, impeller speed, specific interfacial area and temperature.

Constant interfacial area stirred vessel

Estimation of nitric acid dissociation constant using eUNIQUAC model

The solvent extraction operation in nuclear fuel reprocessing is carried out in nitric acid medium owing to the complexation abilities of nitric acid with uranium and plutonium, and also favorable extraction of uranium and plutonium nitrates with Tri-n-butyl phosphate (TBP) extractant. Hence, thermodynamic dissociation constant of nitric acid was estimated by directly solving the dissociation reaction equilibrium. eUNIQUAC model was used for the estimation of activity of species during the estimation of dissociation constant. The eUNIQUAC model parameter was presented for the determination of activity coefficients of ionic species, neutral HNO3 molecule and water activity up to 18M concentration of nitric acid. The estimated dissociation constant at molar scale is 17.37, which agrees well with the most of the dissociation constant reported in the literature.

Fast Reactor Fuel Cycle Facility

Fast Reactor Fuel Cycle Facility is being built with the objective of closing the fuel cycle, and ensuring sustained fuel supply for PFBR, with provision for expansion to cater to two more fast reactors planned at Kalpakkam. It is a multi-unit mega project of DAE, co-ordinated by BARC, NFC & IGCAR and being executed by IGCAR. It is co-located along with PFBR and is a self-contained facility encompassing all the activities of the fuel cycle, namely fuel reprocessing (FRP), fuel fabrication (FFP, RUP, CSP) and Waste Management Plants (WMP).

Construction of the facility began in 2014, after obtaining all the statutory clearances from regulatory bodies viz. AERB, MoEF, TNPCB etc, and infrastructure, utility and service buildings are completed. In the nuclear island, the seismically qualified nuclear plant buildings are founded on hard rock (weathering grade III), starting from (-) 24 m, and the construction of all the buildings are under progress with many of them reaching above ground levels. Simultaneously backfilling of soil is also being carried out in a phased manner in-line with the construction sequence. Construction of associated infrastructure, utility and service buildings have been completed.

Procurement of major raw materials required for the project such as stainless steel plates, lead ingots, pipes etc have been completed and manufacturing is underway for several long delivery and high value equipment such as lead bricks, master slave manipulators, process tanks etc. Concurrently, development, testing and manufacturing of process equipment is also under progress and many of them have been manufactured, received at site and are undergoing validation.

Overall view of FRFCF site under construction

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

HEALTH, SAFETY & ENVIRONMENT

Radiological Safety

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD personnel monitoring services covering about 3200 occupational workers of IGCAR and BARC facilities, whole body monitoring under routine and special monitoring procedures for about 950 occupational workers of various active facilities of IGCAR and contract workers engaged by active facilities and bioassay services for about 200 occupational workers were also carried out. Dose data and personnel data along with finger print and photograph of the radiation workers were periodically updated in NODRS. In-situ/in-house testing of about 150 HEPA filter banks in IGCAR, Kalpakkam and 40 HEPA filter banks in NFC, Hyderabad were tested.

Various samples around radioactive facilities and other samples for low level counting and determination of radioactivity from different institutions and industries were also catered to. About 126 radiation survey meters from various nuclear facilities at Kalpakkam, NDRF, Arakkonam, SHAR, ISRO, CPCL, Chennai, BEL and other industries were calibrated at regional gamma calibration facility. Radiometry assessment of FRFCF lead bricks used in hot cells was carried out to verify their shielding integrity.

The Online Nuclear Emergency Response Decision Support System (ONERS) was upgraded with several new features as per AERB EP5 and NDMA guidelines. The DSS was configured with high resolution weather prediction and dispersion models along with site specific spatial database for all the operational Nuclear Power Plant sites and the system was installed at NPCIL Head Quarters as well as Emergency Monitoring Cell, AERB, Mumbai. Training on the ONERS was provided to operating engineers of MAPS-NPCIL. Experiments on Sodium aerosol leakage through capillaries and concrete specimens were conducted for characterizing environmental source term under various mass concentration, pressure, capillary size and humidity conditions.

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 800 employees.

Samples collected around radiation facilities and from other institutions involved in collaborative projects were analyzed for the radioactivity levels. Environmental radioactivity measurements comprising of soil, water and air (Radon, Thoron and C-14) measurements was continued for Kalpakkam Complex and demonstrated the continued compliance of levels in comparison to world average values. As a part of water quality studies, samples of ground water within the complex and sea water were analyzed for various heavy metal content and chlorination.

As part of societal applications, IR thermo graphic studies on early detection of breast cancer among women in association with MS Ramaiah institute

Radiation awareness programme conducted at Kalakkam & Anupuram

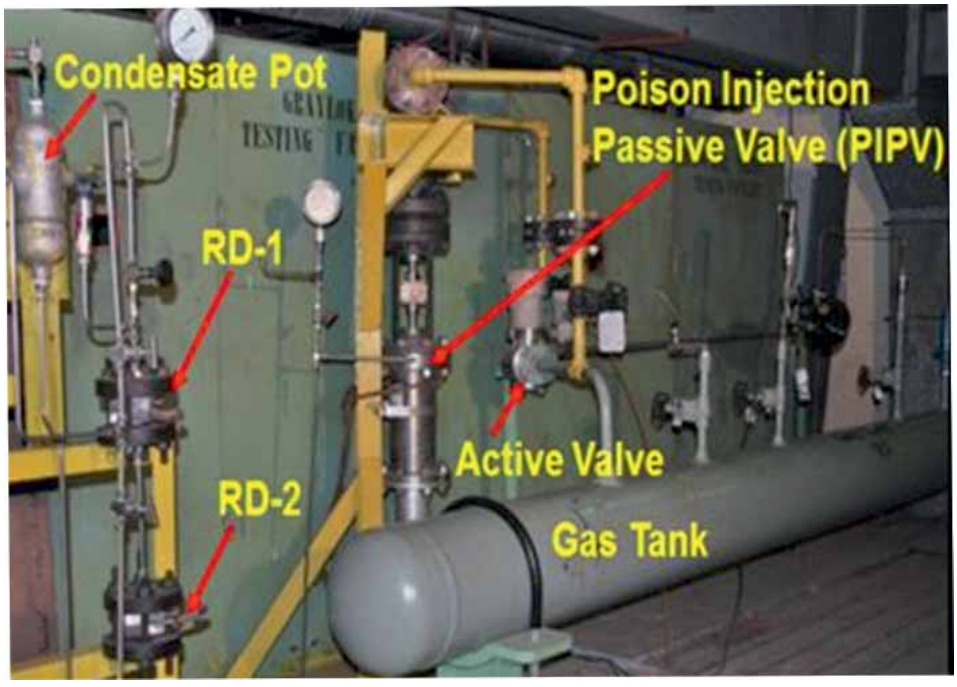
of technology, Bangalore was carried out. Service extended to archeo-metallaurgical investigation for about 3000 bronze idols from ASI, India. Radiation awareness programme for students and teachers from various schools around Kalpakkam, women residents in Kalpakkam and Anupuram were conducted for promotion of DAE activities in nuclear energy sector and societal applications.

CHAPTER

3

NUCLEAR POWER PROGRAMME STAGE-III

Facility for graphite oxidation studies



Passive Poison Injection System (PPIS)
experimental facility

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

AHWR physics design was focussed on the safety studies required for regulatory clearances for thorium-plutonium fuel core. A modified design of the control rods improved the core power distribution. Computer codes were developed to model the core perturbations.

Hydro dynamic forces in Gravity Driven Water Pool (GDWP) were estimated. Thermal Hydraulic Tests in Tarapur established that AHWR can be operated under natural circulation with adequate safety margin and stable channel flow during power manoeuvring from cold start-up (2% full power) to 130% full power.

Experiments for design validation of core catcher for Indian NPPs were carried out with 550 kg of high temperature melt generated using in-house thermite technology. In-vessel retention capability of 700 MWe PHWRs was demonstrated at prototypic condition with 500 kg melt.

A Flow Instability Detection and Warning System (FIDWS) was developed to detect the onset of flow oscillations in coolant channels of nuclear reactors. The system monitors thermal hydraulic instabilities in coolant channels to enhance the safety and stability of the plant. The system performs real time analysis of the

High Temperature melt generation using Thermite Technology

flow signals to determine instantaneous decay ratio & accumulated decay ratio for each coolant channel and indicates the stability status online. Hardware & Software was tested using FIDWS Simulator & validated in AHWR Thermal Hydraulic Test Facility (ATTF) at Tarapur, and Integral Test Loop (ITL) and Parallel Channel Loop (PCL) in BARC. The system was qualified for extreme conditions of humidity, temperature and radiation as may be required for C&I of NPPs.

Flow Instability Detection and Warning System (FIDWS) to detect the onset of the flow oscillations in coolant channels of nuclear reactors

In order to improve the core discharge burn-up and power distribution, worth of reactivity devices were re-assessed. Minimum required reactivity worth of AR/RR and SRs were assessed to be about 5.0 mk each against the actual worth of 12 mk each. Therefore, the design of the reactivity devices were modified to improve the core power distribution and reduce the power dip in the vicinity of reactivity devices and improve average discharge burn-up by about 3.6 GWd/Te.

AHWR has been designed for passive removal of decay heat using Isolation Condensers (ICs) submerged in the Gravity Driven Water Pool (GDWP) holding 8000 m^3 of water. GDWP is located above the steam drum of the reactor to enable natural circulation. A full-scale Integral Test Loop (ITL) was installed to simulate the natural circulation characteristics of AHWR under normal and transient conditions. Decay heat removal of AHWR during prolonged SBO was carried for more than 7 days without operator intervention. The pin temperature fell steadily and remained well within safe limits.

Passive Poison Injection System (PPIS) was developed to shut down AHWR passively, in the event of wired shut down system failure. It uses a combination of indigenously developed passive valves and devices which actuate due to increase of pressure in the Main Heat Transport system and injects the liquid poison into the moderator to shut down the reactor. A scaled experimental facility was built for integrated study of poison injection and performance of passive devices. The system actuation by high pressure steam was demonstrated successfully simulating reactor conditions.

Passive Poison Injection System (PPIS) experimental facility

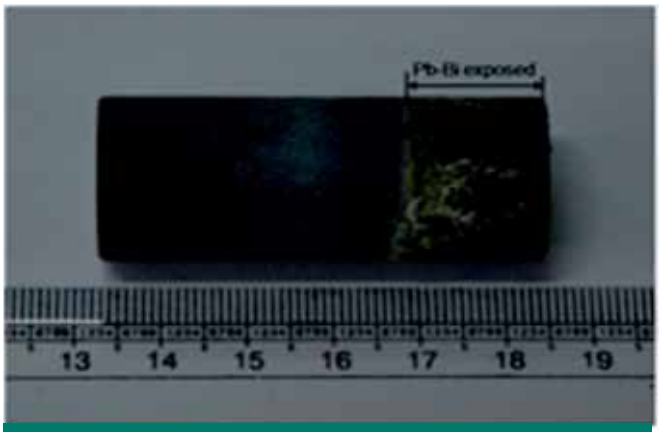
Passive Containment Isolation System (PCIS) was designed to prevent release of radioactivity from AHWR in the event of Loss of Coolant Accident (LOCA) or Main Stream Line Break. PCIS isolates the reactor containment from atmosphere by making a water seal in 'U' shaped ventilation duct using the differential pressure between containment and atmosphere. CFD simulations of PCIS were validated by experiments.

THORIUM FUEL CYCLE

Molten Salt Reactors (MSRs) can be fuelled by any fissile material including Thorium. MSRs have several advantages over solid fuelled reactors. Thermo physical and thermodynamic studies on fluoride systems relevant to MSRs were undertaken. Solubility limits of Zr^{4+}, Nd^{3+}, Y^{3+} and Sr^{2+} in fuel salt mixture were determined. Activities of LiF, NaF and KF in coolant were measured. Density and thermodynamic properties of alternate fuel salts containing CaF_2 were investigated.

The silicide coated Nb-alloy was tested for oxidation at 1250°C and in liquid Lead-Bismuth Eutectic (LBE) alloy at 875°C for prolonged duration. Aluminide coated Inconel test pieces were also tested in molten LBE up to 600°C. Corrosion studies were carried out in LiF-ThF_4 salt, which is being considered as blanket salt of Indian Molten Salt Breeder Reactor (IMSBR).

Solubility limits of major fission products such as NdF_3, SrF_2, YF_3 and ZrF_4 in the fuel salt mixture containing 78 mol% LiF, 20 mol % ThF_4 and 2 mol% UF_4 at 700 °C were measured to be 7.5±0.2, 1.6±0.1, 1.4±0.2 and 3.4±0.4 mol % respectively, using high temperature calorimetry. Activity of individual components viz., LiF and KF in the liquid coolant salt (FLINAK) was measured as a function of temperature by KEMS technique and the activities of LiF and KF are 0.17 and 0.02, respectively. In order to maintain neutron economy and reduce ^7Li loading in fluoride based fuel salt systems, several alternate fuel salts $(LiF)_{0.7}(CaF_2)_{0.08}(ThF_4)_{0.22-x}(UF_4)_x$ (x = 0.04, 0.08, 0.12 and 0.16) were investigated for their thermophysical properties.



Silicide coated Nb-1Zr-0.1C alloy tube exposed to liquid Pb-Bi at 875°C for 200 h

Molten salt technology is being developed for Indian Molten Salt Breeder Reactor (IMSBR) and high temperature solar thermal power plants. Molten Salt Natural Circulation Loop (MSNCL) was installed in BARC for thermal hydraulic, instrumentation development and material compatibility studies. Molten mixture of $NaNO_3$ and KNO_3 was used as a working fluid. The loop has been operated at maximum temperature of 600°C and various steady state and transient experiments have been performed. Further, in-house developed computer codes were validated by the experimental data.

Nb-1Zr-0.1C is considered as a structural material for High Temperature Reactor components for its high creep strength at high temperatures and the ease of fabricating compared to other refractory metal alloys. The Nb-alloy has to be coated to protect against oxidation in air at high temperature. Silicide based protective coatings were formed on the Nb-1Zr-0.1C alloy samples and tubes using pack siliconizing process. Oxidation and liquid metal corrosion of the alloy was studied at high temperatures. The coated alloy showed superior oxidation and LBE corrosion resistance at high temperatures. The alloy was found to be a promising material for coolant channels of high temperature reactors.

Corrosion studies on LiF-ThF_4 salt, which is being considered as blanket salt of Indian Molten Salt Breeder Reactor (IMSBR) is carried out in the Molten Active Corrosion Test Facility (MAFCorr). Valuable experimental data on its corrosion behaviour of LiF-ThF_4 was obtained up to 750°C.

KAlpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) relicensed till June 2020 continued to operate successfully with improved Safety Control Plate (SCP) drive mechanisms and Integrated Control and Information System (ICIS) developed by BARC. KAMINI reactor has been operating at 30 kWt and serving as an unique facility for neutron activation studies, neutron radiography of pyro-devices of Indian Space Research Organization (ISRO) and neutron detector testing.

OTHER THORIUM REACTOR SYSTEMS

Facility for graphite oxidation study was setup to determine the kinetic parameters of the oxidation reaction of graphite specimens at 600°C, 700°C, 800°C and 900°C by measuring the weight loss online in controlled oxygen environment. Graphite is the moderator and reflector material for Innovative High Temperature Reactor (IHTR) and Indian Molten Salt Breeder Reactor (IMSBR). This facility will help in determining the service life of a given grade of graphite at the temperature of interest.

Facility for graphite oxidation studies

MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

A high temperature liquid metal loop is being developed to carry out Magneto Hydro Dynamic (MHD) and corrosion studies to generate data required for

design verification of Indian Test Blanket Module (TBM) of ITER. Simulation of flow rates and estimation of materials performance in flowing Pb-Li liquid for fusion reactors has been taken up. For this purpose a submerged radial flow centrifugal pump was integrated with a loop.

In a fusion reactor, the flow of liquid Pb-Li alloy can achieve flow rates as high as 40 lpm. In order to recreate the flow pattern of the fusion reactor, a mechanical pump driven liquid metal loop was developed. The loop is integrated with a specially designed submerged radial flow centrifugal pump. Considering the highly corrosive nature of lead and its alloys, all wetted parts of the loop, including the impellor, loop piping, etc., were fabricated out of modified 9Cr-1Mo steel which is known to be resistant to Pb-Li corrosion. Typical inventory of the Pb in the loop is 500 kg and the loop can generate corrosion data at very high flow rates up to 60 lpm and pressure up to 14 bar as required for actual fusion reactor blanket applications. The loop was commissioned with liquid lead at 723 K and liquid metal flow was tested for motor speeds from 200 – 1400 RPM.

Al based coatings on the Reduced Activation Ferritic Martensite (RAFMS), which are structural materials for components of Test Blanket Module (TBM) in fusion reactors, are being considered to protect the surface against corrosion from flowing liquid breeder at 325-480°C and prevent permeation of tritium from Pb-17Li into steel. Aluminide coatings were developed using hot dip technique followed. Coatings were subjected to heat treatment at 950 °C for 5 h under oxidizing conditions. The samples were given a second heat treatment at 750 °C for 2 h. Optical microscopy revealed that the dipped samples have two distinct layers: an outer 32.2 μm thick layer and an inner 18.31 μm layer. Heat treatment increased the thickness of both the layers significantly. The XRD revealed the presence of Al and Si on the coating while the heat treated samples have presence of Fe-Al intermetallics.

CHAPTER

4

ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES DEVELOPMENT AND THEIR APPLICATIONS

View of Apsara-U reactor

CYCLONE-30, Cyclotron Machine at Medical Cyclotron Project (MCP) at VECC

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

Installation and commissioning of Instrumentation & Control Systems, Reactor Regulating Systems and COIS Data Servers and Operator workstations has been completed.

APSARA Control Room

View of Apsara-U reactor

The APSARA Upgraded Research Reactor Facility is a 2 MWth swimming pool reactor with compact core loaded with Low Enriched Uranium (LEU) fuel, light water as coolant & moderator and Beryllium Oxide as reflector. This reactor will provide enhanced facilities for various kinds of research, shielding experiments and training of scientists and engineers. The APSARA-U Reactor became critical on 10th September 2018 at 18:41Hrs.

An independent analysis of the constitution of initial core of APSARA-U and its First Approach to Criticality (FAC) were simulated using reactor physics codes. Initial core was explicitly modelled and the neutron count rates and expected k-eff was estimated for different core configurations envisaged. The neutronic simulations were carried using whole core monte-carlo method, transport at lattice and diffusion at core level and 2D full core transport using lattice homogenised cross-section. The results helped in qualification of the APSARA-U physics design.

After the FAC, the thermal neutron flux was measured at two elevations using Foil Activation Method. Bare and Cd-covered Gold (Au) foils were used for this purpose. The fluxes thus measured at the two locations were 8.32 X 108 n/cm2/s and 1.21 X 108n/cm2/s.

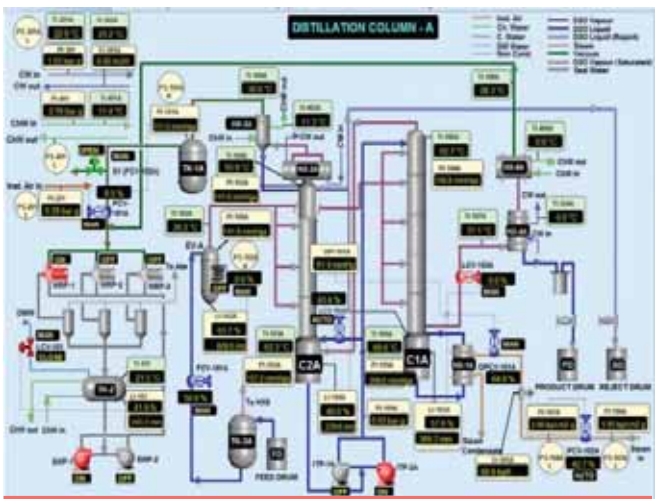
Upgraded APSARA research reactor uses five Reactivity Control Mechanisms (RCMs) namely: two Shut-off Rods, two Control-Cum Shut-off Rods and One Fine Control Rod. Design of RCMs was qualified on a full-scale test station. Dedicated test consoles have been designed and fabricated for the purpose of prototype testing and out-of-pile testing at the reactor site. Five RCMs along with absorber assemblies have

been installed and commissioned on the reactor. Spare mechanisms also have been assembled and tested for future use in the reactor.

Various Sub-assemblies and Components such as Reactor Trolley, Core Support Structure, Ion Chamber Support Structure-I & II, Grid Plate and Outlet Plenum were manufactured in-house for APSARA-U. Other peripheral components like Beam Tubes, Core Position Coupler Swivelling Bolt & Nut Assembly, Fission Counter Detector Assemblies, Tray Rod Assemblies, different types of Hangers in Pool and various other components were also manufactured.

DHRUVA

Major revamping of process and control systems for the advancement of Heavy Water Upgrading Plant after 30+ years of operation at BARC was completed and the plant was made operational again to cater to the requirements of research reactors. The newly installed PLC-SCADA based control system has improved plant availability, helped in safe operation of the plant with better operability & control and reduced the requirement of working personnel in active areas.

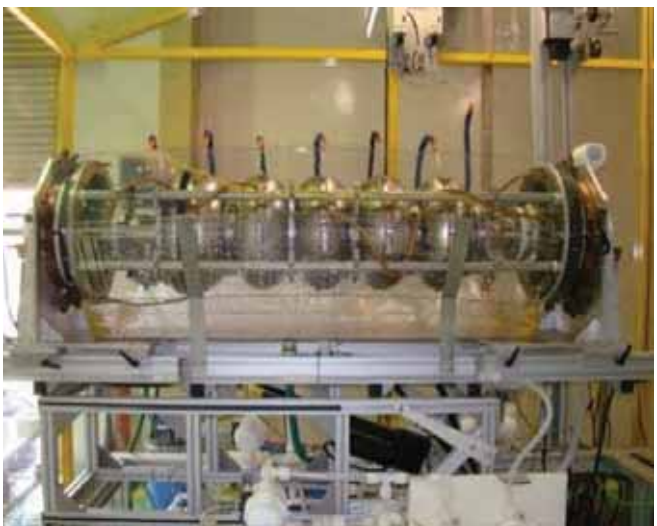


PLC-SCADA of D_2O Upgrading Plant, BARC, after major revamp

Indigenous bulk gamma monitor reactor has been developed for failed fuel detection of DHRUVA reactor. The detector probe comprises of a 1"x1"size cylindrical, NaI based Scintillation crystal attached to a PMT. The monitor has protection against radiation over-exposure. Successful field evaluation test of the unit was carried out in loop-3 of Dhruva reactor.

ACCELERATORS

The first five-cell 650 MHz (β=0.92) Superconducting Radio-Frequency (SCRF) cavity fabricated at RRCAT was processed and tested using the developed in-house facilities. This five-cell cavity was electro-polished, annealed at 800 ºC, high pressure rinsed, baked at 120 ºC and tested at 2 K in vertical test facility using 650 MHz low level RF system and 500 W solid state amplifier. An excellent low field quality factor 4 x 10^{10} and an accelerating gradient of 17.5 MV/m was achieved



Electro-polishing of five- cell 650 MHz cavity

Second five-cell cavity

An improved second five-cell 650 MHz (β=0.92) Superconducting Radio Frequency (SCRF) cavity was fabricated using the experience gained during fabrication of the first 650 MHz SCRF cavity. The second cavity was fabricated with better control on geometrical accuracy and optimized beam welding parameters. The

field flatness of as fabricated cavity before processing is measured to be 85%, which is the large improvement over earlier developed five-cell cavity where the fabricated field flatness was 45%. The final length of the cavity is 1401.12 mm which is also within tolerance of ± 3 mm to design length of 1400.245 mm. The second HB 650 MHz SCRF cavity shows better control on various mechanical and RF parameters on account of improved fabrication technique.

For the ongoing superconducting RF development efforts, first 5-cell, beta-0.92, 650 MHz Nb SRF cavity was characterized at cryogenic temperatures of 2 K and 4 K in VTS facility. The cavity reached an Eacc in excess of 17 MV/m. A second five cell cavity was fabricated by electron beam welding for which qualification and tuning of constituents (dumbbells and end half cells) were carried out at room temperature before final welding to ensure that resonant frequency and length remained at design values. The resulting formed cavity has demonstrated an excellent field flatness of 90%. The room temperature qualification and tuning were conducted using in house developed procedure and qualification setups. A 650 MHz, 5 kW, 10% duty cycle, pulsed SSPA has been developed to enhance the capabilities of existing RF system of RRCAT VTS. The new amplifier developed using 8 high power LDMOS transistors enables faster RF conditioning and adds high power pulse testing capabilities to exiting setup.

The room temperature setup used for RF characterization of dumbbell structure

The experimental setup of Ion source coupled with LEBT

A filament based multicusp arc discharge type H- ion source has been successfully coupled with solenoid magnet based low energy beam transport (LEBT) system for beam transportation and characterization studies. The experimental setup is shown in the picture. H-ion source was operated in the pulsed mode with maximum of 8 mA current at 50 keV energy with 0.5 ms pulse duration and 2 Hz repetition rate.

A general methodology has been developed to design a compact lattice for the 1 GeV H- Indian Spallation Neutron Source (ISNS) superconducting linac by following the non-equipartitioned design approach, yet ensuring beam stability in end-to-end beam dynamics simulations through careful design of suitable matching sections, and by appropriate adjustment of field/phase of the cavity along with the strengths of focusing magnets.

Design of a suitable lattice consisting of bending magnets, focusing quadrupoles, chromaticity correcting sextupoles, corrector magnets, RF cavities, injection and extraction magnets and Beam Position Indicators (BPIs) has been completed for the proposed 1 GeV proton Accumulator Ring of ISNS, which will convert the 10 mA, 2 ms H- pulses from the injector linac to proton pulses through a charge exchange injection scheme. It will also suitably paint a broader stable beam inside the accumulator ring with pulse width compressed to 0.65 μs.

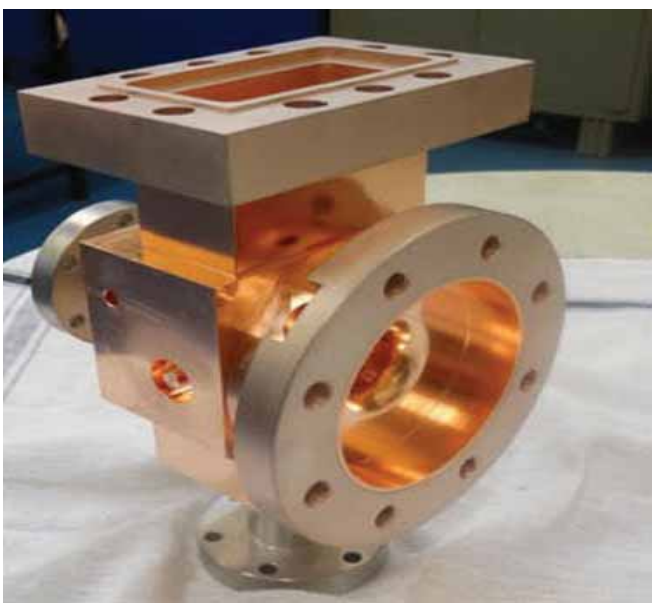
As a part of technology development, a prototype 100 kW, 1 MHz pulse RF power amplifier system was

developed for Accumulator Ring of pulsed proton Accelerator. The RF power amplifier assembled with Tetrode tube, anode power supply, grid power supply, RF driver amplifier, HV RF matching network was tested with pulsed RF power of 100 kW at 1 MHz.

100 kW,1 MHz RF amplifier

A prototype 20 kV IGBT based solid state switch has been developed to evaluate the possibility for replacing the PFN charging thyratron tube in 6 MW peak power microwave system. Series connected lower voltage IGBTs have been used with proper balancing and isolated driver circuits. The switch has been tested with the microwave system installed at linac in actual operating conditions at 220 Hz pulse repetition rate. The modulator performance and the electron beam current were obtained same as with the thyratron charging switch.

Laser photocathode RF guns are sources of high brightness electron beams, which are used in the injector electron linac systems of most of the operating x-ray free electron lasers and in many advanced synchrotron radiation sources operating worldwide. Such photocathode RF guns have demonstrated the ability to generate relativistic (2-5 MeV) electron beams with very short bunch length (< 10 ps and up to 100s of fs) and with very small emittance (up to 1 mm mrad). A 1.6 cell, S-band Laser Photocathode Radiofrequency (RF) Gun has been designed, developed, tuned to desired RF parameters with a field flatness < 5 %, and qualified through low and high power RF testing. This photocathode RF gun is designed to deliver 1 nC charge in 10 ps bunches with an energy > 2 MeV and a normalize RMS electron beam emittance < 5 mm mrad. This RF gun can serve as a high brightness injector for future light sources projects.



Laser photocathode RF gun

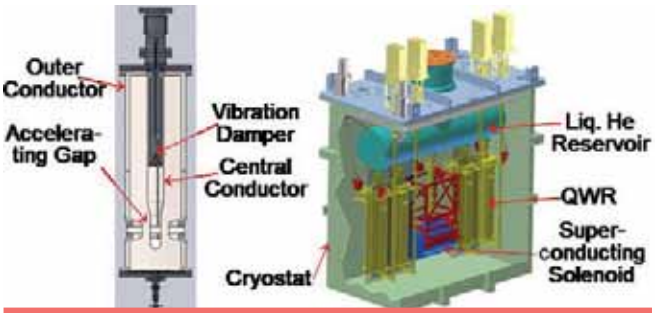
Installation of Rare Ion Beam (RIB) post-accelerators

The beam-line between 3rd and 4th Linac modules (L3 & L4) having two 45 degree bending magnets, 19 quadrupole magnets, inter-connecting beam-tubes, beam diagnostic boxes, vacuum pumps etc. has been installed in their optimized locations. The 4th and 5th LINAC modules have been installed, low power RF measurements have been completed and high power conditioning up to 3 kW power has been done.

Super-conducting Quarter Wave Resonator (SCQWR)

Rare Ion Beams (RIB) are beams of unstable nuclei and they offer many exciting research opportunities. In VECC, a RIB facility has been developed in which the RIBs can be produced using proton and alpha beams from the cyclotron, ionized, the RIB species of interested is selected using an on-line isotope separator and accelerated to about 1 MeV/u using a combination of Radio-Frequency Quadrupole

(RFQ) and five LINEAR accelerators. Super-conducting Quarter Wave Resonators (SCQWR) are the ideal choice to accelerate RIBs from 1 to 2 MeV/u (After 5th LINAC) as they offer higher acceleration gradient.



Different components of the SCQWR structure (left) and Arrangement of the SCQWRs and solenoid inside the cryostat (right)

The optimized structure of the SCQWR is shown in the above figure. The outer conductor is a double walled structure filled with liquid helium and has two drift tubes projected inside. The inner conductor is filled with liquid helium and it has a hole at the bottom part through which the ion beam passes. The dimensions of this two accelerating gap structure has been optimized by rigorous Radio-frequency simulations. The operating frequency of the SCQWRs will be 113.61 MHz and has been designed for 5 MV/m acceleration gradient in CW mode. The picture shows the arrangement of four SCQWRs and a super-conducting solenoid which will be placed inside the cryostat.

Detailed beam dynamics simulations have been performed during this optimization process. For this purpose, the electromagnetic field from 3D RF simulation has been used for a realistic situation. These QWRs suffer from the problem of beam steering during acceleration – which will be taken care during their alignment and the necessary course of action has been finalized through beam dynamics simulations.

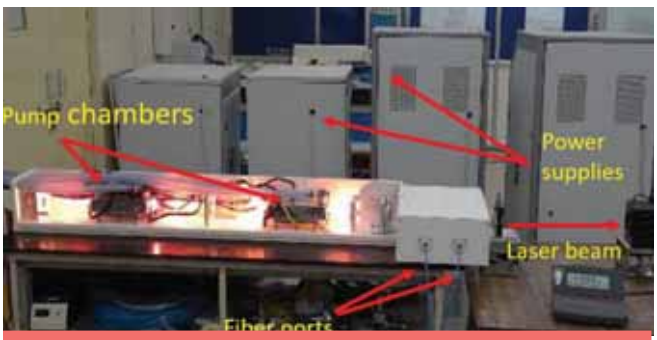
The QWRs in our design have their vacuum system separate from the cryostat vacuum. The necessary modifications have been incorporated during the engineering design. This modification will allow easier assembly in the clean room, less downtime in case of a cryostat problem and to avoid long time performance degradation (Q-disease) problem of the QWRs. The design of the QWR has been completed and ordered for fabrication. This activity is being pursued in collaboration with TRIUMF, Canada

At BARC, a networked and automated system consisting of 30 varied intelligent radiation monitors for Gamma, X-Ray and Neutron flux were developed for LEHIPA to track and monitor the accelerator beam loss and for radiation safety of personnel. The centralized as well as local monitoring has been provided by networking to four local servers as Local Operator Panels (LOP) and a Central main console. The Integrated Test Facility is required for full scale testing and user validation of Beam loss & radiation monitoring of LEHIPA.

Helium vessel jacketing of Niobium Superconducting Single Spoke Resonator was completed. The stainless steel vessel built around Niobium cavity was delivered to FERMI Lab, USA, and tested for high power performance. The cavity would now be integrated with the first SSR-1 Cryo module being built at FERMI Lab to accelerate the charged particle for Proton Improvement Plant (PIP-II) project.

LASER TECHNOLOGY

An optical fibre coupled dual cavity dual flash lamp ceramic reflector pump chamber based Nd:YAG laser has been developed. The average output power and peak power achieved from the laser was 1040 W and 20 kW respectively. The output pulse duration is in the range 2-40 ms and electrical to laser conversion efficiency achieved was 5%. The laser can be operated at a repetition rate of 1-100 Hz. The use of a ceramic reflector avoids frequent coating required in the case of conventional gold reflectors, and the beam quality has improved with a M^2 value 65 as compared to 110 in the case of gold reflectors. This laser has potential application in cutting and welding of thick sections of steel.

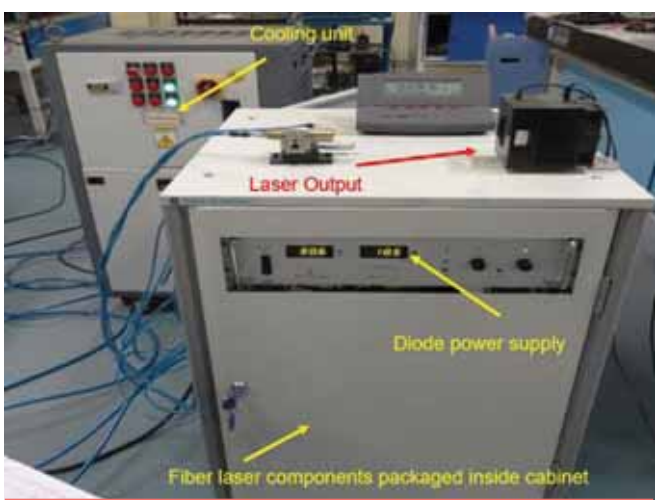


In-house developed 1040 W average power and 20 kW peak power Nd:YAG laser

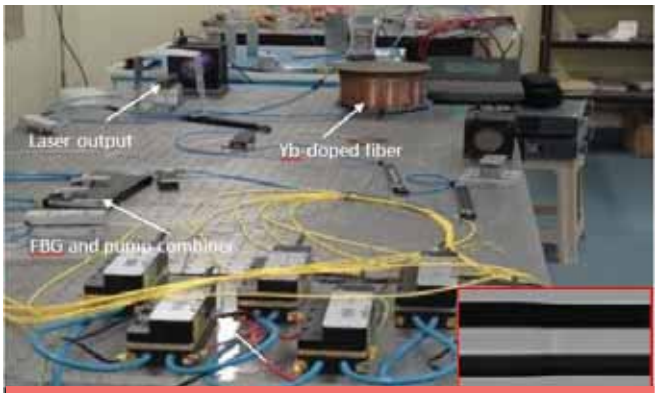
250 W average power Nd:YAG laser system for welding of fuel pins at IFFF, BARC

A 250 W average power pulsed Nd:YAG laser system with three port time shared fiber optic beam delivery has been developed for laser welding of nickel alloy fuel pins. This laser system provides a maximum pulse energy of 100 J at 20 ms pulse duration, with variable pulse duration of 2-20 ms and pulse frequency of 1-100 Hz. A welding chamber, along with a motion controller for fuel pin welding and a CCD camera based system for online viewing and monitoring of the welding process, has been integrated with the laser system. A control panel has been provided for the laser welding process control, and for ease of operation during the production of fuel pins. This complete system has been installed at the IFFF, BARC for the production of fuel pins.

An engineered version of a 250 W of all-fiber single transverse mode Yb-doped CW fiber laser has been developed in-house. A single integrated heat sink package has been developed for the Yb-doped fiber, multimode pump combiner, HR and OC fiber Bragg gratings and splice joints. The pump diode block, diode power supply and fiber laser oscillator block have been



An engineered version of in-house developed 250 W all-fiber Yb-doped CW fiber



A table top view of 700 W single transverse mode all-fiber Yb-doped CW laser

packaged in a single cabinet. A beam delivery fiber of 10 m length has been spliced with the fiber laser oscillator, and cutting/welding nozzle has been attached for material processing application. This laser system will be installed at R&D TAPS, Tarapur, NPCIL for cutting of up to 3 mm thick sheets and welding of up to 1 mm thick SS.

The output power of a 500 W CW, Yb-doped fiber laser developed earlier has been enhanced to a level of 700 W with an all-fiber configuration, while maintaining a single transverse mode output. The laser output is emitted from a 20 mm core diameter double-clad fiber, and the output spectrum was peaked at 1080 nm with a line width of 2 nm. An optical to optical conversion efficiency of 76% has been achieved. This all-fiber Yb-doped fiber laser will be useful in cutting of up to 8 mm thick stainless steel with less than 200 mm kerf width, and for welding to a depth of about 4 mm in SS.

Two numbers of engineered versions of Diode-Pumped Solid State (DPSS) green laser systems in a coupled cavity configuration with average output power more than 50 W at 532 nm have been developed and characterized. Each of these laser systems produce Q-switched pulses of 40 ns duration at a repetition rate of 9 kHz. Further, two numbers of engineered version of a DPSS green laser system with ~ 45 W of average power at 532 nm with less than 40 ns pulse duration at repetition rate of 6.25 kHz have also been developed and characterized. These laser systems were continuously operated for 8 hours and the stability of output power and pulse timing jitter of the green laser was measured. The long term stability of the average green power was measured with ±0.7 W of fluctuation in the output power. The timing jitter of the pulses was

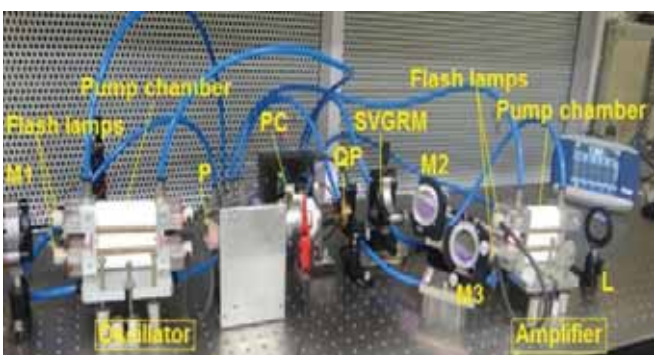
measured to be ±3ns during 8 hours operation. All the lasers were triggered optically by using an optical triggering unit, and the systems incorporate all standard safety and operational features. The lasers have been installed at BARC, and all these lasers have successfully been used for several long hour campaigns.

Diode pumped solid state green laser with 55W average power at 532 nm

High power (2.5 kW), multi-module Nd:YAG laser

A laboratory model of a high power, multi-module, diode pumped CW Nd:YAG laser (1064 nm) has been developed to deliver e" 2.5 kW optical power with an optical conversion efficiency of more than 39%. The laser system consists of 3 numbers of modular gain medium in series, with an optimized distance of separation within a plane-plane symmetric resonator with overall length 466 cm and with a 50% reflectivity output coupler. Each module consists of a grooved, Anti-Reflection (AR) coated and 0.6 at% doped Nd:YAG rod of length 150 mm & diameter 6 mm placed in a diffuse type sixty degree rotated side-diode pump chamber having 30 Nos. of CW water cooled diode laser bars (73 W, 808 nm). A maximum output power of 2.6 kW has been achieved with 6.57 kW total optical pump power. Further, the laser beam was efficiently coupled into a 900 μm core diameter optical fiber for beam delivery with an overall transmission efficiency of 90%. This laser has potential applications in material processing, including thick metal-sheet cutting, deep penetration welding and cladding etc.

A table-top laboratory model of a lamp-pumped, electro-optic Q-switched, high energy Nd:YAG laser (1064 nm) master-oscillator-power-amplifier system has been developed, which is capable of delivering more than 7 J energy within 10 ns pulse duration. It consists of a master oscillator & a single stage, single pass power amplifier of identical pump heads having a 15 mm diameter & 100 mm long barrel grooved Nd:YAG rod. This system has potential applications in surface modification of materials through shock peening for their enhanced fatigue and corrosion resistance.



High energy (7 J) Nd:YAG laser oscillator-amplifier system in operation

Laser marker systems are being developed at RRCAT wherein a DC and slow pulse current controlled power converter is required to drive the laser diodes. Five numbers of indigenous, compact, card based laser diode drivers rated for 10 A / 20 V have been developed using a switch-mode power converter technology. The salient features of the converters, which have been developed as an import substitute, are: small size, light weight, low cost, high reliability and ruggedness.

Batch of five laser diode drivers developed for laser marker systems

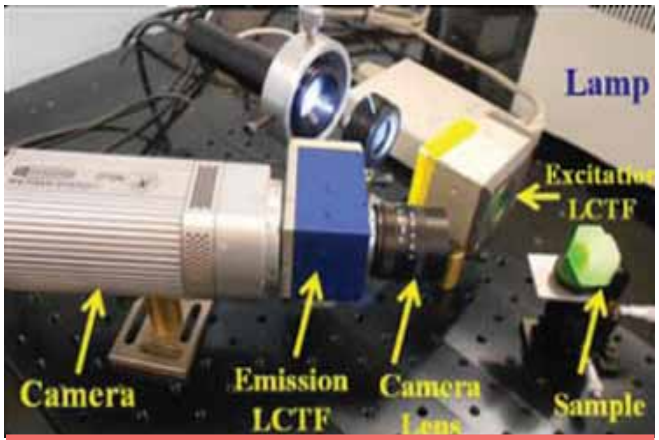
Refurbished sealed off CO_2 lasers

Sealed off CO_2 lasers find extensive applications in marking and engraving. However, these lasers have limited operating life and refurbishment technology for these aged lasers is very expensive. In this context, an indigenous technology has been developed to refurbish non-functional imported sealed off CO_2 lasers. The technology has successfully been applied to refurbish imported 100 W lasers from the Indian Security Press (ISP), Nasik, which employs them for marking security features on stamp papers and passports. The refurbished lasers are currently working satisfactorily in their production line. In addition, three power supplies of 250W CO_2 lasers have also been repaired. Refurbishment of the non-functioning lasers has resulted in a significant saving of foreign exchange.

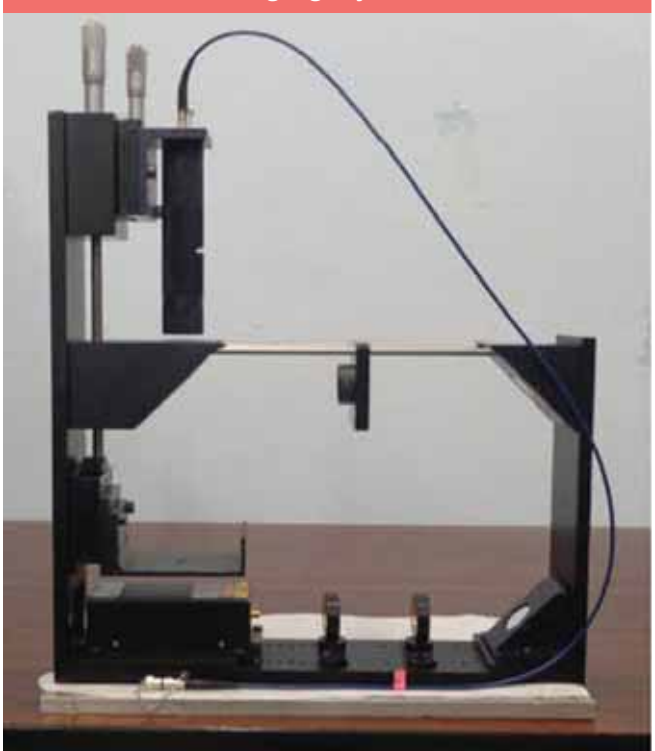
At BARC, a Laser-TIG hybrid welding system has been developed by integrating a one kilowatt continuous wave Nd-YAG laser with a TIG welding power source. This combination augments depth of penetration of TIG power source and enhances gap bridge ability of Laser source. Hybrid welding studies of RAFMS steel, RAFMS-SS316L and SS316L-CuCrZr dissimilar joints were made using this system.

Laser Applications

A Liquid Tunable Filter (LCTF) based synchronous hyper-spectral imaging system has been developed for obtaining synchronous fluorescence spectral information from each spatial point of the sample surface being interrogated. A Lab view based Graphic User Interface (GUI) has been designed and developed for providing synchronized control of the two LCTFs and CCD camera for automated acquisition of the full sequence of a hyper-spectral image.



Hyper-Spectral Synchronous Fluorescence Imaging System



Opto-mechanical module for the measurement of Raman spectra from concealed food /biological samples

A compact and portable opto-mechanical module based on the principle of Spatially-Offset Raman spectroscopy (SORS) has been developed for depth sensitive Raman spectral measurements from concealed food/biological samples. It has provision for varying the spatial-offsets between illumination and collection by turning a micrometer screw fitted with the module, thereby enabling interrogation of subsurface depths inside the target sample.

A hand-held fluorescence probe has been designed and developed for the interrogation of sub-surface depths in a layered turbid sample using the principle of off-confocal detection. The performance of this probe has been tested by recording the fluorescence signal from a bi-layered turbid non-biological sample comprising a green dye card with a layer of tissue paper (250 micron thick) on its top. It was found that with the help of the probe, one can successfully record the fluorescence spectra in situ from the top (i.e. the tissue paper) as well as the bottom layer (green dye card) of the sample.

Hand-held probe for measuring depth-sensitive fluorescence signatures in a layered turbid sample

Raman spectra have been measured from palm oil adulterated ghee samples using a Raman probe based experimental system developed in-house. Significant differences have been observed between the Raman spectra of ghee and palm oil. A Partial Least Square (PLS) regression based chemometric algorithm, performed via independent and leave-one-batch-out cross-validation, was able to predict palm oil adulteration in ghee with an accuracy of 90 % for an adulteration greater than 10 percent.

The laser cutting technology developed earlier for the bellow lip weld joint has been modified with a refined tool design and interlocks for the safety of the tool, motor and controller for more reliable and repeated operations. Laser cutting of 609 bellow lip weld joints has been successfully carried out during an EMCCR campaign at KAPS-1 reactor in nine days of round the clock operation. The separation of bellow rings was also ensured during the campaign. The successful laser based remote cutting resulted in an enormous reduction in MANREM consumption, time and cost.

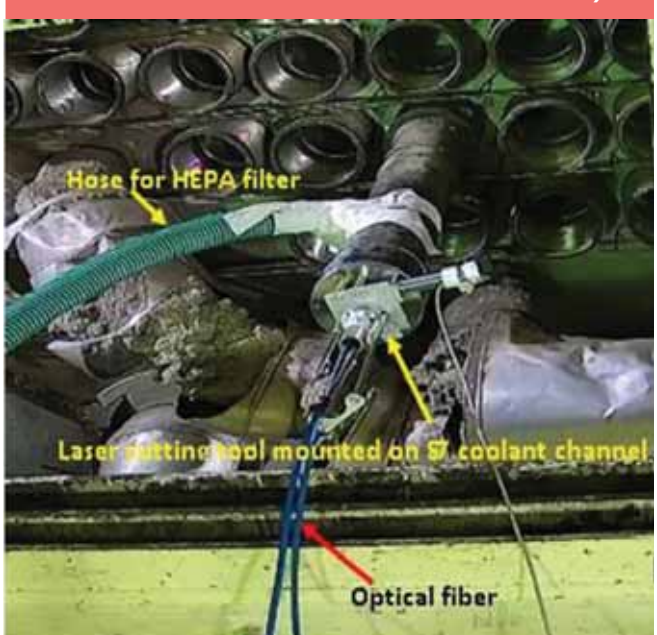
Laser cutting tool for bellow lip mounted on coolant channel

In-situ laser cutting of bellow lip weld joint in KAPS-1 reactor

In-situ removal of two selected coolant channels R6 and S8 of RAPS-4 reactor has been carried out using a remotely operated and indigenously developed 5 kW peak power fiber coupled pulsed Nd:YAG laser. The coolant channels were removed for post irradiation examination data. Laser based cutting technology enormously reduced the radiation dose consumption, time and cost for the operation, which was not possible to be carried out by mechanical methods due to space restrictions and high radiation dose.

Pressure tube stubs of the R6 and S8 coolant channels of the RAPS-4 reactor, and the O-9 and Q-9 coolant channels of MAPS-1 were required to be retrieved for post irradiation studies. End fitting of MAPS-1 & 2 reactors have different dimensions as compared to those of RAPS-3 & 4 reactors. Hence the underwater laser cutting tool developed earlier was modified and gas-assisted underwater laser cutting technology was deployed for the retrieval of pressure tube stubs of all the eight end fittings, with pressure tube stubs of length 200-220 mm, in minimum time and with minimum radiation dose consumption.

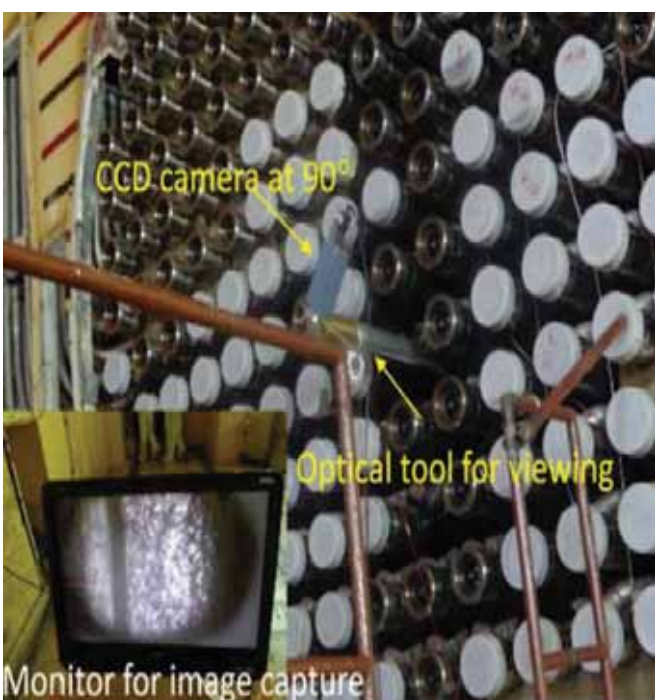
Underwater laser cutting arrangement for PT stubs at MAPS-1 (Insets show laser cutting tool for PT stub and laser cut PT stubs)



In-situ laser cutting of stuck north end of S-7 coolant channel of KAPS-2 reactor

During an En-masse Coolant Channels Replacement (EMCCR) campaign, the S-07 coolant channel of the KAPS-2 reactor was stuck in the calendria, and it could not be removed by mechanical methods. Laser cutting technology was developed and deployed successfully at the split sleeve location for the removal of the stuck north end of the S-07 coolant channel in high radiation environment.

A metallic mirror based periscopic optical imaging system has been designed and developed with online CCD camera based viewing system having view at 90° with respect to radiation field emission direction. This optical viewing system has been deployed successfully at MAPS-1 reactor for detection of leak in the end-shield.



2.5 m long periscopic optical tool for in-situ viewing of end-shield leak at MAPS-1

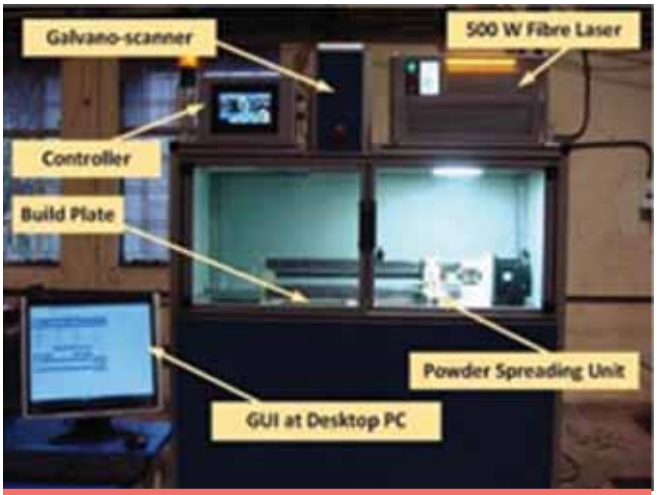
Steam generator tubes (14 mm ID and 1 mm wall thickness) of KGS-4 reactor are axially over-rolled up to a length of 80 mm in tube sheet at two locations, and safe removal of faulty tubes was difficult due to a large pulling load requirement exceeding its yield/ rupture point of 4 tons. A remotely operable, controlled depth laser based axial grooving process with miniature laser cutting nozzle of 12.5 mm diameter has been developed and qualified for removal of over-rolled faulty SG tubes in the KGS-4 reactor.

Laser cutting tool inserted in SG tube for axial grooving

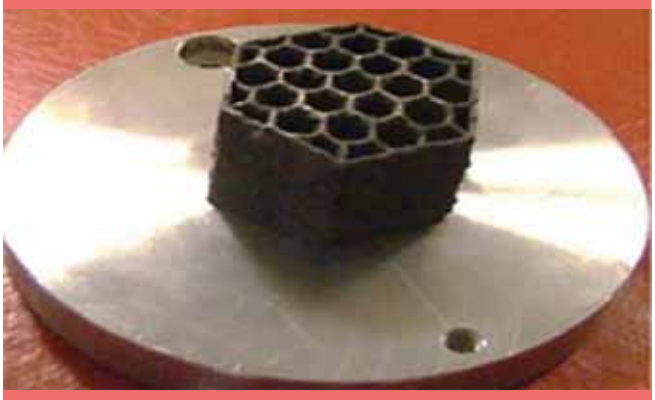
Axial and circular laser cutting tool

Axially laser grooved SG tube.

A Laser Additive Manufacturing system using 500 W fibre laser based Powder Bed Fusion (LAM-PBF) approach has been conceptualized, designed and developed. The system, with a build-volume of 250 mm x 250 mm x 200 mm, will cater to the fabrication needs of single material complex components involving small intricate features, thin walled structures and overhang geometries. The geometries fabricated are shown in the picture.



500 W fibre laser based LAM-PBF system

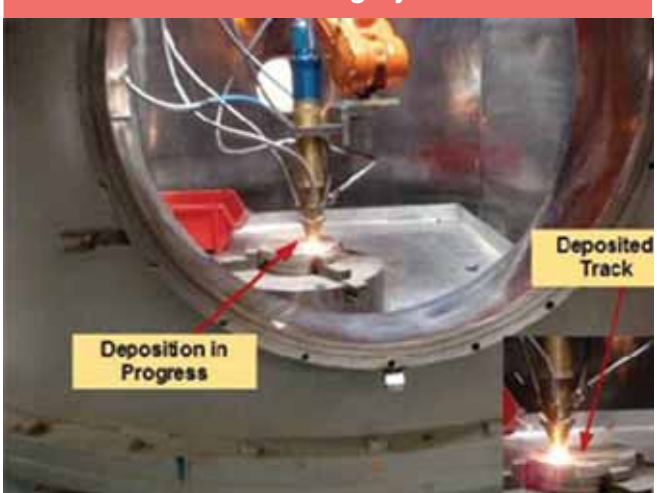


Hexagon hannelled nipple

External and internal geared geometry with honeycomb core.

A robot based large volume workstation of laser additive manufacturing has been developed by overcoming the limitations of the conventional approach. This will cater to engineering jobs within a working volume of 1 m3 in a processing station envelope of 1.5 m diameter x 2.6 m height. The system is capable of carrying out additive manufacturing under controlled environment with impurities level, specifically oxygen and moisture, below 100 ppm.

In-process large volume-laser additive manufacturing system.



Developed large volume-laser additive manufacturing system.

The presence of surface defects is known to adversely affect the fatigue performance of engineering components. In this respect, laser peening has been used on SAE 9260 spring steel as a remedial measure to enhance its tolerance for surface defects with respect to its fatigue performance. The results of the work hold promise for suppressing adverse effect of pre-existing surface defects on the fatigue life of engineering components

Trapping of cold 87Rb atoms in a dipole trap of a far detuned laser beam has been demonstrated. The trapped atoms were found to obey the potential structure provided by the dipole laser beam, which is in the shape of fine straight line. The potential depth of the dipole laser beam was 3 mK for 20 W power. The number of trapped 87Rb atoms in the dipole trap was 105.

A Two Isotope Magneto-Optical Trap (TIMOT) has been developed for a bosonic and fermionic mixture of Krypton atoms. Simultaneous cooling and trapping of metastable 84Kr (84Kr*) and metastable 83Kr (83Kr*) atoms has been achieved by overlapping the cooling laser beams for these isotopes in the same region of a chamber where a Zeeman slowed atomic beam was injected to load the TIMOT. The TIMOT has 1x105 number of atoms of each isotope.

SPECIAL MATERIALS

Using high purity raw material, about 25 kg Lithium Titanate (Li_2TiO_3) pebble has been fabricated and sintered. XRD analysis confirmed the formation of single phase Li2TiO3.

ADVANCED TECHNOLOGIES

Lab CVD reactor is one of the most critical step in demonstration of High Purity Silicon Wafer production Technology from metallurgical grade silicon. Lab Scale Chemical Vapour deposition reactor for bulk production of high purity polycrystalline silicon rods was operated for the first time in India and 6 rods were successfully grown having diameters ranging from 13 to 21 mm.

Quartz bell jar reaction for chemical vapour deposition of high purity silicon rods

Radiation resistant polysulfone-based composite ultrafiltration (UF) membrane was developed and rolled into spiral configuration. A membrane set-up housing a spiral UF membrane module and 3 resin columns was installed and commissioned at AFFF, Tarapur, for decontamination of ultrasonic bath water used for cleaning MOX fuel. The decontamination factor obtained with the membrane module alone is 2250, making the water suitable for recycle and reuse at full capacity.

Ultrafiltration (UF) Membrane manufacturing set up in AFFF, Tarapur

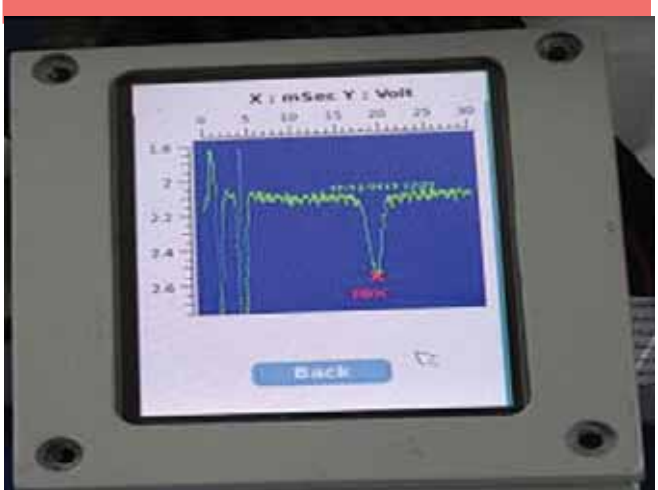
An optical periscope was developed for remote monitoring of operation of various instruments in the radioactive area of Waste Immobilization Plant (WIP). A CCTV camera integrated to the periscope provides imaging & zooming capabilities. The periscope is adequately shielded to protect the camera sensor and associated electronics from radiation damage.

Electronics & Instrumentation

ECIL, Hyderabad and IGCAR, Kalpakkam took up development of an Ion Mobility Spectrometry (IMS) based indigenous Explosive Detection System for detection of explosives like TNT,RDX, PETN etc. The drift tube of the IMS detector needed a compact high voltage pulsed supply and a high voltage dc supply for controlled acceleration of the charged ions to be detected. RRCAT has successfully developed the dc and the pulsed supply as required by ECIL. The dc supply is rated for -5 kV / 250 μA DC and pulse supply is rated for -5 kV / 200 μA. Both the supplies have been integrated with the detector unit and tested successfully for detection of explosives like TNT.

Twelve sets of supplies have been developed at ECIL under expert guidance of RRCAT and are being integrated with the detector units. The “Technology transfer” process for high voltage supplies has been completed and required training has been imparted to the ECIL technical personnel, for fabrication and integration of the supplies with the detector unit. The integrated explosive detectors will be supplied to OPSA (Office of the Principal Scientific Adviser to the Government of India), New Delhi for further deployment of these detectors with other agencies at different places in India.

Detector units under assembly at ECIL



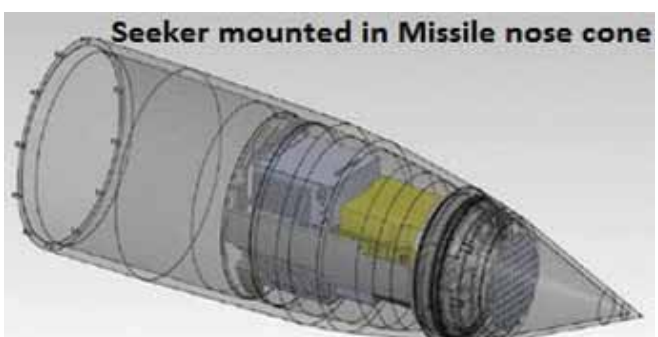
RDX detection on detector screen with RRCAT HV pulsed and HV dc supplies

Special Programmes

The RF seeker is a joint design and development of BrahMos aerospace, DRDL (DRDO), BARC and ECIL. BARC and ECIL. A precision servo control system for stabilization and positioning of two axis gimbal mechanism, which steers the RF seeker radar antenna precisely towards the designated target point have been developed. The RF seeker is designed to be compact, lightweight and capable of withstanding severe Electro Magnetic Interference and harsh environmental conditions.

RF seeker

Indigenously developed vibration fence consists of Perimeter Intrusion Detection (PID) controller, triboelectric cables and alarm monitoring system. PID controller implements event detection & classification algorithm to discriminate human intrusion events like climb, cut and fence lift from other environmental disturbances. The prototype is deployed in BARC covering around 200 meter fence.



RF seeker mounted in Missile nose cone

The prototype RF seeker deployed in BARC covering around 200 meter fence

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.

BARC produced ^{192}Ir of 56,000 Ci activity for industrial applications. Apart from this, several medically important radioisotopes such as ^{99}Mo, ^{131}I, ^{177}Lu, ^{153}Sm and ^{125}I have been produced for healthcare. 3,000 Ci of radioisotopes have been processed and deployed through BRIT to various hospitals and nuclear medicine centers.

During the year 2018 various types of sealed radioactive sources in suitable solid substrates were fabricated and supplied to customers for their applications in medicine, oil and gas industry, calibration of instruments in electronics and nuclear industries etc. Indigenous ^{125}I brachytherapy sources were developed in Radiopharmaceuticals Division and supplied regularly to various hospitals, such as, Sankara Nethralaya (Chennai), P.D. Hinduja Hospital (Mumbai), Sri Ramkrishna Hospital (Coimbatore) and Government Medical College & Hospital (GMCH, Chandigarh) for the treatment of eye cancer patients. This year, GMCH, Chandigarh became the first medical centre in Northern India offering eye brachytherapy facility to needy cancer patients using the source developed in BARC.

During the year 2018, 747 consignments of sealed radioactive sources (which includes low level laboratory check sources and custom-made sources) containing beta, gamma, positron, conversion electron, X-ray and low energy gamma emitters have been supplied to various customers for medical, industrial and other specific applications through BRIT on commercial basis. For calibrating the dose calibrators used in hospital radiopharmacy, 137Cs vial sources have been fabricated for the first time and supplied to a nuclear medicine centre. Strontium-90/Yttrium-90 large area sources have been supplied to NPCIL power stations

for use in portal monitors. Cobalt-60 polymer film sources have been fabricated for use as PIP tag sources in oil and gas industry. Nickel-63 annular copper ring deposited sources prepared by in-situ electrochemical deposition technique for use in Electron Capture Detectors (ECD) in gas chromatography applications have been supplied to ECIL (Hyderabad). These radioactive sources which are fabricated and supplied by Radiopharmaceuticals Division serve as indigenous economical alternatives to the imported sources.

RAPPCOF facility continued the tasks related with the 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 4214 kCi during the financial year 2018-19, which is a milestone in the history of BRIT. RAPPCOF successfully fabricated Co-60 Teletherapy Source with highest RMM possible as of now, i.e. 242 RMM, indigenously. After obtaining special arrangement approval from AERB, RAPPCOF was successful for transportation of eight adjuster/absorber rods in four consignments from KAPS, Gujarat to RAPPCOF during the reported period.

AGRICULTURE

Crop Improvement

Crop improvement work has made significant contribution in terms of varieties released in cereals and pulses and number of different mutant lines tested against abiotic and biotic stress. In case of rice, Trombay Chhattisgarh Dubraj Mutant -1 (TCDM-1) was released by Indira Gandhi Krishi Vidyapeeth, (IGKV), Chhattisgarh. TCDM-1 has yield advantage of more than 35% over parent variety (Dubraj) with semi-dwarf plant stature and enhanced tillerring. Another rice variety Trombay Karjat Kolam, BARCKKV-13, developed through collaborative research with Regional Agricultural Research Station, Karjat, DBSKKV, Dapoli, was recommended for release for cultivation in the Konkan region of Maharashtra. This dwarf variety, early maturity, superior grain quality and high yield can replace the traditional Kolam rice varieties in this region.

Field view of "TCDM-1 (Trombay Chhattisgarh Dubraj Mutant-1) (released for Chhattisgarh State)

Rice variety "TKR Kolam" (BARCKKV-13) (Released for Konkan Maharashtra)

One of the salt tolerant rice selection, BARCKKV-16, was promoted from AVT-I (salinity trials; Kharif 2017) with yield of 36.83 q/ha [31.39% higher yield over Panvel 2 (Check)] to AVT-II. It was evaluated in AVT-II (salinity trials in Kahrif-2018) in the Maharashtra state.

Field view of salt tolerant rice line "BARCKKV-16"

Trombay cowpea variety TC-901

In pulses, Trombay cowpea variety TC-901, the first central variety has been released and notified for summer growing regions of north zone, comprising of Gujarat, Rajasthan, Haryana, Uttarakhand, Madhya Pradesh and Maharashtra States. TC-901 is early maturing (70 days) and high yielding (1100 – 1350 kg/ha), with 15% increased yield over the national check RC101 and resistance against yellow mosaic virus and root rot diseases.

In banana, out of 8 mutant lines, a mutant line, TBM-9 was selected, which performed better than the control with a bunch weight of 29 kg with early maturity (294 days). This mutant is being multiplied at National Research Centre for Banana, Trichy, TamilNadu for further large scale field trials. The mutant lines are registered with NBPGR, New Delhi and IC numbers have been obtained. Transgenic banana plants over-expressing MusaSNAC1, a transcription factor imparted drought tolerance in banana by modulating stomatal closure and H_2O_2 content. With regard to iron biofortification in banana for increasing the iron content, several transgenic banana plants were regenerated with OsNAS1 and OsNAS. Out of this, 200 transgenic lines of Grand Naine and Rasthali have been given to National Research Centre for Banana, Trichy, Tamil Nadu to grow and analyse increased iron content in the fruits.

Banana mutant line (TBM-9) growing in the field along with a harvested bunch

Transgenic Rasthali and Grand Naine banana Plants in net house trial at NRCB, Trichy from Iron biofortification

In biotechnological approach for crop improvement, irradiated chitosan as a 'biostimulant' was used for improving overall productivity and stress tolerance. This biostimulant has been 'Recommended for Release' for commercial application in sugarcane cultivation by the Joint Agresco Meeting held at Mahatma Phule Krishi Vidyapeeth, Rahuri.

FOOD PROCESSING

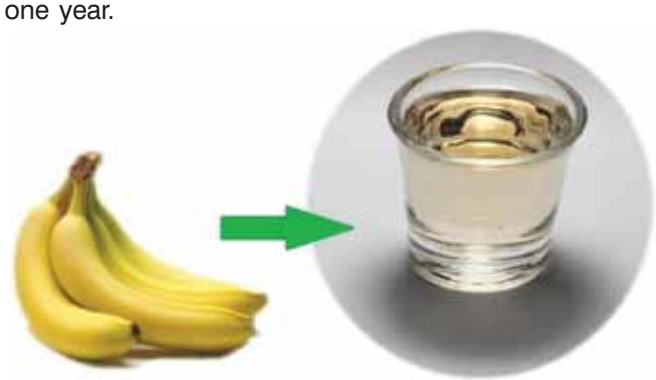
A demonstration electron beam radiation processing facility named ARPF is being developed at Indore. Two electron linacs with beam power 5 kW and beam energy of 10 MeV have been shifted to the Agricultural Radiation Processing Facility ARPF site. The picture shows the two linacs installed side by side at the facility. After obtaining AERB approval, Linac-1 has been commissioned at beam power of 5 kW and the commissioning of Linac-2 is in progress. The 10 MeV electron linac-based experimental irradiation facility operating at RRCAT was used by various researchers from all over the country for irradiation on the agricultural and industrial samples. The irradiation experiments carried out at the facility during this year are summarized as follows. A preliminary study has been initiated in collaboration with ICAR-Central Citrus Research Institute, Nagpur on Nagpur mandarin fruits (Citrus reticulate Blanco) for shelf life extension using electron beam and to study its effects on bio-active components. These samples were irradiated in dose range of 0.3 kGy to 1.5 kGy. The electron beam facility has been used for irradiation of large number of rice variety seeds (Dandras, Kanak bas, Sanchuriya, Dhaniya Phool, Samundrachini & Vishnubhog, Chirayinakhi, Zeeraphool) in the dose range of 50 Gy to 750 Gy. This work is being done in collaboration with Indira Gandhi Krishi Vishwavidyalaya, Raipur (CG) and NABTD, BARC.

Linac-B1 and Linac-B2 installed at radiation processing facility

Electron beam irradiation of different rice varieties for mutation breeding

Research on radiation processing of agricultural commodities to develop new products and applications continues to be the focus. These include the use of a combination treatment of radiation processing (400 Gy) and GRAS chemicals for extension of shelf life of fruits such as green grapes (Sharad, Sonaka and Thompson), pomegranate, litchi, mangoes (Alphonso and Kesar) and ready-to-eat apple slices.

Radiation processing was also employed for development of ready-to-eat shelf stable processed & fortified products from Jamun fruit pulp, shelf stable anti-diabetic nutraceutical incorporating fenugreek microgreen, mint and herbal (Gurmar). De-bittered and pasteurized bitter gourd juice retaining anti-diabetic activity and banana juice have been developed which are microbiologically safe with long shelf life of up to one year.



Fresh Banana Juice Technology

De-bittered Karela Juice Technology

Shelf life extension of ready to cook Alu Wadi and Kothambir, traditional Maharashtrian snack items, up to 4 months at ambient temperature was achieved using combination of radiation processing and vacuum packaging of the products. Protocols for preparation of energy bar from Ragi and Amaranthus flours were standardized.

Flesh foods such as intermediate moisture spiced chicken cubes under vacuum packing and irradiation (5 kGy) enhanced the shelf-life by 1 year while storage of fresh fish and shrimp can be enhanced employing hurdle technologies. A Shelf stable fish soup premix was also prepared using gamma irradiation processing for microbial decontamination of the product.

Intermediate Moisture Shrimp

Intelligent Packaging

Scale up of technology for Xanthan gum production to 1000 liters was carried out successfully. Novel active food packaging materials which has antimicrobial properties, intelligent packaging film that can indicate the quality of food product by colour change have been developed. Thermoplastic biodegradable sealable films were developed using corn starch and polyvinyl alcohol and methylated guar gum in combination with nanoclays was found suitable for packaging of minimally processed fresh-cut produce.

In the area of basic research, abscisic acid and phylloquinone/ naphthoquinone were identified as antimutagenic compounds in honey and spinach, respectively. Effect of gamma radiation on changes in physicochemical and functional properties of different food hydrocolloids like locust bean gum and psyllium husk gum was assessed and efficacy of the irradiated gum for development of different functional food products was evaluated. Besides this, preservative potential of papaya peel extract in meat, use of gamma radiation and microwaves in destruction of aflatoxin in peanuts were also assessed. Feasibility of newer radiochromic film and lithium and calcium borate-based glass dosimeters developed for food irradiation application was assessed. Studies on mechanism of programmed cell death in Xanthomonas campestris were continued.

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 285 customers from all over the country. Source strength of the plant was increased up to 700 kCi so as to increase the throughput of the plant. Eight new customers for Spice, Ayurvedic raw material and pet feed were registered with the facility during last nine months. New products such as coconut water powder, liver extract powder, watermelon powder and tobacco were also successfully irradiated to achieve microbial decontamination.

During the current financial year, 4749.56 MT of spices and other products were processed against the annual target of 4500 MT.

ISO 9001:2015 (Upgraded from 9001:2008) Certification for Quality Management System was received for Radiation Processing Plant, Vashi (BRIT) for providing Gamma Radiation Processing Services for Hygienization of spices, ayurvedic raw materials, pet feed and packaging materials.

Source replenishment of 200 kCi of Co-60 was carried out for Radiation Processing Plant, Vashi (BRIT) to increase the throughput in September, 2018.

Activities at Dosimetry Group of RPP includes the following:

Additional revenue was obtained from GRPS related products and services which include the production & supply of 2.0 Lakh Ceric-Cerous Sulphate dosimeters for various gamma irradiators in the country and around 1500 Nos. of Ceric-Cerous Sulphate dosimeters were made and exported to Atomic Energy Regulatory Board, Sri Lanka, for absorbed dose measurements.

Radiation Processing Plant recommissioning dosimetry was carried out in eight plants in the country for low, medium and high dose application. Dosimetry for mango irradiation was carried out at M/s Innova Agri Bio Park, Bengaluru, M/s IFC, Vashi, for approval of the facility by USFDA – APHIS for quarantine purpose.

Plant commissioning dosimetry for Dry Sludge Gamma Irradiator at AMC, dosimetry for medical products sterilization plant at M/s Pinnacle Therapeutics Pvt. Ltd., Ahmedabad and plant commissioning dosimetry for Class VI and Class III products of M/s EMI were provided by BRIT.

Dose rate certification were provided for 10 Nos. of blood irradiators supplied to various cancer hospitals and four Nos. of Gamma Chambers that were supplied to research universities in the reported period.

New MoU for Radiation Processing Plants in Private Sector

BRIT signed an MoU with M/s ZarimsDrynamics LLP, Ahemdabad for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products near Kheda, Gujarat. A MoU was signed with M/s Solas Industries, Noida for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products at Mathura (Uttar Predesh). A MoU was signed with M/s Microtrol Sterilization Services Pvt. Ltd., Mumbai for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products at Rewari (Haryana). A MoU was signed with M/s HiMedia Laboratories Pvt. Ltd., Mumbai for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products at Ambernath (E), Maharashtra. A MoU was signed with M/s AV Gamma Tech LLP, Mumbai & M/s Gamma Agro Medical Processing, Hyderabadfor setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products nearAmbernath, Thane&near Aerospace Park, Bangalore.

MoU signed with M/s ZarimsDrynamics LLP, Ahemdabad

MoU signed with M/s Solas Industries, Noida

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 Radioimmunoassay (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 radiopharmaceutical 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 thyroid cancers. Approximately 632 Ci of Na^{131}I and over 23000 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).

Pneumatic based, remote foot operating ATOMLAB 400 Dose Calibrator is installed inside the fume hood and in between the transport box of both, ^{131}I-NaI Solutions (IOM-1) plant in the main Production Laboratory. This set-up would help increase the integrity of Quality Assurance as well as decrease the MAN REM dose.

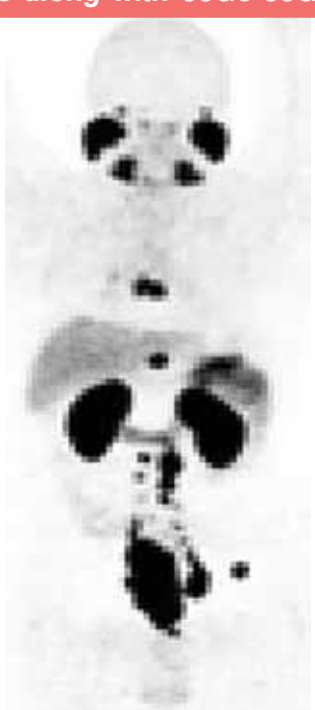
BRIT continues to supply I-131 labelled therapeutic product, I-131-Lipiodol, used for the treatment of Hepatocellular Carcinima [the most common type of Liver Cancer (single patient dose is 75mCi of I-131)] which was launched last year in collaboration with RPhD, BARC.

During the reported period, another milestone of 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) has been installed and cold commissioning is awaited. Trial cold runs for pharmaceutical validation are presently being undertaken.

Amongst the other therapeutic products supplied by BRIT, such as P-32 [Samarium Phosphate Colloidal Injection] for radiation synovectomy, Sm-153-EDTMP injection for bone pain palliation, ready-to-use ^{177}Lu-EDTMP injection for bone pain due to the spread of cancer in bones, a new therapeutic radiopharmaceutical, namely, Lu-177-DOTA-TATE which was launched last year for treatment of metastatic (somatostatin receptor positive) neuroendocrine tumors (NET) has gained a lot of importance. 47 Ci in 494 consignments were supplied to nuclear medicine centers all over India during the reported year 2018-19.

BRIT has introduced two ready-to-use diagnostic radiopharmaceuticals based on peptide labelling with Gallium-68 (Ga-68) isotope for imaging cancers of different origin. Supply has started for ^{68}Ga-Prostate Specific Membrane Antigen (PSMA) for diagnosis of Prostate Cancer and ^{68}Ga-DOTA-TATE for the diagnosis of neuroendocrine tumours (NET). These radiopharmaceuticals were supplied to the nuclear medicine centres 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.

^{68}Ga-Radiopharmaceuticals synthesis module along with 68Ge-68Ga generator



^{68}Ga-PSMA scan carried out with BRIT product

During the year 2018-19, more than 16,500 Nos. of cold kits for formulation of 99mTc radiopharmaceuticals (19 products; BRIT Code-TCK) in nearly 16,000 consignments were formulated, lyophilized, QC tested and supplied to various nuclear medicine hospitals all over India.

Supply of cold kits to various nuclear medicine hospitals all over India

Nearly 525 Ci of ^{99}Mo, in 2150 generators in form of Sodium Molybdate solution, for solvent extraction generator, Coltech generators and Geltech generators is supplied to the Nuclear Medicine Centres in India.

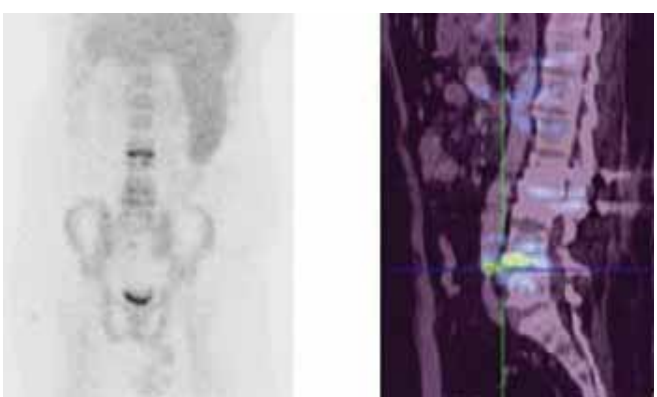
More than 2,50,000 In-vivo diagnostic investigations are estimated to have been carried out this year with varied diagnostic radiopharmaceuticals, the major one being, ^{99}mTc based cold kits and ^{99}Mo-^{99}mTc generator systems and around 17000 therapeutic applications are estimated to have carried 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-^{99}m Radiopharmaceuticals' was awarded the certificate 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).

Various Technetium-99m Cold Kits for the preparation of Technetium-99m radiopharmaceutical injections were exported to Chile, South America.

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 476 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 2018-19. More than 15000 patients benefitted with PET investigations in the reported year.

During the year at BARC, considerable progress has been made towards the development of various PET imaging agents. Gallium-68-labeled NOTA-UBI (Ubiquicidin 29-41), an infection imaging agent was developed. Gallium-68-labeled BPAMD is a well-known PET agent used for the skeletal imaging of patients suspected to be suffering from bone metastases. Methodology for the formulation of lyophilized BPAMD kit, which will enable the hospitals to formulate the patient dose of the agent in a convenient and single-step process at the hospital radiopharmacy has been developed. The efficacy of the kit has been evaluated by imaging a few cancer patients in collaboration with KMCH, Coimbatore. The kit has also been provided to Post Graduate Institute of Medical Education and Research (PGIMER, Chandigarh) for clinical evaluation. The whole-body image of a cancer patient, recorded after administration of 68Ga-BPAMD has been prepared using freeze-dried BPAMD kit, at 30 minutes post-administration.



PET/CT image showing uptake of ^{68}Ga-NOTA-UBI (29-41) in spinal TB

Production of ^{99m}Tc-based SPECT RPhs were carried out. A total of 74.39 GBq of ^{68}Ga-DOTATATE and 17.08 GBq of 68Ga-PSMA-11 of ^{68}Ga based PET RPhs were produced during the year. A total of 3856.30 GBq of ^{177}Lu-DOTATATE and 395.69 GBq of ^{177}Lu-DOTA-PSMA-617 of ^{177}Lu based therapeutic RPhs were produced during the year. Radiochemical Purity, Sterility Testing & Bacterial Endotoxin Testing were carried out for all batches of RPhs produced before releasing for administering to the patients.

Patients referred to Radiation Medicine Centre (RMC) for diagnostic and therapy purposes were examined by Nuclear Medicine consultants and studies were carried out as per their instructions. Patients admitted to the therapy ward are administered high dose radioiodine therapy and ^{177}Lu-DOTATATE and ^{177}Lu-PSMA-11 therapy.

Scintigraphy (in vivo radionuclide imaging) services were carried out during January to December, 2018. A total of 13,641 no. of patients were scanned during the year.

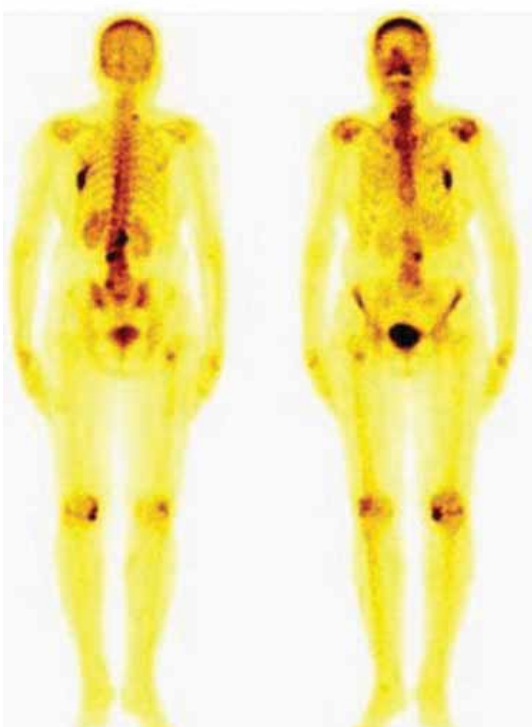
A single vial freeze-dried kit has been developed for the formulation of 99mTc-labeled dimeric RGD peptide derivative for non-invasive monitoring of breast cancer patients. Clinical investigations have been initiated in breast cancer patients in collaboration with PGIMER, Chandigarh.

Technitium-99m-labeled Human Serum Albumin (HSA) nanocolloid, used as a sentinel lymph node radiotracer for prognosis of several cancers, is regularly prepared in Radiopharmaceuticals Division and supplied to various nuclear medicine clinics through BRIT. During the year, efforts had been directed to enhance the shelf-life of the lyophilized kit used for the preparation of the agent and approval from the competent authority has been received towards the use of this improved kit for the treatment of human patients.

Liver cancer is a leading cause of cancer-relates deaths world-wide. Trans Arterial Radio Embolization [TARE] is a preferred mode of treatment in a section of patients to whom the surgical resection of affected liver is not possible for various reasons. Radiopharmaceuticals Division of BARC had recently developed a two vial kit for preparing a TARE agent, namely 188ReN-DEDC/ Lipiodol. Clinical evaluation of the agent was performed in collaboration with three premier hospitals of our country, namely All India Institute of Nuclear Medicine (AIIMS, New Delhi), Tata Memorial Hospital (TMH, Mumbai) and Kovai Medical Center and Hospital (KMCH, Coimbatore). In the year 2018, the use of the kit for human administration has been approved by the competent authority, thus making this radiopharmaceutical an approved agent in India.

^{131}I-labeled Lipiodol is another such agent developed in Radiopharmaceuticals Division for the treatment of unresectable liver cancer. During the year, 5 batches of ^{131}I-Lipiodol injection was prepared and supplied for providing the radiotherapeutic treatment to the patients suffering from liver carcinoma.

During the year 2018, plant-scale multi-dose formulation of 'ready-to-inject' ^{177}Lu-labeled DOTMP, a potential radiotherapeutic agent for bone pain palliation, has been developed and preliminary clinical investigations have been performed in eight cancer patients in collaboration with PGIMER, Chandigarh. A freeze-dried DOTMP kit, which enables the formulation of the agent at the hospital radiopharmacy was also developed and the lyophilized kits have been supplied to AIIMS (New Delhi) and PGIMER (Chandigarh) for the treatment of cancer patients suffering from metastatic skeletal carcinoma originated from various types of primary cancers.



Post-therapy scintigraphic image of a patient, suffering from metastatic prostate cancer after administration of 70mCi dose of ready-to-inject ^{177}Lu-DOTMP

During 2018, strong efforts have been directed to standardize the formulation of various radiolabeled antibodies such as, Rituximab (for the treatment of Non Hodgkin's Lymphoma), Trastuzumab (for treating breast cancer patients) and Nimotuzumab (for treating epidermal growth factor receptors expressing cancers).

Dosimetric studies with ^{177}Lu-Trastuzumab in patients with breast cancer have recently been initiated in collaboration with TMH (Mumbai).

As a part of Government of India's 'Make in India' initiative, development and manufacturing of a new indigenous Nd:YAG laser welding machine has been achieved in collaboration with RRCAT (Indore) for encapsulating miniature 125I brachytherapy seeds in biocompatible titanium tubes towards their use for treatment of eye cancer.

Neutron irradiation of natural cerium based CeO_2 microspheres has been carried out to prepare ^{141}Ce point sources for their use as marker sources in nuclear medicine diagnostics. Two such sources have been supplied to RMC and KEM Hospital (Mumbai) for their use during clinical settings.

Radiation Technology Equipment

Indigenous rechargeable phantoms

Indigenous rechargeable phantoms have been fabricated in-house at Radiopharmaceuticals Division for their use in quality assurance of gamma cameras installed at two different nuclear medicine centres in Mumbai. Radiochemical processing of about 1 Ci of 141Ce has been accomplished for use in these phantoms. Four consignments of 141Ce have also been supplied to RMC and KEM Hospital (Mumbai) for intended application.

Bhabhatron unit with Multi Leaf Collimator (MLC)

In the area of affordable cancer treatment, to improve clinical performance, radio therapy machine Bhabhatron has been integrated with Multi Leaf Collimator (MLC) system to provide radiation field to irregular tumour geometries. Hon'ble President of India inaugurated the Bhabhatron unit with MLC, installed at ACTREC, Kharghar, Navi Mumbai during his visit to BARC.

Blood Irradiator

Four Blood Irradiators-2000 units with Cs-137 source (9116 Ci) have been supplied to hospitals in India during April 2018 to March 2019.

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 1381 radioimmunoassay (RIA) and immunoradiometric assay (IRMA) kits to serve about 1,25,250 in-vitro investigations, were supplied to various hospitals, research centers 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 k/as Jonaki), Bengaluru, and Kota continued the services of ready-to-use-radiopharmaceuticals to surrounding nuclear medicine hospitals, preparation & supply of labelled compounds, radioanalytical certifications and processing of Co-60 sources for their various uses in Engineering Programme of BRIT respectively. 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.

During the year 2018-19, approximately 270 Nos. of Technetium cold kits for formulation of ^{99}mTc-radiopharmaceuticals were supplied to various Nuclear Medicine Hospitals in Kolkata. Fluorine-18 isotope was successfully produced for the first time using CYCLONE-30 in Medical Cyclotron Project (MCP), Kolkata during the reported period 2018-19. Fluorodeoxyglucose (FDG) synthesis was also carried out at RCR, Kolkata, and also FDG synthesis module

was indigenously developed at RCR, Kolkata located at Variable Energy Cyclotron Centre (VECC). 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 avail the services from this center.

F-18 target and its associated systems/modules

CYCLONE-30, Cyclotron Machine at Medical Cyclotron Project (MCP) at VECC

Regional Centre, BRIT, Bengaluru supplied 85 Ci of ready-to-use ^{99}mTc-pertechnatate to nuclear medicine hospitals and 820 TCK cold kits were sold through retail outlet and door delivery for the preparation of ^{99}mTc-radiopharmaceuticals to nearby nuclear medicine centers. Gamma irradiation unit, BI-2000 is decommissioned and sent to BRIT, Vashi Complex for loading of new Cs-137 source. Radioanalytical Laboratory analyzed and certified 186 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 ^{99}mTc-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 centers in Delhi and NCR regions. During the period 2018-19, Regional Centre, Delhi has been involved in the production & supply of 22.7 Ci of clinical grade, ready-to-use Tc-99m radiopharmaceuticals injections. RCR, Delhi has obtained NOC from AERB for the procurement of ^{68}Ge/^{68}Ga generator from abroad. The procurement of hot cell, labelling module and automatic dose dispenser for setting up of 68Ge/^{68}Ga generator facility at Regional Centre, Delhi is in progress.

During the period, Regional Centre of BRIT, Hyderabad (Jonaki) obtained NOC from AERB to procure Sodium Molybdate solution (185GBq/week) & ^{68}Ge-^{68}Ga Generator (1.85GBq/Six months) to initiate the supply of Tc-99m and Ga-68 radiopharmaceuticals to local Nuclear Medicine Centers. It received exemption from authorization for safe disposal/transfer of radioactive waste for Jonaki, BRIT, and transport permission from AERB to start the production & supply of ready-to-use ^{99}mTcO$_4$- (pertechnatate). RCR, Hyderabad, has also set up Sterility Testing (ST) and Bacterial Endotoxin Testing (BET) laboratories where physicochemical tests, ST and BET tests were all performed for batches of ^{99}mTcO$_4$- (pertechnatate) using Autosolex before their supply. It also continued the synthesis and supply 32P labelled nucleotides (436 consignments – 287.5mCi) and a few molecular biology reagents such as Taq DNA Polymerase (7.7 Lac Units), PCR master mix and enzymes, for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research of the country. It marketed ^{35}S-labelled amino acids products and TCK cold kits (972 Nos.), produced at BRIT, Vashi Complex.

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 2018-19, Labelled Compounds Programme has supplied 21000

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. Work related to design and fabrication of Tritium trapping system was completed and is successfully being implemented for the production of TFS sources during the reported year. 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.

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. Supply of 150Ci of Tritiated water was supplied to M/s ONGC.

To promote the Non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology, HWB is working with number of organizations/institutions. There is a great global demand of D-labelled compounds, NMR solvents, APIs and drug entities. HWB is receiving requests for supply of heavy water, deuterium gas, DDW from various organizations.

Heavy Water Board has collaborated with M/s. Clearsynth & M/s. SYNMAR for non-nuclear application of heavy water. Each the parties have taken 550 kg heavy water from HWB. M/s. Clearsynth has also taken 500 kg of DDW from HWP, Manuguru for carrying out study on potential use of DDW as portable /energy drink. M/s SyNMR has given the list of their products. M/s Clearsynth has shared the spectra of CDCl3 produced by them which shows few impurities, HWB has shared the brief process detail with M/s Clearsynth in order to improve the quality of the product.

For synthesis of deuterated API, HWB has taken initiative for collaboration with NCL, Pune and ICT, Mumbai. Two collaborative projects with NCL, Pune have been identified for synthesis of deuterated methanol and a few deuterated building blocks for medical use.

Four projects have been started with ICT, Mumbai under DAE-ICT Centre on applications of deuterium in medicinal chemistry viz., synthesis and evaluation of bio-enhanced & targeted drug delivery system of deuterated Mitocurcumin, modified deuterated polyphenols as chemotherapeutic and antimicrobial agents, modified novel deuterated amino acids and small molecules. These deuterated analogs are expected to have potential of increasing the lifetime of active drugs and therapeutic importance for improved potency.

Collaboration work with ACTREC is under discussion for taking up phase –II studies on potential of DDW for cancer therapy on a project “Evaluation of anticancer potential of deuterium depleted water (DDW) on human breast and lung cancer cell and experimental tumor model”.

To promote non-nuclear application of Deuterium and Heavy Water, exhibits were put up in various conferences such as NUJ-DAE meet at Kaiga, IISF at Lucknow, DAE workshop at Dehradun, CII Pharma Conclave at Delhi, etc.

Radio Analysis

Radioanalytical Laboratory (RAL) carried out the assay for the 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; 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 2018-19, Radioanalytical Services at Vashi Complex carried out more than 5520 tests on export/domestic commodities and 1374 tests on water samples (gross alpha, gross beta ^{226}Ra & ^{228}Ra). The laboratory is accredited by NABL for testing 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)

ISOMED facility, engaged in contract gamma radiation processing services for terminal sterilization of the medical products has processed 2664 Cubic mtrs of products.

New Projects

DAE Medical Cyclotron Project: Radiopharmaceutical Facility

Production of F-18 using CYCLONE-30 Medical Cyclotron at BRIT, VECC, was initiated. Fluorodeoxyglucose (FDG) target was installed followed by the preparation of ^{18}F-FDG. Procurement of bio-quality control equipments like PTS (portable endotoxin testing system), incubator for sterility testing, sterility reagents (media), and Bacterial Endotoxin test (BET) reagents etc. has been completed. Installation of different instrumentation modules such as Syringe drive module, Helium manifold, Target manifold module and Liquid distribution cabinet (input/output), supplied by M/s IBA, were completed. The liquid target assembly was installed on the corresponding target stations provided inside the FDG target vault. Two targets were assembled, installed and successfully tested for any leakage or any vacuum problems. Mechanical support for both, the targets were designed and fabricated indigenously. Electric cables were routed to the control room where the control PLC is installed. Teflon tubing connections required for the F-18 targets operation were completed and tested. Cold run was carried out to test different operations and the consistency of the system before the hot trials, or in other words, with F-18. Thus, FDG synthesis was successfully completed for the first time at RCR, BRIT.

Setting up of Fission based ^{99}Mo Production Facility

External civil construction is completed & occupied. Internal civil modification is ongoing and only 50% completed so as to accommodate M/s. INVAP design layout of the processing equipment. More than 80% of the equipments required in the plant and machinery has been received and their installations are in progress.

External and Internal view of Fission Molybdenum Project (FMP) 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.

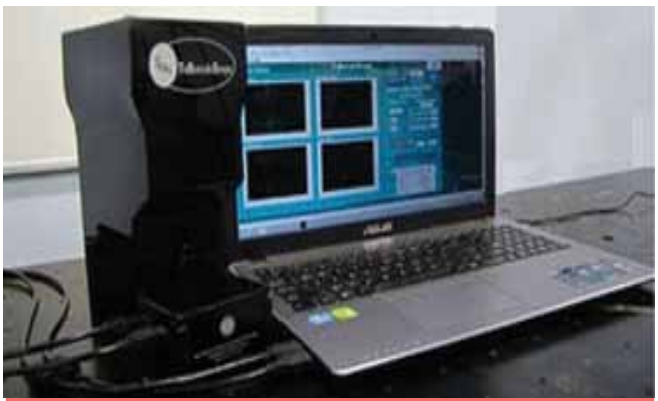
Technology Development for Radiation Technology Equipment

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.

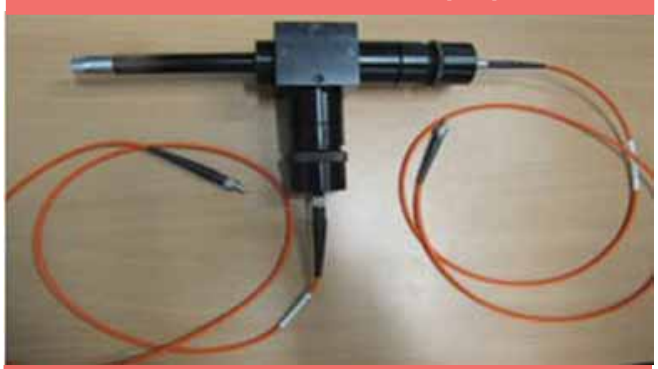
Biomedical Applications

A hand-held optical imaging device has been developed for real-time non-contact in-situ imaging of fluorescence from bacterial bio-burden in wounds, which allows easy demarcation of bacterial film on wounds. The efficacy of the developed system has been assessed by detecting the fluorescence images from bacteria infected wounds in mice treated with pro-drug-aminolevulinic acid (ALA). Since the bacteria rapidly synthesize porphyrins, a red fluorescent compound, in the presence of ALA, it provides a very good image contrast as compared to assessment under white light illumination.

The Technology of a 'TuberculoScope' developed at RRCAT, Indore, which is a low-cost, easy-to-use and portable point-of-care device for detection of Mycobacterium tuberculus (the bacteria responsible for TB disease), has been transferred to M/s RTK Meditech, Indore, through the 'Technology Transfer and Coordination Division' of BARC, Mumbai. Due to the technology transfer, the 'TuberculoScope' is now available from an Indian industry at much lower cost as compared to the presently used imported equipment.



"TuBerculoScope" along with the graphic user interface on a laptop



"Raman probe" developed at RRCAT

The technology of a Raman probe developed at RRCAT, which is meant for in situ measurement of good quality, Raman spectra from low Raman-active materials like biological tissues within a few seconds, has been transferred to M/s Applied Optical Technologies Pvt. Ltd., Thane, through the 'Technology Transfer and Coordination Division' of BARC, Mumbai. The developed Raman probe is expected to enhance the utility of Raman spectroscopy systems in biomedical applications, where in-situ measurement of Raman spectra is often desired but not possible because of unavailability of a suitable Raman probe.

Alternative Applications of Heavy Water

The $H_2{}^{18}O$ of 95.5% O-18 enrichment is used in PET scanning and 10% O-18 enrichment is useful in metabolic studies. The first indigenously developed O-18 production plant at HWP, Manuguru has reached the enrichment of O-18 up to 75% during the report period.

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 TMC, a Grant-in-Aid institution of the DAE, GOI, comprised of nine centres - the main Tata Memorial Hospital (TMH) in Mumbai; the Advanced Centre for Treatment, Research & Education in Cancer(ACTREC) at Kharghar, Navi Mumbai; the Centre for Cancer Epidemiology (CCE)at Kharghar, Navi Mumbai; the Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) at Aganampudi, Visakhapatnam; the Homi Bhabha Cancer Hospital (HBCH) at Sangrur, Punjab; the Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) at Mohali, Punjab; the Dr. Bhubaneswar Borooah Cancer Institute (BBCI) at Guwahati; the Homi Bhabha Cancer Hospital at Varanasi, Uttar Pradesh. The Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC) at Banaras Hindu University (BHU), Varanasi, Uttar Pradesh was due to be operational by February 2019.

The over 50 year old Tata Memorial Centre (TMC), an established authority on cancer management in India continued to treat cancer patients who flocked from all over the country.

The year 2018 had almost 75,000 patient registrations; 4 % more than last year. The Preventive Oncology patient registration rose by more than 25 % to a figure of 7179. There was 15 % increase in the

number of patients for Radiotherapy as a result of extension of the working hours. The department of Radiodiagnosis also revealed increased number of investigations with the numbers, more than doubling for Interventional Radiology. Similarly, Single-Photon Emission Computed Tomography (SPECT) scan patients rose by almost 25 % as compared with last year. The Medical Social service sector counselled and guided over 50,000 patients; an increase by over 25 %. The recent introduction of a special Home Care team from ACTREC campus by the Palliative Medicine department was very well appreciated by the patients as evidenced by the increased number of such visits by over 50 %.

The numbers of patients registering online increased to more than 8500. Of the total registration of almost 75,000 new patients, majority provided government issued documents like driving license, voters Id, senior citizens card, Aadhar Card etc. to ascertained their identity, and the demographics for travel concessions, epidemiological studies etc.

Poor patients of the State made use of the recently launched, the Mahatma Jyotiba Phule Jan Arogya Yogana (MJPJAY) Scheme by the State of Maharashtra.

Mouth and Breast cancers continued to be the leading cancer sites for males and females respectively.

The cancer related drugs and consumables were supplied to all the patients (of TMC & its satellite centres) at a substantial lower cost than the Maximum Retail Price (MRP). The costs of various investigations were also lower than those prevalent in the respective towns or cities. In general, the cost to patients for their cancer management was cheaper at TMC satellite centres outside Mumbai.

All TMC satellite cancer centres had provisions of smart cards for patients that would enable them to make cashless transactions and also to see their reports online. Provision was also made for seamless patient referrals across these centres without the need for re-registration and, also for their data to be viewed and updated across these centres.

Till date, there were 2,19,824 active Smart Card users that carried out 13,88,980 transactions to the tune of almost INR 3,00,00,00,000/-.

The uniformity of various patient and administrative related web-based modules made it easy for the patients who continued their treatment at the TMC satellite centres, or those who were referred to TMH for management. The live viewing and updating of patient records made it easier for the clinicians to treat patients from any TMC's satellite centre.

Taking digitalization forward the hospital became almost paperless, filmless and cashless. More than 95 % of the patients dealt with cashless transactions through the use of their TMH provided smart cards.

The TMC-Navya online second opinion cancer services continued to be popular with the general public. More than 26000 patients from over 60 countries have utilized this service.

The year 2018 saw the full-fledged activities for the commissioning of the 179 bed Homi Bhabha Cancer Hospital (HBCH), Varanasi in the month of May. Dignitaries like Shri Yogi Adityanath, Chief Minister of Uttar Pradesh, Shri Piyush Goyal, Union Minister of Railways and Minister of Coal, Dr. Shrikant Mishra, Chief priest of Kashi Vishwanath temple and Swami Shri Varishtanandji from the Ramakrishna Organizations visited the hospital around its commissioning period. There was increased impetus to ensure that the other 350 bed cancer hospital (the Mahamana Pandit Madan Mohan Malaviya Cancer Centre) in the campus of the Banaras Hindu University (Varanasi) was commissioned by the first quarter of year 2019.

The bed strength of HBCH, Sangrur was increased from 30 to 100 and, the Government of Punjab donated generously for establishing an Interventional Radiology section in the hospital; the first in the State of Punjab.

Efforts were ongoing to commission the Radiotherapy Block at HBCHRC, Visakhapatnam and, of the HBCHRC in Mullanpur, Mohali at the earliest.

Revamping was also planned for the recently acquired Dr. B. Borooah Cancer Institute, Guwahati. Any deficiency, in terms of facilities, equipment, staffs etc. were to be addressed and the dilapidated Academic block was to be demolished to construct a new Ancillary Building.

Talks were ongoing for the construction of a dedicated cancer wing in the campus of Sri Krishna

Medical College (A Bihar Government Undertaking) in Muzaffarpur, Bihar under the aegis of TMC by the DAE and the Government of Bihar.

To accommodate the growing needs of TMH and the increasing patient load, the Government of Maharashtra allocated a 5-acre plot of land in the Haffkine Institute for Training, Research and Testing in Parel, Mumbai near the hospital. This plot of land would be used to construct a new hospital with residential quarters for doctors and, a Dharamshala for patients. With additional infrastructure, TMH would be in a position to deliver state of the art treatment services to many more needy patients in an effective and efficient manner. For the benefit and convenience of the patients, the Dharamshala would be the first structure to be constructed and, about 25 % of the work was already completed.

The National Cancer Grid (NCG) funded through the DAE, continued to grow and now had more than 170 centres across India. As its offshoot, the NCG Virtual Tumor Board (VTB) grew as a web-based platform that included online, multiple clinical experts to address complicated patient management issues.

A lot of new activities were seen in the ACTREC campus. There was increased Out-Patient load at ACTREC in the past few years as new patient registrations were accepted there. There were space constraints and in 2018, a new spacious and well-designed patient waiting area was created on the ground floor with all amenities. The structural work for the installation of the National Hadron Beam Therapy in the ACTREC campus in Navi Mumbai had begun and it is likely to be completed soon.

The ACTREC campus also houses a separate building, the Radiological Research Unit (RRU) for conducting scientific & research work in Nuclear & Molecular Imaging, Radiotherapy and Radiodiagnosis. Work for the same is continued and the structure would be completed soon.

Work had begun for a separate wing in ACTREC, the Hematolymphoid, Women & Children Cancer Centre (HWCC) that is dedicated to patients with Hematolymphoid cancers and for Women & Children with cancer. The work began in the end of year 2017 and it is expected to be completed by 2020.

Few important scientific contributions made a significant positive impact on cancer management, these includes the beneficial effects of pre-operative exposure to progesterone mediated by modulation of surgical stress; development of a freely available PDZ (Post-synaptic density, Drosophila disc large tumor suppressor and Zona occludens) protein database, the PDZscape that consolidated the mutations & diseases associated with PDZ containing proteins; established that the loss of Plakophillin3 (PKP3) led to increased tumor formation and metastasis; the role of proteasomal acitivity essential for survival and recurrence of radiation-resistant glioblastoma cells and a novel Ribonucleic Acid (RNA) in situ hydridization (ISH) based methodology called RNAscope Assay that detected Human Papilloma Virus (HPV E6/E7 messenger RNA (mRNA) of seven high risk HPV subtypes in Formalin Fixed Paraffin Embedded (FFPE) tissue samples.

^{60}Co Teletherapy Sources for Cancer Hospitals

Twenty ^{60}Co-teletherapy sources with total activity of about 224 kCi in the range of 154 and 232 RMM were supplied to various cancer hospitals in India. Out of these, three numbers of Co-60 teletherapy sources with the strength of 214 RMM, 209 RMM and 210 RMM were exported to Sri Lanka through M/s Teambest Theratronics Asia Pvt. Ltd. Another Co-60 teletherapy source (177 RMM) was exported to IMO International Health Systems Ltd. (IIHS), Nigeria. Yet another 10 Nos. of sources are fabricated and ready for supply. Twenty decayed sources were unloaded from the teletherapy units and stored for fabrication of irradiator source. These sources were fabricated at RAPPCOF, Kota using Co-60 produced indigenously in nuclear power reactors.

WATER

Water Purification, Desalination of water & Isotope Hydrology

BARC developed a 5 cubic meter/day Brine Concentrator Unit with Thermo Vapour Compressor, to address the environmental issue of disposal of brine from desalination plant. BCU has demonstrated its performance to concentrate brine from 7-20 wt.%.

Indigenous development of BCU provides the technological knowhow of the process for management of brine from desalination plants to achieve Zero Liquid Discharge (ZLD) systems.

5 cubic meter/day Brine Concentrator Unit with Thermo Vapour Compressor

Sampling from deep groundwater in Haryana

Isotope hydro-geological investigations were carried out for the identification of paleo-channels in Haryana, Gujarat, Rajasthan and Uttar Pradesh. Isotope study showed existence of paleo-channel in Kurukshetra, Haryana, and Allahabad, Uttar Pradesh. In Haryana the paleo-channel is acting as recharge conduit to groundwater from high Himalaya. These paleo-channels can be recharged by artificial means which can serve potential groundwater source. The deep ground waters in Gujarat and Rajasthan are paleo-water but they have been recharged in the past (1800 to 29,000 years BP) by precipitation.

Isotope hydrology was carried out in Tapoban-Badrinath geothermal area to understand the source and origin of thermal waters, to estimate the approximate residence time of thermal waters and to calculate the reservoir temperature. Stable isotopes (ä18O, ä2H) data confirmed the meteoric origin of the thermal waters. The mixing phenomenon between thermal water with shallow ground water was substantiated using tritium (3H) and chemical data. The estimated mean transit time of the Tapoban thermal water is found to be between 40 to 44 years whereas for Badrinath thermal water it ranges from 102 to 112 years. Various models were applied to estimate the subsurface reservoir temperature and the reservoir temperature was found to be 130±50oC.

Geothermal spring in Badrinath area (91°C). Gas collection is in progress.

INDUSTRIAL APPLICATIONS

Electron beam processing of engineering materials

A cotton-based superabsorbent for selective absorption of oils from oil-water mixture was developed by electron beam assisted topography and surface energy modification. The superabsorbent was found to be strongly hydrophobic and oleophilic in addition to

being biodegradable and heat resistant. Based on the electron beam grafted superabsorbent, a prototype was developed for separation of hydrocarbons from a mixture of hydrocarbons and water. The device can also be used for separation of organic contaminants such as benzene, toluene, ethyl benzene, chloroform, dichloromethane, tributyl phosphate and triphenyl phosphate from industrial or municipal wastewaters and protection of cotton based materials from wetting.

Prototype device developed for demonstration of oil-water separation

Radiotracer investigations in an ethyl acetate production reactor of M/s IOL Chemicals and Pharmaceuticals Limited, Ludhiana, Punjab

Radiotracer investigations were carried out in paper-pulp digesters and wastewater treatment plant at M/s Trident Industries Limited, Barnala, Punjab and in an ethyl acetate production reactor at M/s IOL Chemicals and Pharmaceuticals Limited, Ludhiana, Punjab for process diagnosis, measurement of hydrodynamic parameters and evaluation of design of the reactors. For investigation in a paper-pulp digester, Tc-99m as sodium pertehnate was used as radiotracer for tracing the aqueous phase. Several flow abnormalities were identified in one of the two digesters. For investigating flow dynamics of wastewater in an effluent treatment plant, Iodine-131 was used to measure Residence Time Distribution (RTD) of the wastewater. Results indicated bypassing dead volume and poor mixing of wastewaters within two different aeration tanks of the wastewater treatment plant. The radiotracer experiments in an ethyl acetate production reactor were carried out to measure the mean residence time and degree of mixing and validate design of the reactor. No flow abnormalities were found in the reactor and it was behaving as per design criteria.

The RTD measurements using radiotracers were also carried out in a cross flow reactor at M/s Engineers India Limited, Gurugram, and Haryana to evaluate hydrodynamic performance of the reactor. Radiotracer investigations were carried out for online detection of leakages in heat exchanger systems at the Baroda Refinery of M/s Indian Oil Corporation Ltd (IOCL). Timely identification of leaking heat exchangers prior to the scheduled shutdown reduced the down-time of the refineries by a period of 15-20 days resulting in significant revenue saving to the refineries.

Sealed radioisotopes and radiation based industrial radiology

BARC carried out extensive nuclear radiation based radiometry and imaging investigations for industrial components and assemblies for various departmental projects, including critical non-destructive evaluation studies for engineering specimens used in power reactor engineering and test reactor loops and prototype facility for radiochemistry work. In addition to this, high-energy gamma radiometric investigation for thickness qualification for Product Transfer Cask, Waste Transfer Casks, Ion Chamber Housing Assembly for KAPP-3&4 and RAPP-7&8 and Hot-cell shielding integrity were also carried out.

Training and Certification in Industrial Radiography and Radiation Safety

As part of skill development and upgradation programme in non-power applications of radioisotopes, radiation and non-destructive evaluation and radiation

safety, BARC conducted three batches of Radiography Testing Level-2 training programme and seventy-six trainees from across the country successfully passed the qualifying examination this year. The training programme is conducted as per guidelines of IS-13805 (Bureau of Indian Standards) and IAEA-TECDOC-628/ Rev.2. BARC RT Level-2 course extensively covers radiation safety as specified in AERB/RF/Training-Syllabi/2012 approved by the Atomic Energy Regulatory Board (AERB), Government of India.

X-Ray Baggage Scanning System

Indigenous Imaging software for X-ray Baggage Inspection System (XBIS) has been developed and integrated with XBIS machine manufactured at ECIL. Three X-Ray Baggage Scanners with this software have completed field trial successfully. The system meets the image quality requirements of penetration, spatial resolution, wire resolution and Contrast sensitivity of commercial systems. This product will serve the security needs at public places, airports and railway stations.

Radioisotope Sources supplied by BRIT

Industrial Irradiator Sources

Seventy two irradiator sources with total activity of around 4000 kCi were supplied in sixteen consignments to various processing plants within the country. One single supply of Co-60 Irradiator source (1000kCi) was exported to REVISS SERVICES Ltd. (UK).

Radiography Sources

A total of 646 consignments of Ir-192 & Co-60 radiography sources with total activity 24597.5 Ci were supplied from April 2018 to March 2019.

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. 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.

Isotope Application Services

Gamma scanning of IOCL Mathura Refinery

Lower spent catalyst powder output from reactor to the regenerator was observed in Fluidized Catalytic Cracker Unit (FCCU). Coke deposition or lumps formation was suspected in the packing present in the annular region of the reactor. To identify the location of the problem, four cordial scan lines were identified and around 10 m of the section was scanned by 80 mCi Co-60 source. The radiation data was recorded by scintillation detector and plotted as elevation versus count rate. Good flow of powder flow was observed in one half of the reactor section whereas in another half, intermittent flow was observed with few lumps present. Off specification products were obtained from the debutanizer column of FCCU unit. The column height was around 35m and diameter around 2.5m. Two scan lines were identified for two pass trays of the column. The attenuation profile obtained indicates that the trays were mechanically intact. Flooding and high vapor density was observed at some locations of the column. Very high sulphur content was observed in the lean amine generated from amine regeneration column. Due to highly corrosive environment in the column, mechanical damage was suspected inside of the column. The column height and diameter were 25m and 2m respectively. Scanning of the column concluded that all the trays in the column are intact with liquid up to the weir height and appropriate clear vapor space. Uneven liquid distribution over the chimney tray was observed.

Mechanical arrangements to be carried out on debutanizer column, IOCL, Mathura

Gamma scanning of BPCL Kochi Refinery

In vacuum column of Kochi refinery, high MCR, Asphaltenes and metals content in VGO was observed. It was suspected that wash oil bed#5 is not functioning properly. Probable causes may be maldistribution,

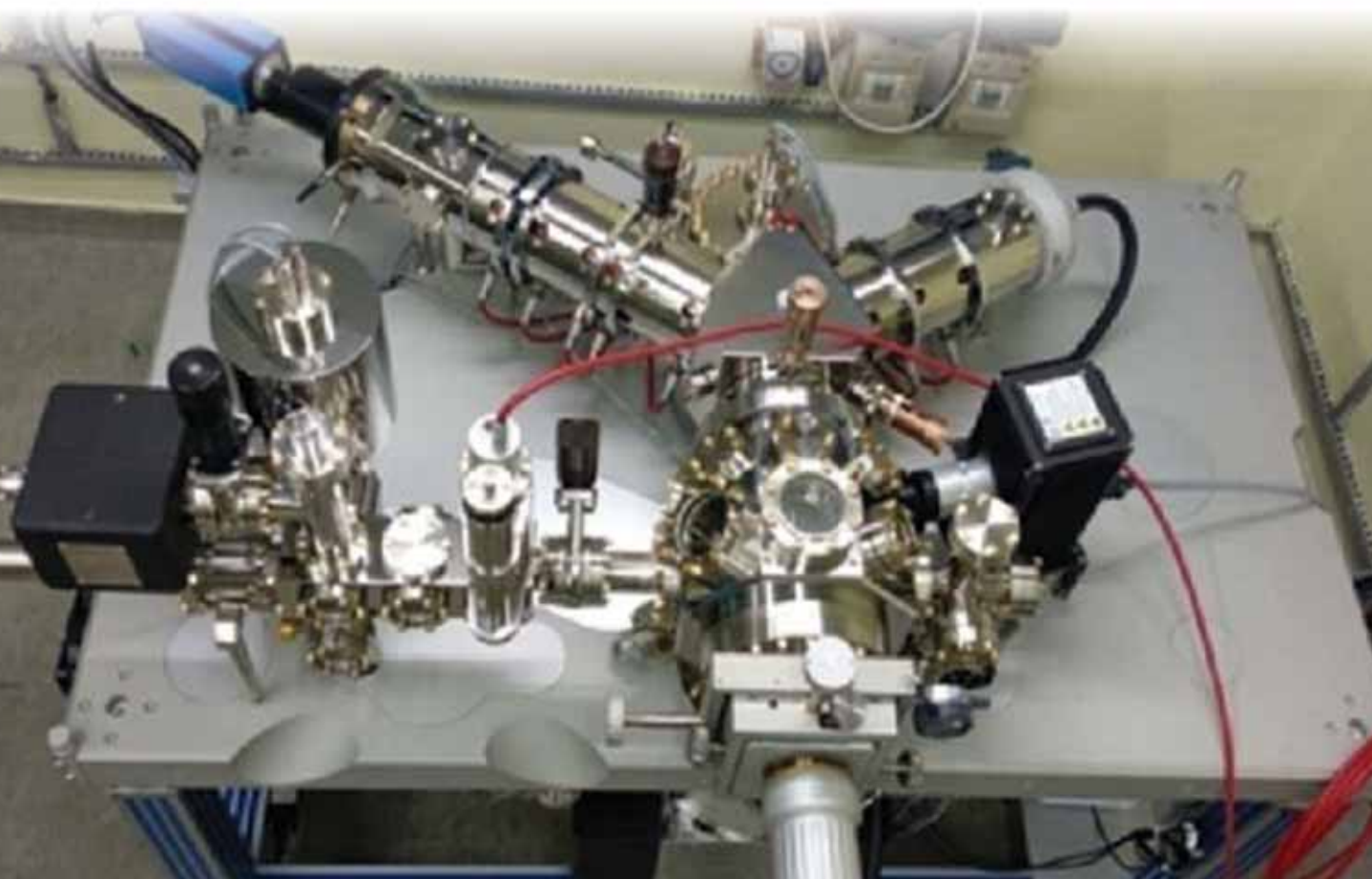
coking, bed packing damage etc. hence BRIT was requested to carry out gamma scanning to ascertain the cause of malfunction. Four cordial and two diagonal scanlines were identified for the gamma scanning of wash oil bed to identify the cause of malfunctioning. 150 mCi of Co-60 was used to scan the wash oil bed of vacuum column. Gamma scanning results showed improper functioning of liquid distributor above the bed. Uneven liquid distribution was observed over the bed; however, bed was mechanically intact.

CHAPTER

5

BASIC AND APPLIED RESEARCH

Commissioning of the Low-energy Electron Microscope cum Photo-Emission Electron Microscope (LEEM-PEEM) facility at SINP



Largest capacity chillers ever made in India for ITER

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

One of the most well-known open problems about Ramanujan's τ function is a conjecture of Lehmer which states that τ (n) 6 ≠ 0 for all n. This conjecture has been investigated by several distinguished mathematicians, e.g. Deligne, Serre, Rankin, Selberg and so on. In joint work with J.M. Deshouillers, Y.F. Bilu and F. Luca, Sanoli Gun of IMSc showed that the first k many τ -values are non-zero if and only if infinitely many blocks of consecutive values of τ of length 2k are non-zero. In order to prove this, IMSc used certain techniques of Ramanujan, some recently developed Sieve theoretic tools and the Sato-Tate conjecture which is now a theorem.

At TIFR, work was carried out on several questions and problems in Algebra, Analysis, Lie Groups, Number Theory, Algebraic and Differential Geometry and Combinatorics. A result was proved about when the symmetric spaces over ûnite and local ûelds, carry generic representations of the group. A complete answer to a conjecture of Kleinbock on p-adic dichotomies in dynamics was given. Progress was made concerning the relationship between the etale fundamental group and the stratiûed fundamental group. A proof of a cubulation theorem for surface-by-free groups was given. Connections were established between extreme value theory from probability and Patterson-Sullivan measures arising from geometry and hyperbolic dynamics. A Cheeger inequality for continuous limits of graphs was found. It was proved that certain thin groups have discrete commensurators. The properties of base change of automorphic forms on GL(n) for solvable extensions of number ûelds were established. A complete characterization of when a pair of l-adic representations of the Galois group of a number ûeld is locally potentially equivalent at a suûciently large set of places was established.

At the TIFR Centre for Applicable Mathematics, Bengaluru, well-balanced numerical methods for solving Euler equations with gravity which work for very general solutions have been developed. Non-conservative Godunov type numerical schemes are developed for weakly hyperbolic pressure less gas dynamics system. Asymptotic behaviour of singular solutions for quasilinear PDE's with exponential nonlinearities has been established. A smooth stratification result is obtained for the singular set of the free boundary for the fractional heat obstacle problem.

Some of the research work that were pursued in the areas of computer science as well as systems science includes a new combinatorial object called a "double sampler" was introduced. It was shown that if the sampler used to construct the code is part of a larger double sampler, then one can efficiently list-decode the code with large distance; On learning and testing of function, new properties of a class of functions called submodular functions were shown, which are fundamental to optimization and Under Information Theory and Communications, a new information theoretic formulation for plausibly deniable communication was given.

At HRI, important results have been obtained in the study of finite groups which provide a wealth of set theoretic solutions of the quantum Yang-Baxter equation. The classification of integrable modules for certain Lie algebras has been obtained. This is of great interest in both mathematics and physics.

A central theme of modern algebraic geometry is the study of moduli spaces, related to geometrical objects such as curves, surfaces etc. A recent work extended the construction of certain moduli.

Given an integer $k \geq 1$, the problem of finding k-additive bases for the set of natural numbers has been an important problem in additive number theory. This is connected with famous unsolved problems in mathematics like the Goldbach problem. A number of new results have been obtained in this area.

Some of the fundamental questions in Number Theory are concerned with whether various special

numbers that occur in mathematics, such as *e*, ð, etc., are expressible in terms of each other by simple linear relations, for example, linear relations that have rational number coefficients. It has been shown that certain infinite sums, representing these transcendental numbers, cannot be so related.

PHYSICS

In Astronomy and Astrophysics at TIFR, science observations with TIFR Near Infrared Imaging Camera-II (TIRCAM2) on 3.6 meter Devasthal Optical Telescope (DOT) on the direct port, which is the largest optical telescope in India, were carried out successfully. TIRCAM2 is now permanently mounted on the side port of DOT for science observations.

A record of ten different atmospheric science instruments were launched from TIFR Balloon Facility, Hyderabad using high altitude balloons on February 10, 2018 to measure physical, chemical and radiative properties of clouds and aerosols in the Upper Troposphere and Lower Stratosphere (UTLS) region, under joint collaboration with the National Atmospheric Research Laboratory-Indian Space Research Organization (NARL-ISRO), National Aeronautics and Space Administration (NASA, USA), Centre National de la Recherche Scientifique (CNRS-Orleans, France) and other national research institutes.

Successfully conducted a balloon launch on 28-10-2018 carrying TIFR Far-Infrared 100 cm telescope (T100). The T100 performed as designed with a Japanese Fabry-Perot spectrometer (FPS) at the focal plane. The performance of the FPS system was as expected and Carbon line was detected from several Galactic star-forming regions. Successfully tested Wi-Fi broadband communication system using 9.9 cu.m. Kytoon under joint collaboration with Center for Development of Telematics (C-DOT), New Delhi in December 2018. Optical design of Multi-Object Infrared Spectrometer (MOIS) is in the final stages.

The final test and close-out reports on the InfraRed Spectroscopic Imaging Survey (IRSIS) Laboratory Model have been submitted to ISRO (Space Science Office) for approval of the project. The preliminary design review (PDR) is scheduled in July 2019. The TIFR-ARIES Near Infrared Spectrometer (TANSPEC) spectrometer is expected to be commissioned on the 3.6-m DOT by April 2019. The next T100-FPS balloon flight will be conducted in April 2019.

At TIFR's National Centre for Radio Astrophysics, Pune, the work on upgrading the GMRT has crossed most of the final milestones: feeds and receivers to cover the frequency range from 110 to 1460 MHz was completed and installed for all the 30 antennas. The digital back-end that processes the dual polarisation signals from all 30 antennas for both interferometry and array mode applications, was also completed. Maser units were installed and made operational at both GMRT and ORT. On the SKA front, a major milestone was achieved in July 2018 with the successful completion of the Critical Design Review (CDR) of the design of the Telescope Manager work package. On the science front, deep uGMRT images are now becoming available. Preliminary results from some very high quality, low noise images reaching very low noise levels in the final maps have been reported. Interesting observations of magnetic stars have resulted in the discovery of 3 new objects with special properties and this could open up a new sphere of study, pioneered with the uGMRT. The first detection of a RRAT (Rapidly Rotating Radio Transient) source was done with the uGMRT. Carbon Monoxide emission has been detected from high redshift Damped Lyman-alpha systems using the ALMA telescope, allowing for the first time a direct measurement of their total molecular gas mass.

In Nuclear and Atomic Physics at TIFR, electromagnetic moments of high spin isomers have been measured and compared with large scale shell model calculations for nuclei near N=82 shell gap to understand the configuration of the isomers. The evidence of true multiple chiral bands based on different configurations has been established in 195Tl nucleus in the A~190 region. A plunger system was developed for the INGA set-up to measure the lifetime of the excited states in the pico-second range. Excited states of 160Yb were measured to investigate the signature of tetrahedral symmetry in nuclei. The PLF (joint facility of TIFR and BARC), was operated for research in nuclear physics and other allied interdisciplinary areas with about 75% uptime. This year a dedicated beryllium beam cycle (2 month duration) was carried out. The design and fabrication of SS prototype of low beta Nb cavity has been initiated. Proposals for upgrade of RF

amplifiers and control system have been initiated. A systematic conditioning of the HV modules of Pelletron was carried out to achieve the desired performance of the modules having newer version of the accelerating tubes.

In Theoretical Physics at TIFR, novel signatures in the shape of the cosmic microwave background (CMB) spectrum of decaying dark matter and new unstable particles in the early Universe were proposed. A new approach based on clustering of data according to contaminant properties was proposed to separate cosmological signals in the CMB data and applied to the Planck satellite data. A gravitational dual to the Sachdev-Ye-Kitaev model was proposed and quantum chaotic behavior in the presence of black holes was derived in the gravity model. A detailed study of quantum quenches in one-dimensional non-relativistic Fermi gas was made, using group theoretic techniques, and some universal rates of relaxation to equilibrium were found. An effective theory of fermions was written down which describes results of the lattice computation of long-distance correlation functions of axial vector and pseudoscalar currents quite well. A model was set up for quarkonium propagation through QGP including thermal screening and dissociation, which nicely describes the data for the suppression of high-pT quarkonia obtained in heavy-ion collisions at the LHC and RHIC. Using a large-scale computer simulation at the high-performance computational facility of the Indian Lattice Gauge Theory Initiative (ILGTI), masses of several new charm-beauty subatomic particles were predicted from first principles with unprecedented accuracy. A set of new variables was proposed to detect anomalies in the coupling of W bosons to photons at the LHC. New possible effects of non-standard self-interactions of neutrinos on flavour conversions of supernova neutrinos were explored in a two-flavor framework. The ability of the proposed iron calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) to determine hadron shower direction was determined through simulations. It was also shown that the ICAL detector at INO can probe the presence of sterile neutrinos, their mixing with active neutrinos, and their mass ordering, over a wide mass-squared range.

At BARC, formation enthalpies (Hmix) and mechanical properties of (Th,Pu)O2 and (Th,U)O2 MOX have been determined across the composition range using quantum-mechanical (QM) simulations. Moreover, the formation enthalpies (Ef), mechanical properties, thermal expansivities, thermal conductivity and oxygen diffusion properties of (Th,Np)O2 and (U,Np)O2 MOX have been determined to predict the effect of minor-actinides on the thermodynamic and thermo-physical properties of ThO2-based MOX fuels. In addition, the formation enthalpies and mechanical properties of PuO2-x and NpO2-x sub-oxides ($0.0 < x < 0.5$) have been determined from QM simulations. The generated thermodynamic database of off-stoichiometric oxides will help in the prediction of overall change in the fuel O/M ratio which governs the oxygen diffusivity of Th-based MOX fuels. These studies will provide new insights and predictive understanding of the chemical and physical properties of Th-MOX under extreme environments as well as their ability to accommodate fission products and highly radioactive wastes.

The fission gases (He, Xe and Kr) formed during normal reactor operation degrade fuel performance, particularly at high burn-up. The QM simulations have been performed to determine preferable incorporation (defect) sites for the fission gases in the defective ThO2. This work has also been extended by calculating incorporation and solution energies of halogen fission products (Cl, Br and I) and oxide precipitates (e.g., Ru, Cs, Sr Ba, Y and Zr) which appear during of the Th-based-MOX fuel burnup. This information can be used to device a chemical route for reprocessing of the fuels and separation of fission products where very limited experimental data is available.

A state of the art, fully 3-dimensional particle-in-cell computation tool PASUPAT was developed to simulate charged particle emission and transport self-consistently. PASUPAT can handle multiple species at different temperatures and can handle open and curved boundaries that are perfectly conducting.

Mass and mass resolved angular distributions provide information about the potential energy landscape of the nucleus undergoing fission as well as the nature of the mechanism involved in the fission process. Mass and mass resolved angular distribution was measured in $^{16}O+^{238}U$ reaction by off-line gamma ray spectrometry using 87 Mev ^{16}O beam at BARC-TIFR Pelletron-LINAC facility, TIFR, Mumbai in a new irradiation chamber installed for this purpose.

The trigger system for INO mini-ICAL detector has been developed, integrated and commissioned at the full experimental setup at IICHEP, Madurai. The trigger system detects an event with 100 ns coincidence window and distributes system wide trigger to all the 20 Resistive Plate Chambers. India Based Neutrino Observatory (INO) Project, in its first phase has commissioned (on 8.5.2018) an 85 Ton mini-ICAL 1 Tesla magnet in Madurai, Tamil Nadu equipped with field measurement systems, coil cooling systems and populated with Resistive Plate Chamber (RPC) type detectors. First set of cosmic muons were detected and their directions identified. Researchers from TIFR and collaborating institutions are using it for high energy physics studies.

The 85 Ton mini-ICAL 1 Tesla magnet in Madurai, Tamil Nadu, equipped with field measurement systems, coil cooling systems and populated with Resistive Plate Chamber (RPC) type detectors.

A new neutron powder diffractometer-I with a multi-detector system, consisting of 3He neutron position sensitive detectors, was commissioned at Dhruva reactor, Trombay under the National Facility for Neutron Beam Research (NFNBR) for investigation of magnetic materials over the temperature range of 2 K to 320 K.

Apart from detection of gamma-rays from the standard candle gamma-ray source Crab Nebula, enhanced gamma-ray emission has been observed from Mrk 421 on the night of January 17, 2018. Analysis of the data collected for 5.6 hours indicates that the average flux during the above-mentioned period was around 5 times the flux of the Crab Nebula above 850 GeV. So far, this is the highest gamma-ray flux recorded using TACTIC. In view of the importance of this result, it was reported through an Astronmer's Telegram (Ref: ATel # 11199; dated 18-01-2018).

Major Atmospheric Cherenkov Experiment (MACE) is at an advanced stage of installation at Hanle in the Ladakh. 356 spherical mirror panels (984 mm x 984 mm) spanning 21 m diameter light collector are deployed. The telescope will be the largest operating at an altitude of 4270m. Engineering trials with 50 mirror panels were performed. Various sub-systems of the telescope are functioning satisfactorily. One of the Cherenkov images recorded during camera test runs conducted during moonless dark nights.

Major Atmospheric Cherenkov Experiment (MACE)- work in progress

Monte Carlo Simulations were carried out to estimate the response of the MACE telescope to gamma-rays, protons and alpha particles. The results indicate that MACE telescope should be able to detect gamma-ray signals from Crab Nebula at 5ó significance level in about 2 minutes of observations at an energy threshold of 30 GeV.

Metal Ion- Peptide interactions were investigated for targeted metal ion drug delivery applications using MALDI-TOFMS. The intrinsic binding ability of 7 neuro-peptides (oxytocin, arg8 vasopressin, bradykinin, angiotensin I, substance P, somatostatin, and neurotensin) with copper in 2 different oxidation states (Cu I/II) derived from different Cu+/2+ precursor sources were studied for their charge dependent

binding characteristics. The result shows that these copper bound peptides can be used in peptide receptor radionuclide therapy for burning cancer cells due to their targeted and effective peptide receptor interaction in the cell membrane of tumor/cancer cells/tissues.

Superhydrophobic (water contact angle 168 deg.) and ultra-wideband (entire visible to near infrared, i.e., 400–1100 nm), omnidirectional (0–60 deg.) anti-reflecting (T=98%) polytetrafluoro-ethylene (PTFE) coatings are fabricated in a rapid single step deposition process by electron beam evaporation technique. This development has potential applications in solar cells and flat optical displays as protective cover panels, anti-icing and anti-fogging panels.

A novel metal-dielectric thin film multilayer UV filters were developed for scintillation detector applications. The filter consists of four layered structure of alternating layers of Aluminium and SiO2 deposited over BaF2 crystal. Another wideband antireflection optical coating based on graded refractive index of SiO2 over Gadolinium-Galliun-Aluminium Garnate (CGAG) crystal was developed for scintillation detector applications. This development is based on Oblique Angle Deposition (OAD) deposition technique useful for gradation in refractive index of thinfilms.

LaBr3:Ce Single crystal is an advanced scintillator material for application in gamma spectroscopy with an energy resolution of 3%. However growth of single crystal is technologically challenging, due to its highly hygroscopic nature. $LaBr_3$:Ce single crystals of 1 inch size are grown by Bridgman method and used to develop a high resolution gamma detector.

A major breakthrough in field emission theory was the prediction of field emission current from metallic nano-tipped emitters for the first time. Determination of the local field variation in the emitter apex neighbourhood and the curvature corrections to the quantum tunnelling potential led to this result.

The structural materials of a fusion reactor (Fe, Cr and Ni) are prone to damage due to opening of (n,xp) and (n,xá) gas producing nuclear reaction channels. For a realistic estimation of the integrity of the structural material - not only the stable nuclei, but also the long-lived nuclei produced due to neutron capture and decay are to be considered. The long-lived radio-nuclide like ^{59}Ni not only contributes to nuclear waste but also to radiation damage due to above neutron induced reactions. For the first time ^{59}Ni(n, xp) reaction cross-sections have been measured following the surrogate reaction ratio method in the equivalent neutron energy range of 11.9-15.8 MeV by populating the compound nucleus 60Ni* through transfer reaction ^{56}Fe(^{6}Li, d) at Elab = 35.9 MeV at Pelletron-Linac facility. The ^{59}Co(6Li, á) 61Ni* transfer reaction at Elab = 40.5 MeV has been used as the reference reaction which is the surrogate of ^{60}Ni(n, xp) reaction populating the compound nucleus ^{61}Ni*. The proton decay probabilities have been determined by measuring evaporated protons at backward angles in coincidence with projectile like fragments (PLFs, either d or á) detected around grazing angles. The cross sections for the reference reaction ^{60}Ni(n, xp) are taken from JENDL-4.0 library, which closely reproduce the available experimental data. The cross sections for the desired ^{59}Ni(n, xp) reaction so obtained compare well with the nuclear-reactions-model code TALYS-1.8 using microscopic level densities. The present experimental data are consistent with the evaluated data library of ROSFOND-2015 but not with TENDL-2015 and ENDF/B-VIII, indicating the need of new evaluations for this reaction of importance to fusion technology.

A series of measurements involving ^{6,7}Li projectiles on several target nuclei of medium to heavy masses have been carried out at Pelletron-Linac facility, Mumbai to investigate different projectile breakup modes. Many new breakup channels, viz., new resonance states and different cluster constituents have been identified and their cross sections have been measured, particularly for the reactions ^{6}Li+^{112}Sn and ^{7}Li+^{112}Sn. For these exclusive measurements, with very low coincidence yields, a large area Si-Strip-Detector Array with an angular coverage of 100 degree and 240 detector signals has been setup. To complement the above breakup studies with another weakly bound projectile ^{9}Be, a two-month Pelletron beam cycle involving only ^{9}Be beam has been utilized and several experiments have been carried out successfully.

A novel cryo-cooled discharge approach was adopted to record atomic emission transitions and Hyperfine Structure (HFS) of heavy elements using high resolution Fourier Transform Infrared Spectroscopy. The

atomic spectra and HFS splitting have been measured for many elements in a wide spectral range from UV down to mid-IR regions. A microwave discharge light source cooled with liquid nitrogen and InGaAs detector were employed for recording the hyperfine splitting. With this approach, many new lines were observed for the first time. The spectral analysis for Iodine has been completed in the complete region and has been published as a series of papers in Journal of Quantitative Spectroscopy and Radiation Transfer.

The Rossby-mode instability windows and the gravitational wave signatures of neutron stars in the slow rotation approximation using the Equation of State (EoS) obtained from the density-dependent M3Y and SEI effective interactions have been studied at VECC. It is found that the young and hot rotating neutron stars and neutron stars with low L value lie in the r-mode instability region and hence emit gravitational radiation. Relativistic Feynman-Metropolis-Teller treatment of compressed atom with Coulomb screening in strong quantizing magnetic field has been applied to develop the EoS. It is found that inclusion of Coulomb interaction modifies WD masses further upward and significantly greater than Chandrasekhar limit.

The nuclear fusion at very low energies plays important role in nucleosynthesis of light elements in stellar core and fusion reactors. Quantum tunneling through Coulomb barrier of interacting nuclei using square-well potential with imaginary part well describes fusion reaction. The variations of astrophysical S-factors for the D+D, D+T, D+3He, p+D, p+6Li and p+7Li fusion reactions with energy have been explored. An analytical model based on nuclear reaction theory for non-resonant fusion cross sections near Coulomb barrier has been developed. The astrophysical S-factors involving stable and neutron rich isotopes of C, O, Ne, Mg and Si for fusion reactions are calculated in the centre of mass energy range of 2-30 MeV.

Entrance and exit channel effects on bimodality is investigated at different impact parameters and incident energies. Lattice gas model for nuclear multifragmentation reactions is developed and multiplicity derivative, specific heat and second moment are calculated from this model. Pion and delta multiplicities for different input conditions are studied for estimating nuclear symmetry energy. The results are compared with other internationally known BUU and QMD models. Effect of fragmenting source size and freeze-out volume on new signatures of nuclear liquid gas phase transition like multiplicity derivative and largest cluster size derivative are studied. Precise calculation of fission yields and kinetic energy distribution of fission fragments using state-of-the-art microscopic theory.

The second order relativistic hydrodynamics has been used to study the acoustic oscillation in relativistic fluid. The causal dispersion relations have been derived with non-vanishing shear viscosity, bulk viscosity and thermal conductivity at nonzero temperature and baryonic chemical potential for investigation of the fluidity of Quark Gluon Plasma (QGP) at finite temperature. The power spectrum of fluctuations in the momentum distributions of particles have been estimated with optical Glauber and Monte-Carlo Glauber initial conditions for relativistic heavy ion collisions by using computer code developed at the Centre. The effects of background electromagnetic fields are being studied extensively to understand astrophysical objects as well as exotic phenomena in highly energetic nuclear collisions. These studies on the properties and dynamics of strongly interacting particles at finite temperature and density in the presence of magnetic fields have revealed several new and interesting results which will help us in revealing unknown aspects concerning the phase and symmetry structure of such systems.

An approximate scheme along with new signatures has been developed to study the transition between two complex chaotic systems as a function of interaction strength.

The nuclear physics experiments performed in the field of charged-particle spectroscopy, gamma-ray spectroscopy, fission dynamics etc., using beams from K-130 cyclotron at VECC and other accelerators facilities in INDIA include Research activities such as Study of Cluster Correlation in 20Ne+9Be and 16O+12C Reactions; Fission Dynamics Studies; Nuclear Structure Studies using Gamma ray Spectroscopy; Giant Dipole Resonance (GDR) Studies and Developmental Activities such as 4 π charged particle detector array (4π-CPDA) and Neutron detector development.

The installation, commissioning and training of the LEEM-PEEM system has been successfully completed at SINP during 7th-22nd March 2018. This is the first such LEEM-PEEM facility available in India. The Low Energy Electron Microscopy (LEEM) and Photo-Emission Electron Microscopy (PEEM) are complementary imaging methods which are not only powerful for imaging the surfaces at very high spatial resolutions (4 nm) but also for the study of different dynamical processes at surfaces in real-time. Due to the low electron energy used in LEEM (e.g., 1-10 eV), the surface structure, surface morphology, as well as surface magnetism can be studied at the same microscopic sample region, almost simultaneously, with minimal damage to the surface. Operation of the LEEM system is similar to Transmission Electron Microscope (TEM), with the main difference that due to the low electron energy the electrons are back-diffracted from the surface of the sample and are imaged by the electron optics forming a magnified image on the detector, making this method extremely surface sensitive (1-2 surface layers). Using PEEM, one can image the surface using the differences in the electronic density of states, work function as well as the surface morphologies. In close combination, LEEM-PEEM forms a very powerful method to study the dynamical processes occurring at surfaces which have been missing in the country.

Commissioning of the Low-energy Electron Microscope cum Photo-Emission Electron Microscope (LEEM-PEEM) facility at SINP

Inauguration of Facility for Research in Experimental Nuclear Astrophysics (FRENA)

The Hon'ble Vice President of India, Shri M. Venkaiah Naidu has inaugurated the new state-of-the-art Facility for Research in Experimental Nuclear Astrophysics (FRENA) at Saha Institute of Nuclear Physics, Kolkata on Thursday, 28th June 2018. Shri Bratya Basu, Hon'ble Minister of Information & Technology, Govt. of West Bengal and other dignitaries were present at the venue. FRENA is the first dedicated facility for Research in Experimental Low Energy Nuclear Astrophysics which is centered around a 3 MV Tandetron capable of delivering high intensity ion beams of proton, deuteron, helium to heavy ions till gold with variable energy of high precision.

At HRI, in astrophysics the phenomenon of black hole shadow formation has been studied. The associated experimental observation is one of the major astrophysical results in recent years. The high energy physics (HEP) group has worked on beyond standard model physics, neutrino physics, baryogenesis, dark matter aspects at both present and future accelerator experiments, as well as astrophysical observations proposed at the "Square Kilometre Array"(SKA1). There is also work related to the DUNE collaboration at Fermilab, USA. In string theory, analytic properties of some Green's functions have been proved and the dynamics of the Sachdev-Ye-Kitaev model has been studied.

The quantum information and computation group at HRI has been working on a broad range of subjects involving fundamental as well as technological issues

of the subject. One of these works, on the dynamical transition in a spin 1/2 chain, suggests the need for multipartite entanglement. Another work challenges the common perception that a physical system is inseparable from its physical properties. A thought experiment involving photons is used to demonstrate this. The result has been highlighted in Scientific American. Finally, a new quantum uncertainty relation has been proposed.

Three broad areas have been explored in materials physics. These are new phenomena that happen at the physical edge of topological samples; a method to study dynamical properties at finite temperature and exploring the properties of á-MnO_2, a promising material for use in batteries.

The 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. A recent study has been performed, analyzing data from the IceCube Neutrino Observatory at the South Pole, looking for changes in neutrino oscillation behavior caused by long-range interactions from large collections of electrons (selected as PRL Editors' Suggestion). 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.

The condensed matter theory group at IOP 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, strongly correlated systems etc. During last year, with the help of theoretical modeling and experimental collaboration, the group members have investigated a macro-molecular crowding mediated mechanism of the formation of bacterial nucleoid, its helicoid morphology, central positioning and precise segregation in growing E.coli cells, new transport signature of Majorana fermions via the spin-selective coupling to the ferromagnetic boundary, magnetic exchange properties of anisotropic Dirac materials, transport properties of driven semi-Dirac materials, unusual spin wave spectrum for helical spin configuration for the α-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. A major contribution has been made to the recent observation of the Higgs boson production in association with a pair of top quarks by the CMS experiment at LHC, which is the heaviest fermion known till date (published in PRL). 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. Commonly used ion beams are that of H, He, C, N, Si, Mn, Ag and Au. After the recent upgradation of low energy 3MV accelerator of IOP, there is a significant increase in the number of users (both internal and external). During this period the accelerator facility has catered several users from University College of Engineering, Vishakhapatnam, OUAT-Bhubaneswar, Indraprastha University-New Delhi, SOA University-Bhubaneswar, BARC-Mumbai, 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.

Precision timing analysis of radio pulsars is used as a tool to probe various aspects of fundamental physics. The most basic task is to measure the spin and orbital periods of pulsars, and the rate of the change of these periods as accurately as possible. However, the measured values of the rate of change of the orbital and the spin periods are affected by different dynamical effects like velocity and acceleration of the pulsars relative to the solar system. For the last few decades, some simplistic models have been used to eliminate these dynamical effects and estimate the intrinsic values of the rate of change of periods. However, these simplified models are valid only for pulsars close to the solar system. Recently, a more accurate model was developed by IMSc, which is valid for even pulsars far away from the solar system. Being very accurate, this model has become popular among all pulsar astronomers worldwide. The python code to implement this model is developed and the same is publicly on web.

The School of Physical Sciences at the National Institute of Science Education & Research (NISER) continued the academic programmes in various disciplines of Physics. Some of the major research facilities and equipment added to NISER include; Microfocus single crystal X-ray machine, Micro-Raman Spectrometer and Non-Cryo Transmission Electron Microscope, Dielectric Spectrometer and Transmission Electron Microscopy.

CHEMISTRY

At TIFR, a novel nanoparticle-based method was developed to fluorescently probe the orientation of membrane proteins. This technique revealed that Alzheimer's amyloid beta molecules are oriented with their N-termini towards the outer side of the bilayer. A peptide based copper-binding mimics of blue-copper protein were developed and characterized. A versatile theoretical framework capable of describing electron transport through molecules in a wide variety of natural and synthetic environments was developed. Cu^{2+} selective chelators that exhibit 10^8 times higher conditional stability constants toward Cu^{2+} over Cu^{+} and other biologically relevant metal ions were developed. An example of W doped TiO_2 nano-rods in which the photocatalytic activity improved with increasing number of catalytic cycles was demonstrated. The spin density localization was shown to play a critical role in designing singlet fission chromophores that are electronically coupled to a process to generate two triplet excitons at the cost of one photon. The binding energies of a number of OH—S H-bonded complexes were determined using photo-fragmentation spectroscopy. The weakly activated C-H in the imidazole ring was shown to play a significant role in the enhanced water solubility of 1-methylbenzimidazole compared to benzimidazole.

A lithium ion pouch cell using indigenously developed carbon coated $LiFePO_4$ cathode material was developed at BARC. The Xantphos capped Pd(II) and Pt(II) supramolecular complexes with bridging dithiol ligands were successfully isolated by self-assembly. The palladium complexes are excellent catalysts in Suzuki C–C cross coupling reactions under mild conditions, and are easily reusable. The comparative catalytic activity of the tetranuclear Pd

complexes of phosphines of varied bite angles, has been demonstrated. Overall, the present Pd complexes showed improved catalytic activity than the previously reported dppe analogues.

For the first time, both thermo physical and transport properties of U3Si2 have been calculated using first principles calculations. The computed results are close to the reported experimental values. Computational chemistry predicts the improvement of photo conversion efficiency of Ni and V doped SrTiO3 for generation of hydrogen by solar water splitting.

Synthesis of phosphoramidate group bearing ionic liquid as an extractant of uranium Phosphoramidate group bearing Task Specific Ionic Liquid (TSIL) was synthesized. It is an eco-friendly, simple and selective Liquid-Liquid Extractant (LLE) for U. The TSIL is found to provide a high Distribution Ratio (DU) of 174±5 for U when extracted from 5 mol L^{-1} HNO3 medium. The DU value is also found to remain constant even at higher acidities. Such high DU value resulted in high separation factors for U (αU/M; M = any element other than U). A detailed study on the infrared (IR) spectroscopy and extended X-ray absorption fine structure (EXAFS) spectroscopy of U loaded ionic liquid phase revealed that the extraction occurs through two uranyl ($UO2^{2+}$) complex species. The high electropholicity of the P=O group of phosphoramidate and the extraction mechanism is responsible for high DU values at high acidities.

A methodology to determine concentration of deuterium in Zr-2.5Nb alloy using Secondary Ion Mass Spectrometer (SIMS) was developed and tested on deuterium gas charged samples received from PIED. The methodology provides the surface and depth distributions as well as the mean concentration of deuterium in Zr-2.5Nb samples.

The probable fuel salt compositions for thermal and fast molten salt reactors were determined from thermodynamic description of the LiF–NaF–MgF_2–ThF_4–UF_4 system. It was observed that the addition of MgF_2 to fuel salts mixture: (LiF-ThF_4-UF_4) reduced the final melting temperature.

Laser Induced Breakdown Spectroscopy (LIBS) system was developed for accurate measurement of Cs content in glass samples (0-20%) remotely from 1.2 meter distance.

Complexation of Np by organic P-containing ligands in humic substances is an important topic of research due to its relevance in migration of Np in aquatic environment. The aqueous complexation of Np in different oxidation states by HS and Phenylphosphonic Acid (PPA) is investigated using electrochemical and UV-Visible absorption spectroscopy. The cyclic voltammetric measurement indicates the complexation of both oxidation states (VI & V) of Np with the ligand. Further, the presence and stability region (via Eh-pH plot) of new species of Np-PPA in two different oxidation states (V & VI) in aqueous solution at varying physicochemical conditions are identified. The kinetics of reduction of Np complexes in different oxidation states are explored by evaluation of heterogeneous electron-transfer kinetic (D0, ko and á) parameters by cyclic voltammetric results.

$Gd_2Zr_2O_7$ doped with 4% Nb is used as a burnable poison. Determination of Zr in presence of Nb and Gd is an analytical challenge. Ion chromatographic separation of Zr from Gd and Nb was explored on a reversed phase column using 2,4-pyridine dicarboxylic acid, methanol and HNO_3. The separated fraction of Zr is determined spectrophotometrically after post complexation with arsenazo III.

Mixed N and O donor ligands have been reported to separate trivalent lanthanides from the trivalent actinides. Three N-heterocyclic bis (phosphonic) acid derivatives were synthesized and evaluated for the extraction of Am^{3+} and Eu^{3+}. The results indicated the formation of anionic complexes in case of all the three ligands, where Aliquot-336 was used as an anion exchanger for the extraction of the anionic metal-ligand complexes. The extraction ability of these ligands followed the order: PyPOH > PhenPOH > BipyPOH and none of the ligands showed any selectivity between Am^{3+} and Eu^{3+}. Density functional theoretical calculations were performed in order to understand the extraction and complexation behaviour of these ligands and the results indicated non/weak participation of the 'N' atoms of the heterocyclic rings in the direct bonding with the metal ions, and this results in poor selectivity of these classes of ligands between trivalent actinides and lanthanides.

Np was separated from acidic feeds containing mixture of actinides viz., U, Np, Pu and Am. Several separation methods were tested using feed solutions

containing actinides in 3M HNO_3. The actinide mixture was subjected to a reducing solution followed by loading onto the column prepared using the developed resin. While U and Pu were not held onto the column, Np was held which was eluted using a complexing agent like EDTA. The purity of the product was checked by alpha-spectrometry and separation of Np from Pu was found to be good with a DF value of 300. Radio-ruthenium recovery was attempted using ^{103}Ru tracer taken in acidic feeds using $NaIO_4$ as an oxidant and n-dodecane as the trapping agent for RuO_4. The precipitation of RuO_2 (black precipitate) in the organic phase after Ru extraction causes problem for back extraction of Ruthenium. Alkaline hypochlorite solution was used as the stripping agent which led to >90% Ruthenium back extraction into the aqueous phase in 20 min. Membrane studies carried out using polypropylene flat sheets filled with n-dodecane showed promising results for Ru recovery as the formation of RuO_2 was avoided by simultaneous extraction and stripping in transport studies and > 90% Ru recovery was achieved.

Evidence of the phase separation of ethanol-water binary mixture confined in mesoporous silica with different pore size has been obtained using Positron Annihilation Lifetime Spectroscopy (PALS). A bulk-like liquid in the core of the pore and a distinct interfacial region near the pore surface have been identified based on ortho-positronium lifetime components. The lifetime corresponding to the core liquid shows similar behaviour as the bulk liquid mixture while the interfacial lifetime shows an abrupt rise within a particular range of ethanol concentration depending on the pore size. The abrupt increase is attributed to the appearance of excess free-volume near the interfacial region. The presence of excess free-volume has been attributed to the microphase separation of confined ethanol-water primarily at the vicinity of the pore wall. The study has shown that probing free-volume changes at the interface using PALS is a sensitive way to investigate microphase separation under nanoconfinement.

Activator free $ZnAl_2O_4$ nano-phosphors, synthesised through a sol-gel combustion route, could be used both as a blue and white light emitting material depending upon the annealing temperature. The material also has a potential to be used in optical thermometry. The phenomena were linked to various defect centers present in the matrix and their changes upon thermal annealing. Various defect centers such as anionic vacancy, cationic vacancy, antisite defect, etc. were found to be responsible for the tenability. A detailed time resolved photoluminescence coupled with electron paramagnetic resonance studies confirmed these findings. These data were further corroborated by FTIR, EXAFS, Positron annihilation and DFT based calculations.

A microfluidic method was developed to synthesize PAM beads using droplet flow in a microchannel. Spherical beads in the size range of 0.9-1.2 mm with a narrow size distribution could be prepared in continuous mode. The effects of different variables such as flow rates of the feed phase and carried phase, residence time, microfluidic junction design and microchannel diameter on bead size and polydispersity index were quantified.

PAM beads produced by microfluidic route in continuous mode

A styryl based organic dye, commercially known as LDS-798, has been identified to display an exceptionally high fluorescence response towards albumin proteins in buffered solutions as well as in serum matrices, displaying fluorescence enhancement by 500 fold in the near-infrared region (688 nm). Further, the dye also shows very high selectivity towards albumin compared to other proteins and amino acids. As a fluorescence sensor, LDS-798 offers several

advantages such as label free operation, high sensitivity and selectivity and most importantly giving emission in the biologically advantageous red region, with minimum interference from auto fluorescence.

A state of the art single molecule fluorescence spectroscopy and imaging facility was developed. The setup is based on laser scanning confocal fluorescence microscope coupled with single photon detection, where we can easily detect fluorescent dyes with single molecule sensitivity. The facility is currently being used to carry out research on bio-toxicity of radioactive metals and structure-function relation of bio-molecules. The setup can provide substantial reduction in activity handling.

A lithium ion pouch cell using indigenously developed carbon coated $LiFePO_4$ cathode material was developed in collaboration with NSTL, DRDO, Vizag. The cyclability of MCMB-LFP Li-ion cell was evaluated for 100 cycles. A full-cell lab prototype for Sodium-Ion Batteries (SIBs) with discharge capacity of 266/ mAh/ g^{-1} was developed in collaboration with IIT Bombay using indigenously synthesized disordered mesoporous carbon anode from biowaste and NVP (sodium vanadium phosphate) cathode. To check the feasibility of the full cell for practical applications, a LED panel was switched on using a single coin cell. The technology for synthesis of carbon coated $LiFePO_4$ cathode and $Li_4Ti_5O_{12}$ anode was transferred to M/s Vrinda Petroleum and Chemicals Pvt. Ltd. A MoU was signed between BARC and M/s Nicomet Industries Ltd, Goa, for incubation of production of nickel-cobalt-manganese based active cathode battery materials.

BIOLOGY

"Fed-microRNAs" that stop the production of proteins required during fasting were identified. Perturbing these fed-microRNAs result in molecular and physiological changes with associated increase in blood glucose levels, reminiscent of a pre-diabetic state. Analysis of optical trapping data on a cellular organelle that is being carried around in the form of a "cargo" by dynein and kinesin suggested the activity of motors is stochastic, independent of each other, and can be described as a process with no memory — a Markov chain. The experimental study in Drosophila larvae showed that cholinergic activity in the central nervous system induces association between the enzyme and a molecular motor, Kinesin-2, in a time bound manner at a certain developmental stage, which facilitated the flow towards the synapse. This is the first evidence indicating that the neuronal activity could promote cargo-motor interaction in vivo. In a separate study, it was shown that an atypical septate junction established between the somatic cells during the later stages of spermatid differentiation plays a crucial role in keeping the maturing spermatids within the enclosure until they are fully differentiated. A study on the axonal transport using the worm C. elegans on the mechanism of vesicle selection and transport towards synapse revealed periodic release of calcium ion in situ. A paradigm to physiologically stimulate touch neurons without optogenetics has been established to correlate the trigger of Calcium release. The research using Malaria parasite identified a persistent IgM autoantibody response in patients infected with P. vivax infections but not the dengue virus.

At the TIFR's National Centre for Biological Sciences, Bengaluru, under Development and Genetics, a study explained the role of miRNA-mediated regulation in the domestication of rice. It was observed that miR397 was expressed at very high levels in wild relatives and at negligible levels in high-yielding cultivated lines and hence miRNA397 plays a crucial role in domestication of rice. In Neurobiology, a key investigation highlighting the mode of intraflagellar transport in the inner ear revealed a mechanism on how protocadherin-15 (Pcdh15) is transported in the hair bundle found in the hair cells of the inner ear. Under Theory and Modeling, a study demonstrated that chaotic dynamics modulates gene expression and up-regulates certain families of low-affinity genes, irrespective of noise. Under Ecology and Evolution, a multi-site study indicated that herbivore-induced change in dominance is the best predictor of herbivore effects on biodiversity in grassland and savannah sites. A study revealed that although butterflies harbour distinct microbiomes across taxonomic groups and dietary guilds, the dramatic dietary shifts that occur during development do not impose strong selection to maintain distinct bacterial communities across all butterfly hosts. A key event in 2018 was the inauguration of the National Cryo EM Facility.

The biofilms generated from axenic cultures of the cyanobacterium, Nostocmuscorum (Nm) exhibited the ability to sequester wide range of concentrations of Cd (II) [0.5 to 100 ppm] from aqueous solutions having pH in the range of 5-10. Adsorption followed Langmuir's isotherm, indicative of monolayer of adsorption and exhibited an adsorption capacity of 13-13.5 mg g-1 when tested in media. The N. muscorum biofilm could sequester the Cd(II) effectively from natural water samples (Banganga lake, Mumbai) spiked with Cd(II).The Nm biofilm also showed the ability to tolerate not only high concentrations of Cd(II) but also other organic and inorganic wastes present in the polluted waters.

Whole genome sequencing, gene assembly and annotation was performed for Chryseobacteriumculicis. The genome size of Chryseobacterium PMSZPI was 3.824868 Mb. Annotation results showed the occurrence of genes related to oxidative and heavy metal stress, antibiotic and metal transport, biofilm formation and adhesion, secretory system and motility. This bacterium showed higher tolerance to number of heavy metals or antibiotics, reduced gliding motility in presence of toxic metals, biofilm formation by the cells under metal supplemented conditions and superior uranium bioprecipitation. Using information from genome sequence, a metal translocating PIB type ATPase gene has been cloned from this bacterium and full-length protein (70kDa) has been expressed.

Cyanovirin-N (rCV-N), a 11 kDa lectin of cyanobacterial origin, which has a promising vivo activity against Human Immunodeficiency Virus (HIV), was expressed in E. coli to increase its expression in a soluble and active form. The yield of recombinant CV-N reached 25 mg/ 100 ml culture at lab scale. The monomeric as well as the dimeric form of the protein showed a typical â-barrel conformation. All the three forms of CV-N, i.e., monomer, dimer and monomer-dimer mixture showed very high anti-HIV activity (e.g. 0.5 nM for CV-N mixture), while no significant cytotoxicity (up to 5 μM) was observed. All the three forms of CV-N bound to the HIV surface protein GP120 had low endotoxin content.

Microarrays were synthesized by indigenous micro-arrayers and optimized detection of disease causing mutations. Microarrays were developed for 32 mutations causing inherited breast cancer. A simple, label free detection methodology for detecting single point DNA mutations using an electrochemical biosensor utilizing electrospun graphene doped manganese III oxide nanofibers (GMnO) was developed. As a proof of concept, ultrasensitive detection of del185AG, a mutation specific to BRCA1 gene was demonstrated.

Following the reduction of eye lens dose from 150 mSv to 20 mSv by ICRP, existing chest Thermo Luminescence Dosimeters (TLD) badge was modified as head badge since forehead is close to the eye. An algorithm was developed to estimate eye lens dose following the IEC 62387 (Radiation protection instrumentation-passive integrating dosimetry systems for personal and environmental of photon and beta radiation IEC-62387-2012, Edition 1.0 2012-12) guidelines. A field trial is initiated in all the Nuclear Power Plants to estimate eye lens dose for radiation workers engaged in different types of activities such as Calandria tube inspection, pressure tube installation, etc. during reactor shutdown. Initial results indicate that in most cases the eye lens dose is higher than the whole body dose.

CANCER

Radiation pneumonitis and fibrosis are some of the side effects of thoracic radiotherapy. Selenium is an essential macronutrient with anticancer properties. Synthetic radioprotectors act as adjuvants to reduce pneumonitis in lung cancer patients. A series of selenium containing molecules were synthesised and evaluated for their radioprotection efficacy as adjuvants in radiotherapy. Diselenodipropionic acid (DSePA) is an in-house developed molecule that showed superior anti-pneumonitic effects in mice following thoracic irradiation. Results revealed that DSePA at a dose of 2.5 mg/kg prevented lung pneumonitis and delayed the progression. Toxicity studies in GLP approved labs indicate that DSePA falls under GHS category 3 (>50-300 mg/kg) with LD50 cut-off of 200 mg/kg body weight for mice model and GHS category 2 (>5-50 mg/kg) with LD50 cut-off of 25 mg/kg body weight for rat model. Moreover, experiments in xenograft mice model show that oral administration of DSePA significantly reduces pneumonitis without interfering with therapeutic effect.

Liposomes are highly bicompatible vectors for the delivery of several hydrophilic and hydrophobic drugs with improved pharamcokinetics. PE Gylated liposomal formulation of doxorubicin (LP-DOX) that can evade the immune system was developed. In-vitro studies were performed using formulations in several cancer cell lines such as A549, MCF-7, PC3, K562, Ishikawa, SiHa, T24 and MCF-7, etc. In vitro studies showed significant toxicity of doxorubicin nanoformulation towards A549 and K562 cell lines. Further, this formulation has been tested in-vivo in Swiss albino mice to check its therapeutic efficacy in syngeneic mice model. The syngeneic model study has shown promising outcome, comparable with commercially available formulation (Lipodox) and BARC developed formulation (LP-DOX) showed comparable efficiency in reducing the tumor size, without inducing significant spleen toxicity.

SYNCHROTRON & THEIR UTILISATION

At RRCAT, both the synchrotron radiation sources, Indus-1 and Indus-2 were operated as a national facility for the Synchrotron Radiation (SR) user community. Indus-1 was operated at 450 MeV energy, 125 mA current, and Indus-2 was operated at stored current up to 200 mA at 2.5 GeV energy. During the period from April 1, 2018 to March 31, 2019, Indus-1 and Indus-2 were operated round the clock on 321 days. Both the machines were operated reliably and smoothly by following the prescribed safety procedures. Apart from the planned shutdown for upgradations and preventive maintenance, which was for 44 days during the above period, there were no major breakdowns/shutdown in the machine. The shutdown period includes 17 days of shutdown during which the Long Straight section, LS-7, of Indus-2 was vented for installation of the 6^{th} RF cavity and a kicker cavity for the Longitudinal Multi-Bunch Feedback (LMBF) system. After this major upgrade, normal operation of Indus-2 was restored within one month for users with 150 mA @ 2.5 GeV.

During the year, the Indus-1 beam availability for users was 7139 hours against the set target of 7000 hours, and the Indus-2 beam availability was 5412 hours @ 2.5 GeV against the set target of 5200 hrs. Users from various universities, research institutes and national laboratories used the photon beam at six beamlines in Indus-1 and fourteen beamlines in Indus-2, for carrying out experiments.

The Indus-2 Synchrotron Radiation (SR) source is usually operated with an electron beam optics having a horizontal emittance of 135 nm-rad at 2.5 GeV. In experiments during the year, several beam dynamical parameters were optimized to increase the spectral brightness of the photon beam by operating the SR source at a lower horizontal beam emittance of 45 nm-rad. This optimized operation method kept a control on the betatron tunes, closed orbit distortions, beta function distortions, etc. to prevent any beam loss. In the horizontal plane, the electron beam size was reduced from 420 μm corresponding to beam emittance of 135 nm-rad to 280 μm, which corresponds to a beam emittance of 45 nm-rad. It was observed while reducing the horizontal beam emittance that there was a reduction in the vertical beam size also, which can lead to a vertical beam instability. The parameters of the bunch-by-bunch feedback were further optimized for arresting the beam instabilities in the vertical plane.

A data acquisition system has been developed for the acquisition of the profile of the booster beam current pulse for every cycle of beam delivered from the pre-injector microtron during injection in Indus-1 and Indus-2. A LabVIEW-based software has been developed to analyse the acquired data for variation in pulse width and amplitude. This system has been installed in Indus control system and deployed for regular operation.

A data acquisition system has been set up for distributed, high accuracy, isolated, synchronized and simultaneous sampling of signals in Indus-2 for correlation diagnostics across various system signals. A total of 10 DAq hardware modules providing 80 channels have been installed at two widely separated locations, viz. Indus-2 magnet power supply (MPS) hall and the RF area. The system has been deployed for regular use in the Indus-2 storage ring.

Distributed fast data acquisition module installed in Indus-2 MPS hall

A Disaster Recovery Setup (DRS) has been designed, developed and commissioned for the layer-1 part of the Indus accelerator control system. A high availability data logging scheme has also been designed for achieving round-the-clock availability of data with group servers placed physically apart. With this development, it is now possible to operate Indus accelerators from the DRS location also in case of any eventuality.

Harmonic Sextupole (HSP) magnets are needed in Indus-2 to improve its dynamic aperture by suppressing the non-linearity introduced by the existing chromatic sextupole magnets. Compact combined function harmonic sextupole magnets, integrated with additional windings to generate horizontal & vertical dipole and skew quadrupole field components, have been designed and developed to meet these requirements. Twenty such combined function harmonic sextupole magnets have been developed in-house. The magnets have been characterized on a harmonic bench using a rotating coil method. The following picture shows the characterization set-up of one of the series produced harmonic sextupole magnet on the rotating coil harmonic bench.

Harmonic sextupole magnets, showing coils of sextupole, skew quadrupole, horizontal and vertical fields (left)
Magnet characterization on rotating coil harmonic bench (right)

A FMR bench for measurement of resonance line width in microwave garnets for high power circulator has been indigenously developed at RRCAT. Resonance line width (ÄH) is one of the important parameters required in the design and development of high power ferrite circulators. The resonance line width is proportional to the “Gilbert” damping constant which is responsible for losses in ferrites. A novel RF sweeping technique has been developed, which uses discontinuity type coaxial line to measure the resonance line width in ferrite and garnet discs. Various microwave ferrite and garnet samples have been measured using this technique.

A prototype capacitive displacement sensor has been developed in-house at RRCAT, along with its associated electronics. It has been developed to precisely detect any change in the mechanical position of the beam position monitor devices installed in the Indus-2 synchrotron radiation source. The developed capacitive displacement sensor can provide a resolution better than 0.1 μm and an accuracy in the sub-micron range (better than 0.6 μm) for a measurement range of 200 microns, at a data update rate of 2 Hz. A micro-controller based electronics and a data logger software on a host PC processes the data, stores the data in the PC and presents the data in a designed format. Testing and calibration of the sensor has been carried out in lab using a laser interferometer

In-house developed capacitive position sensor and lab calibration setup

Development of an upgraded electrode assembly has been done for integrated type Beam Position Indicators (BPI) for the Indus-2 synchrotron radiation source. These BPIs are specifically used for the measurement of electron beam position at the beam exit side of the dipole vacuum chambers.

Low Conductivity Water (LCW) is used in Indus-2 storage ring for the cooling of a large number of accelerator components such as electromagnets,

photon absorbers etc. The Indus-2 storage ring LCW system has been upgraded to provide coolant water at a lower temperature of 26 °C with an improved temperature stability of ± 0.5 °C (as compared to the earlier supply water temperature of 30 °C with ±1 °C stability) to enhance the performance of Indus-2. This has been achieved through the development and installation of precision cooling set-up, along with a new refrigerated secondary cooling arrangement.

Installation and Commissioning of the sixth RF cavity in Indus-2 has been done. A 505.8 MHz, bell shaped RF cavity, along with all associated elements like an RF input power coupler, Higher Order Mode Frequency Shifter (HOMFS), frequency tuner system, sensing loop couplers, vacuum system comprising of 270 lps sputter ion pump, 1000 lps titanium sublimation pump and a Bayard-Alpert gauge, has been installed in the long straight section LS-7 of the Indus-2 ring. In-situ low power RF measurements of the resonance frequency, quality factor, coupling coefficient, coupling of sensing couplers etc. have been performed. The coupling coefficient for the cavity was adjusted considering 'with-beam' operation of all the insertion devices at 2.5 GeV. The RF cavity, along with the fifth RF cavity installed earlier, was evacuated and baked by circulating hot water for about 36 hours, and a vacuum level of 5 x 10^{-10} mbar has been achieved after cool down. RF conditioning of the cavity has been performed and the cavity has been tested for operation at rated RF power level.

The sixth RF cavity along with vacuum system during baking

View of installed RF circulator at Sixth Indus-2 RF station

An indigenously developed prototype of a high power RF circulator operating at 505.8 MHz with a power handling capacity of 60kW CW has been assembled and deployed in the Indus-2 RF system. The circulator has been field tested under different reflection conditions by varying the power levels and shorting lengths at the output ports. The circulator has been commissioned at Indus-2 and is operating satisfactorily in round-the-clock mode of operation.

A pulsed focusing electromagnet power supply of 110 V, 35 A has been developed for the klystron of the 20 MeV injector microtron. The electromagnet focusing system of a klystron dissipates a major portion of its overall power consumption. Presently, a 110 V, 35 A DC power supply is used with a 5 MW klystron microwave system for the injector microtron, which amounts to a continuous drain of over 3.8 kW power. In the pulsed mode operation, the average power consumption has been reduced by 78 % of the 'dc' mode operation.

A vertically oriented large coating system based on DC magnetron sputtering technique, with an overall size of 1300 mm x 1200 mm x 5500 mm height, has been developed indigenously, installed and commissioned in the UHV Lab. This system will be used for coating of Non-Evaporable Getter (NEG) films on the inside surface of conductance limited narrow bore vacuum chambers used in insertion devices of Indus-2, and in the proposed future low emittance storage ring. A steady-state discharge was obtained at 500 V discharge voltage, 100 mA discharge current and 1.2 x 10^{-2} mbar dynamic argon gas pressure.

Large coating setup

Discharge during coating

New power converters rated for 170 A, 120 V (20 kW) output power, with an output current stability better than +/- 50 ppm, have been developed to replace the 15 year old power converters for quadrupole magnets in Indus-2. This is based on switch-mode power converter topology. Total nine power converter for LS1Q1D magnets have been tested, installed and commissioned in Indus-2, and are operating satisfactorily in round-the-clock operation. 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.

The installed and operational power converter for LS1Q1D magnet in Indus-2

Pinger magnets are basically kicker magnets employed for creating large betatron oscillations in the electron beam to study beam dynamics issues using turn-by-turn measurement capabilities of the BPMs. It is proposed to install two pinger magnets in the Indus 2 ring, one each for the horizontal and the vertical planes, and the development of two power supplies has been undertaken to energise these magnets with inductances of 200 nH and 550 nH respectively. Prototype development of pulsed power circuits of these power supplies has been completed to deliver 5.6 kA and 2.7 kA respectively with half sinusoidal currents of 1 μs pulse width.

Pinger magnet power supply

Active shunt is an essential tool for Beam Based Alignment (BBA) for centring of the electron beam in Indus-2, which helps to find out the offset between the centres of the beam position monitors and the quadrupole magnets. In order to perform BBA, the magnetic field of each quadrupole magnet is required to be varied independently by precisely changing its winding current with the help of an active shunt (± 6 A / ± 80 V) developed in house. So far, thirty-seven active shunts have been built in-house out of which, thirty-two have been deployed in Indus-2. A photograph of the active shunts installed at the power supply hall of Indus-2 is shown in. Beam Based Alignment has improved the beam lifetime, and simplified the commissioning of additional insertion devices into the ring.

Active shunts commissioned in the power supply hall of Indus-2

A smoke exhaust system has been installed in the Indus-2 accelerator complex, which will provide means for emergency response, rescue operations, exhaust of smoke and control of fire. This work has been accomplished as per the requirements of AERB. A new intelligent addressable fire alarm system (Schrack make) has been installed in the Indus accelerator complex to meet the additional requirement of detectors. With the induction of the new system, more than 1,000 fire alarm detectors can be installed. The Public Address (PA) system of Indus accelerator complex has also been upgraded with new paging mikes, priority controller, speaker loop line detector, power sequencer, audio splitter, audio amplifiers etc. The PA system is essential for making announcements to different users during round-the-clock shift operation, maintenance shutdowns and in the event of any emergency.

To correct the beam orbit of Indus-2 against various disturbances of up to about 50 Hz, a Fast Orbit Feedback (FOFB) system is being developed, which envisage the employment of 80 corrector magnets in the Indus-2 ring. Accordingly, 80 power supplies are required to energize these magnets. So far, 70 power supplies have been made.

FOFB Power Supplies installed in the power supply hall of Indus-2

Indus-1 and Indus-2 are national facilities with sixteen operational beamlines on Indus-2 and six beamlines on Indus-1. Two of the Indus-2 beamlines (BL-23 & 24) are dedicated exclusively for machine diagnostics, which provide essential information for the proper running of Indus-2. The number of user experiments performed on the Indus beamlines in the calendar year 2018 was 855. The Indus facilities have been used by researchers from all over the country for a wide variety of materials science studies, leading to 167 papers being published in peer reviewed international journals in 2018. Along with the above utilisation, there has been a continuous effort in improving the facilities at the beamlines. Important areas of research, in which experiments have been carried out at the Indus beamlines include Correlation of the structure with multiferroicity and magnetoelastic coupling in á-Mn_2O_3; Influence of the core-hole effect on optical properties of magnesium oxide (MgO) near the Mg L-edge region; In-situ X ray Absorption Spectroscopy study of Fischer-Tropsch reaction with Co catalysts; Carboxypeptidase in prolyl oligopeptidase family: unique enzyme activation and substrate-screening mechanisms and Total reflection X-ray Fluorescence determination of interfering elements rubidium and uranium by profile fitting.

The SINP involved itself in the Indus-2 activity and taken responsibility to develop a grazing incidence X-ray scattering beamline at BL-13 bending magnet port. The design of the entire beamline was conceptualized collectively by a group of SINP scientists and was commissioned successfully very recently. The available techniques in this beamline are powder diffraction (at ambient condition and also at low temperature), single crystal and multilayer diffraction, reflectivity, diffuse scattering from solid surface and liquid interfaces.

The beamline was formally inaugurated by Director, SINP and Director, RRCAT in presence of other scientists and technical personnel of both SINP and RRCAT on 12th December, 2018. Currently the monochromatic beam is available at the goniometer position in the experimental hutch. The energy of the x-ray beam was also successfully tuned in the range of 5 keV to 12 keV by the Double Crystal Monochromator and was calibrated by elemental absorption edges of Cr, Mn, Fe and Zn. The Beamline is a national facility with SINP acting as a nodal institute for its overall operation, maintenance and upgradation. It is now ready for carrying out scientific experiments using different techniques. SINP will also provide technical support and academic advice in planning scientific experiments by different users of the country.

Part of experimental hutch

A Small and Wide Angle X-ray Scattering (SWAXS) beamline was developed and installed at INDUS-2 synchrotron, Indore to probe mesoscopic length scale of 1-100 nm. SAXS measurements on standard samples were carried out during trial operation and the beamline is now available to users.

An in-situ EXAFS set-up to probe structural changes during a photocatalytic reaction at Indus-2 was installed at BL-09 Energy Scanning EXAFS beamline at Indus-2 SRS. The setup consists of a reaction-cum-measurement cell consisting of quartz and glass windows for UV-Visible radiation in addition to the Kapton windows for X-ray transmission. The reaction cell has features for controlling reactant proportions and product detection with gas chromatograph and be used as a closed reactor for a slow chemical reactor.

A Facility for in-situ study of ion batteries using X-ray diffraction was established at Indus-2 in collaboration with IIT Bombay. The setup is capable of remotely aligning samples for in-situ electrochemical studies, which are important in exploring alternatives to Lithium in ion batteries.

CYCLOTRONS & THEIR UTILISATION

Medical Cyclotron

The DAE Medical Cyclotron Facility has been established at Chalkgaria, Kolkata, by VECC. The cyclotron along with two beam lines has been commissioned during September, 2018. A test irradiation of enriched water sample and production of FDG has also been carried out. The main objective of the facility is to produce radioisotopes to be used in nuclear imaging for medical diagnostic and therapeutic purposes for cancer care. The facility will also be used for various research and development purposes.

At the heart of this facility is a cyclotron called CYCLONE-30, shown in the picture, procured from M/s Ion Beam Application, Belgium. CYCLONE-30 is a negative hydrogen ion accelerator. The negative hydrogen ions produced in an external multicusp ion source is axially injected into the cyclotron. This is a fixed magnetic field, fixed RF frequency and variable final energy dual proton beam cyclotron. There are two RF cavities, called dees, to accelerate the negative hydrogen ions. At extraction radius carbon stripper foils are used to extract two simultaneous proton beams from the machine. The extracted beam energy is adjustable from 15 MeV up to 30 MeV and the beam current is tuneable up to 350 μA. At this pre-commissioning stage, it has been tested purposefully up to 7 μA to keep the radiation level low.

Cyclone-30 at Medical Cyclotron Facility, Chakgaria, Kolkata

In India, few low energy cyclotron installations have also been producing PET radioisotope ^{18}F. However, there is increasing demand for other useful radioisotopes namely, ^{201}Tl, ^{123}I, ^{111}In, ^{67}Ga etc. which have longer half-life. All these radioisotopes require higher energy for their production through a specific nuclear reaction. The DAE Medical Cyclotron Facility will meet this huge demand all over India with a potential export capacity.

Super-conducting Cyclotron (SCC)

Beam dynamics simulations have been done to find out the transmission efficiency of ion beams through narrow vertical space of SCC. Beam Transmission Efficiency under ideal condition and restricted condition of VECC superconducting cyclotron after cryostat repositioning has been studied. The first harmonic component of the magnetic field of SCC corrected from 50 Gauss to 28 Gauss after repositioning of the cryostat. Installation and commissioning of a helium compressor for hooking up with the liquid helium plant. One oil removal module which is capable of handling flow rate of 100 g/s has been designed, developed, installed, interfaced with the compressor, commissioned and tested.

Helium Cycle Compressor

Oil Removal Module

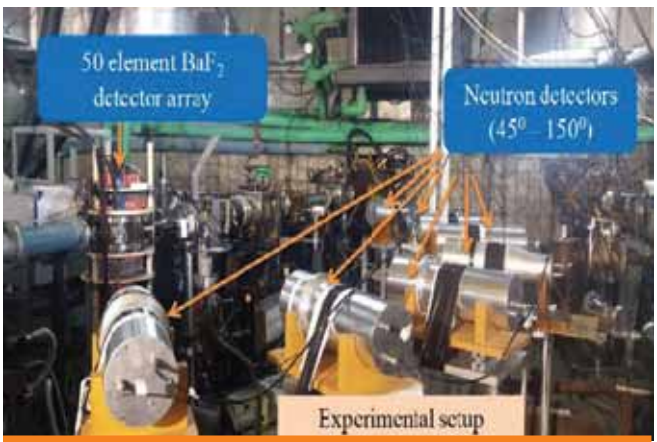
Room Temperature Cyclotron (RTC) Utilisation

The Room Temperature Cyclotron (RTC) has been operating in round the clock shift basis and delivering ion beams to various experimental research programs. The external 14.45 GHz Electron Cyclotron Resonance Ion Source (ECRIS) developed indigenously is regularly producing high charge state heavy ions and light ions which are accelerated in cyclotron. Presently both light (alpha) and heavy ions (nitrogen, oxygen, neon etc.) of various energies are regularly being used to produce radio-isotopes, radiation damage studies and nuclear physics experiments. Apart from in-house users, the facility has been utilised by users from VECC, SINP, BARC, UGC-DAE-CSR-Kolkata, IIEST-Shibpur, Calcutta University, TIFR, University of Mumbai – to name a few.

The cyclotron is regularly fulfilling its target for beam availability and this year also the beam availability target of 4000 hours has been fulfilled.

The maximum usage (46.6%) of the beam time is for nuclear physics. Using heavy ion beams from the cyclotron several experiments have been carried out during this year to study the fundamental properties of nucleus and nuclear reaction mechanism. To study the density dependence of symmetry energy, two different isotopes of tin (^{112}Sn, ^{124}Sn) targets were bombarded with ^{20}Ne and ^{16}O beams. Effect of clustering on the emission of light charged particles was studied populating same compound nucleus in ^{20}Ne+^{9}Be and ^{16}O+^{12}C reactions using part of the Charged Particle Detector Array (CPDA) developed at VECC. The fission and quasi-fission dynamics were studied by bombarding ^{16}O and ^{20}Ne beams on several pre-actinides and actinides targets using Large area Multi-wire Proportional Counters (MWPCs) developed in-house. An extensive experiment was performed to study the saturation of Giant Dipole Resonance (GDR) width at different temperatures using different energy ^{16}O beam on ^{58}Ni target. To investigate the behaviour of Nuclear Level Density (NLD) at high excitation energy (temperature) and angular momentum (spin), neutron evaporation spectra at various laboratory angles were measured using ^{16}O and ^{20}Ne beams on ^{27}Al, ^{58}Ni and ^{93}Nb targets using Large Area Modular BaF2 Detector Array (LAMBDA) and neutron detectors developed at VECC. The results of the experiments have been communicated / published in journals of international repute.

Another significant usage (29.6%) in nuclear physics research was experiments using Indian National Gamma Array (INGA) setup during October - December, 2018 with alpha beams. INGA was setup at VECC as a large national collaboration among various national institutes and universities to pursue the rich variety of nuclear structure studies using high resolution gamma ray spectroscopy techniques. In this second phase of INGA experiments, higher energy alpha beams (40-53 MeV) have been used to probe variety of nuclear structure phenomena which are usually manifested in lower spin regime and thus ideal to investigate with light ion beams. Some of the key physics issues which have been addressed in these experiments are octupole correlation in nuclei of different mass region, wobbling motion in excited



The BaF2 array and neutron detector setup used in the experiment

INGA detector setup for second phase campaign at VECC

nuclei, lifetime measurement of excited states of light nuclei of astrophysical interests etc. During this INGA campaign, eight Clover HPGe detectors along with the BGO Anti Compton Shields (ACS) and two LEPS (Low Energy Photon Spectrometer) detectors of planer HPGe have been used. A data acquisition system based on Digital Signal Processing (DSP) from UGC-DAE-CSR, Kolkata Centre, have been used to record the Compton suppressed data in both coincidence as well as singles mode. A total of eight experiments were carried out with alpha beam. At the end of Alpha beam experiments, a test experiment was also performed using 146 MeV ^{20}Ne beam to test the response of INGA setup with digital DAQ for heavy ion reactions. Above picture shows the INGA setup used for the second phase of experiments at VECC.

Another very important usage (11.6%) of the beam was in the field of radiation damage studies of nuclear structural materials such as Nb, Nb alloy, Ti alloy, V and V alloy etc. using oxygen and Neon beam from cyclotron. The characterisation of the microstructure, defect states, dislocation density as a function of doses will be carried out to understand the effect of irradiation on these structural materials.

PLASMA & FUSION TECHNOLOGIES

Plasma Sterilization of Medical devices, components and baby utensils

Healthcare-associated infections are a major problem in hospitals. Conventional sterilization techniques like autoclaves, hydroclaves and ethylene oxide (EtO) have certain drawbacks while sterilizing heat sensitive devices like catheters, endoscopes, etc. A recently completed collaborative project between IPR and B.V. PERD Centre, Ahmedabad on “Development of Prototype Plasma System for Effective and Uniform Sterilization of Medical Devices, Components and Baby Utensils”, funded by the Gujarat Govt., clearly shows the killing of 4 different bacterial strains (Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Salmonella abony) commonly prevalent in Healthcare-associated infections. The pulsed dc plasma of Ozone and Oxygen effectively kills bacterial species in 1 hour. Hospital components and baby spoons were also successfully sterilized.

Plasma Sterilization System developed at IPR

Atmospheric plasma system for food grain processing

Atmospheric pressure plasma technology (APP), involving the use of non-thermal plasmas, is an emerging technique for enhancing seed germination and better food preservation. Atmospheric pressure plasma generates reactive oxygen species and reactive nitrogen species which interact with seeds and etch the surface. Plasma treatment enhances soaking up of moisture, thus improving germination. Atmospheric pressure plasma treatment can also lead to inactivation of bacteria, bacterial spores, and fungi present on the surface of food grains. Such a plasma treatment system has been developed at IPR and commissioned at Anand Agricultural University for detailed study.

Plasma system for In-line textile treatment

Presently, in all textile industries, de-scouring (removal of wax from surface before printing) is performed using chemicals and water which can pollute the environment. An environment-friendly alternative, which does not use chemicals, is to use a uniform glow

Dielectric Barrier Discharge (DBD) plasma. IPR has successfully developed such a system and tested it for 24x7 continuous operation in June 2018. The plasma is generated using air and no other gas is required. The DBD plasma was applied for treatment of various textile materials and significant functionality improvements have been found to occur within a few seconds of exposure. The system can accommodate a 2.5 m wide web and its guiding mechanism. This system, funded by DST, has been installed and commissioned at MANTRA, Surat.

Plasma system for In-line textile treatment

Rotatable Magnetron Developed at IPR

Rotatable Magnetron

A technically-challenging rotatable magnetron has been developed. It is the first of its kind in India for the sputter coating industry. As compared to the currently-used planar magnetron, where only 40-50% of the target material is utilized due to limited sputtering racetrack area, the rotatable magnetron permits utilization up to 80%. This is a major development for the coating industry using magnetron sputtering technology. The cost of this indigenously developed rotatable magnetron is S! of an imported system.

Denim fading using non-thermal air plasma jet

A system has been developed which incorporates a computerized translation system to automatically make the design on denim using non-thermal air plasma jet as per the image selection.

Images of Denim Fading system

Aditya Tokamak Operation

The discharge duration of confined plasma has been prolonged up to 330 ms (more than the design value of 250 ms) in ADITYA-U Tokamak for the first time. Using a novel gas-puffing technique, the peak plasma density has been raised to $> 6 \times 10^{19}$ m^{-3}, an all-time high for ADITYA-U tokamak, which led to a unique observation of rotation reversal of plasma, reported in very few tokamaks worldwide. The result signifies the achievement of maximum possible confinement time in this category of tokamaks known as saturated Ohmic confinement. A plasma current of 175 kA has been achieved, higher than the value ever achieved in either Aditya or Aditya-U. This was done at a Toroidal field of 1.3 Tesla, 85% of the design value. For the first time, the horizontal plasma position in the ADITYA-U tokamak has been controlled in real time using a Fast Feedback Power Supply. The power supply, responding on fast timescales of 1 millisecond, drives currents up to 1500 A in feedback coils newly installed in ADITYA-U. PID control has yielded good performance. In ECRH-assisted operation, successful start-up has been achieved at a loop voltage as low as 10 V, 50% of the requirement without ECR.

Steady-State Superconducting (SST-1) Tokamak Operation

The Toroidal field coils, which had earlier been used to produce a maximum field of 1.5 Tesla (and 1.8 Tesla for short durations), have now produced 2.7 T at the plasma centre, corresponding to 90% of the design value. The toroidal magnetic field was raised in steps, and was kept above 2 T for more than 15 minutes. This is an important demonstration in terms of planned experiments in future campaigns, where long-pulse plasma operation above 2 T would be done with the assistance of Electron Cyclotron Resonance, Lower Hybrid and Ion Cyclotron Resonance systems. Helium Plasma experiments assisted by the ECR and LH have been performed. In addition, at the end of the experimental campaign, ICRH based wall conditioning experiments were successfully carried out at magnetic fields of 1.1T, 1.5T and 1.6T.

PF3 coil power-supply up-gradation

Series connection of two half-wave three-phase rectifiers has been successfully demonstrated (uniform voltage sharing) on a 3A load and also at no-load full firing. This will allow higher PF coil voltages to drive time-varying currents in the PF3 coils, which is necessary for producing a shaped plasma

Development of Ka-Band Reflectometer System for measuring Radial Electron Density Profile

A Ka-Band Frequency Modulated Continuous Wave (FMCW) Reflectometer has been designed and developed to measure the electron density profile. The super heterodyne detection scheme in conjunction with quadrature down conversion is used for unambiguous phase determination. To overcome the deleterious effects of plasma density fluctuations, the implemented Reflectometry system is capable of ultra-fast sweep over the entire Ka-Band in 5ìs and has high data acquisition rates of 200MSps.

A Study on Neutron Emission from a Cylindrical Inertial Electrostatic Confinement Device

CPP-IPR has successfully demonstrated some essential parameters required for the emission of 2.45 MeV DD fusion neutrons from a steady state portable linear neutron source based on inertial electrostatic confinement scheme. The parameters that control the production of neutrons are the working pressure of the fuel gas, applied voltage, measured current and cathode geometries. The neutrons emitted from the source are confirmed using neutron monitor, bubble dosimeters, nuclear track detectors, and He-3 proportional counter. Presently, the device produces neutrons 10^6 n/sec at discharge voltages ranging from -60 kV to -80 kV, and discharge current of 20 mA to 30 mA.

Solid-state RF generator coupled to ROBIN negative-ion source

An indigenously developed (40 kW, 1 MHz) solid state RF generator has been integrated with an RF based negative ion source (“ROBIN”). Such a coupled system has been set up only for the second time in the world. The aim was to establish generator performance with respect to power coupling and plasma production in the source. Power ranging from 23-40 kW was successfully coupled to produce the desired plasma at pressures between 0.9 and 0.5 Pa.

40 kW solid state RF generator (left) coupled to the negative ion RF ion source test bed (ROBIN) (right)

High Temperature Technologies

Seven-layered W/Cu functionally graded material (FGM) (100 W, 80W-20Cu, 60W-40Cu, 50W-50Cu, 40W-60Cu, 20W-80Cu, 100Cu, by wt %) were fabricated by a spark plasma sintering process (SPS). The influences of sintering temperature on microstructure, physical and mechanical properties of the sintered bulk FGM were investigated. Results indicate that the graded structure of the composite densification after the SPS process and interfaces of the layers also are clearly visible. All

of the layers have a very high relative density, thereby indicating their densification and excellent sintering behavior. SEM and EDX study of the bulk sample cross-section reveal that the graded structure can be retained up to sintering temperature of 1050 °C. In addition, fine microstructure within each layer with good interface bonding was also observed. Sample sintered at 1050 °C exhibited excellent mechanical and physical properties (hardness 239 ± 5 Hv and relative density of 90.5%). The result demonstrates that SPS is a promising and perhaps a more suitable process for fabrication of W-Cu functionally graded materials.

Magnet Technology development

Work is being continued in technological developments related with Nb3Sn and high temperature superconductors (HTS). A laboratory scale Nb3Sn solenoid coil which can produce magnetic field of ~1 T has been wound and heat treatment of the same is in progress. The high voltage compatible electrical insulation system has been developed and Paschen test has been carried out at low temperature. The laboratory scale high temperature superconductor (HTS) based D-shaped magnet fabricated and tested for its cooling characteristics up to 77 K, current charging and magnetic field measurement. The low resistance joints of 5 n&! have been developed and tested at 77 K for HTS magnet applications.

Remote Handling and Robotics Technologies

The major activities include a high vacuum and high temperature compatible inspection arm with supporting advanced technologies like haptic force feedback, dexterous hyper redundant end-effector and a fully immersive virtual reality facility.

Development of Indigenous haptic force feedback arms for Tele-operation

For the flexibility to execute dynamic tasks safely, the RH manipulators are typically controlled using a 'man in the loop' architecture. Haptic systems with real-time force feedback integrated to full 3D virtual reality environment can enable the RH operators to have the sense of virtual presence. A 6 axis master arm has been developed and successfully tested for position control.

Fusion Blanket Technologies

This caters to the indigenous development of blanket technologies required for a future fusion reactor as well as to the development of Test Blanket Module to be tested in the ITER project.

Numerical and Experimental MHD Studies of Lead-Lithium Liquid Metal Flows in Multichannel Test-Section at High Magnetic Fields

Numerical simulation and experiments have been performed at high magnetic fields (1–3T) to study the MHD assisted molten Lead-Lithium (PbLi) flow in a model test-section which has typical features of multiple parallel channel flows as foreseen in various blanket module of ITER.

Corrosion Behavior of IN-RAFM Steel with Stagnant Lead-Lithium at 550°C up to 9000 h

Corrosion study of IN-RAFM (India specific reduced activation ferritic martensitic) steel with static lead-lithium, Pb-16Li has been carried out at 550 °C for different time durations, 2500, 5000 and 9000 h. Flat and tensile INRAFM samples were exposed to liquid metal. Exposed samples were analyzed for micro structural observation and chemical composition by scanning electron microscope equipped with EDX (energy dispersive X-ray spectrometer). Hardness reduction was observed up to a depth of <“15 ìm after exposure to liquid metal. There was no significant reduction in the tensile strength. Dimpled ductile fracture was observed after exposure to liquid metal up to 9000 h.

Neutronic Design Optimization of ITER TBM Port#2 Bio-Shield Plug

In order to serve the requirement of TBM system, a Bio-Shield Plug (BSP) is placed at biological shielding location of the equatorial port. The neutronic design of BSP is important because it serves the purpose of biological shield boundary of ITER port. The neutronic analyses have been performed using the MCNP radiation transport code and FENDL-2.1 nuclear cross section data library. The Activation code FISPACT2007 has been employed to estimate the contact dose rates.

The outcome suggests that B4C and Ferro-boron would be better candidate materials for the bio-shield plug of TBM port.

In gyro-devices, frequency of operation is determined by the cyclotron frequency, thereby the magnetic field. The gyrotron efficiency is determined by the axial length of the electromagnetic field structure, radius of the hollow beam, the cavity Q-factor of the interaction mode (TE03 for present case), uniformity of magnetic field for the resonant value at the interaction region and angular to longitudinal velocity ratio of the e-beam. The interaction is optimum if the hollow beam diameter is same as the E-field peaking diameter of the circularly polarized wave at its interacting mode. For this, field rise from cathode gun to cavity center should be gradual. Magnetic field compression ratio is the reduction in the beam cross-sectional area resulting from increase in axial magnetic field during its traverse from Magnetron Injection Gun (MIG) to the interaction region Field profile optimization has been carried out to meet the beam optics requirement to meet the requirements at both cavity center and cathode gun center.

Magnet Assembly integrated with Gyrotron tube at Institute of Plasma Research

MATERIAL SCIENCE

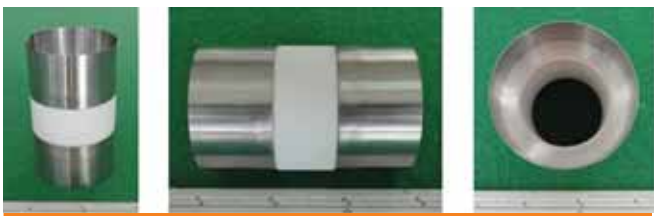
At BARC, composition of the Hastealloy was modified to provide high temperature strength, good resistance to corrosion and irradiation. Based on the preliminary studies, a model composition was worked out. The alloy was air as well as vacuum melted. Multiple melting was carried out to meet the desired composition as close as possible and at the same time achieve the desired surface finish. The alloy was subjected to various modes of deformation. A process has been worked out to form the alloy in various shapes. Welding experiments were carried out to produce defect free weld.

Composed form of Hastealloy

Al_2O_3 is one of the most important structural ceramic. The major drawback is that it sinters at very high temperature. To overcome this, a multistage sintering methodology was developed to densify Al_2O_3 at almost 150-200°C lower compared to normal. A comparative study reveals that the multistage sintering yields more than 98% Theoretical Density (TD) compared to less than 90% TD obtained through conventional route at the same sintering temperature (1250°C). Using this indigenous technique, porous and brittle alumina insulation was sintered to a strong, rigid insulating case for carrying out high temperature hardness testing of UO_2 fuel required by BARC. Various components were fabricated by this method and used for fabricating the high temperature hardness tester. To carry out burst testing of fuel tube, dense (>99%TD) alumina pellets were also made by this method.

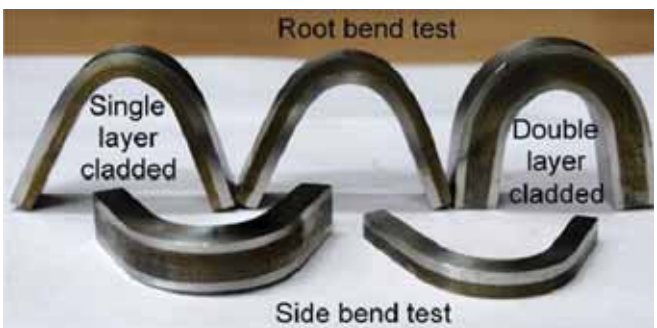
Joining of alumina cylinder to SS cylinder by Active Brazing Alloying (ABA) technique was carried out to fabricate Ceramic brake for Fast Current Transformer (FCT). Helium leak rate of the seal was found to be 5.3

x 10-9 Tor. lit/sec. It will be used as a ceramic brake in Fast Current Transformer (FCT), which is being developed by APPD, BARC, for their Electron LINAC programme.



Ceramic brake made using ABA technique

Corrosion resistant cladded steel plates used in petrochemical and chemical industries for pressure vessels and pipelines applications containing corrosive mediums (including sulphuric acid) were developed. The technology for producing roll bonded sandwich plates with SS 317L as cladding and ASTM 516 Gr 60 Carbon Steel (CS) as backing materials has been developed. Single-layer cladded and Double-layer cladded sandwich plates were successfully produced by hot roll bonding using a laboratory two-high rolling mill. The microstructure of these roll bonded plates were characterized using optical microscopy and Scanning Electron Microscopy (SEM). The chemical nature of the transition layer formed between these two chemically different steels was studied using SEM and revealed the presence of a diluted transition layer of around 5 micron thickness. The integrity of the CS to SS 317L metallurgical bonding was evaluated by root and side U-bend tests and no delamination of the clad was observed in either case.



Single and double layer SS317L cladded ASTM 516 Gr 60 sandwich steel plate specimens after clad integrity test

Solid state lithium electrolyte based on lithium germanium phosphate glass ceramics with NASICON structure was synthesized. Composition was optimized by suitable doping with Al and Si for an optimum electrical conductivity. Electrical conductivity, crystallization kinetics and structural studies using X-ray and neutron diffraction was carried out. Model free kinetics was used to calculate the kinetics parameters. Neutron diffraction studies showed the exact location of low Z lithium and conduction pathway was identified. Doping helped to expand c-axis and increased the pathway resulting higher electrical conductivity. Cells were fabricated with different combination of cathode and anode and tested for cyclo-voltametry at different C-rate. Capacity of 80% of theoretical value has been obtained at lower C-rate. Attempts were made to make thin electrolyte by gel/solution casting. Flexible, self-sustained and thickness less than 100μm solid state polymer electrolytes were made and cells were fabricated for performance testing.

Fabricated coin cell showing the OCV of 3.4V

Flexible thin self-sustained polymer electrolyte fabricated using LAGP

As an operational requirement, CRPF requested BARC to develop hand held ballistic shields having capability of stopping Armour Piercing (AP) bullets (Level IV). Materials Group, BARC developed two test panels (300 mm X 300 mm) using hot pressed boron carbide and carbon nanotube impregnated polymer. These panels were tested against multiple shots of AP bullets and were found to stop them with low back face signature (less than 20 mm).

Ballistic Shield before and after ballistic test

More than 400 pieces of 50 X 50 X 7 mm B4C-CNT composite tiles were hot pressed. 4 numbers of hard armour panels were fabricated using these tiles after machining them into required dimensions. The ballistic performance of these composite armours was found to be satisfactory against AK 47 hard steel core bullets and SLR.

Ballistic Evaluation of B4C-CNT Composite Armour

The conventional thermoelectric material of bismuth telluride has been doped by lead for improving the figure of merit (ZT) for low-temperature range application (<573 K). The figure-of-merit (ZT) of n-type Bi_2Te_3 is ~ 0.47 and optimized $Bi_{1.95}Pb_{0.05}Te_3$ exhibit p-type conduction with enhanced ZT of ~ 0.63 at 386 K. The conversion efficiency of $Bi_{1.95}Pb_{0.05}Te_3$ based single thermoelement with hot pressed Ni/Ag electrical contacts was found to be 4.9% for a temperature difference (ÄT) of 200 K. The efficiency was further enhanced to 12% (at ÄT494K) in the segmented thermoelement consisting of $Bi_{1.95}Pb_{0.05}Te_3$ and $(AgSbTe_2)_{0.15}(GeTe)_{0.85}$ (i.e. TAGS-85).

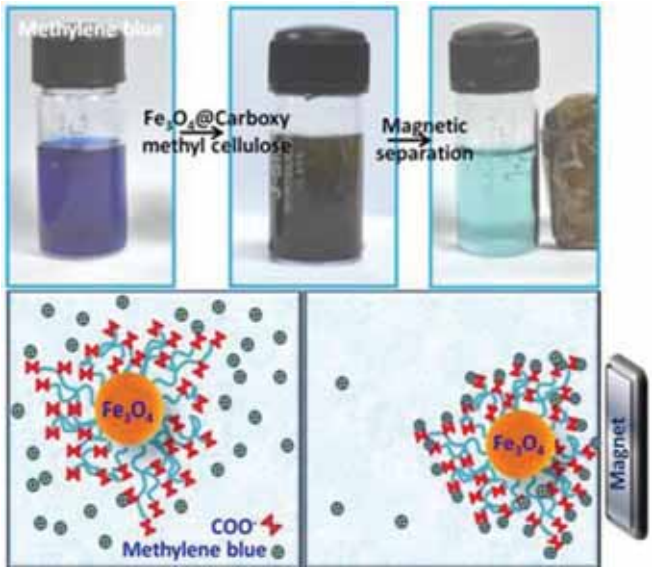
A novel approach for phase identification in binary mixture of nanopowders from deconvoluted valence band spectra using X-ray photoelectron spectroscopy is developed. This new approach is validated in polymorphs of iron oxide and titania nanopowders. A linear correlation between the percentage of the phase and the valance band peak area was observed in both the cases. The phase compositions of the nanopowder mixtures identified from the valence band spectra and X-ray Diffraction data were found to be in good agreement with each other.

The conformational changes of a weak polyelectrolyte, Poly Acrylic Acid (PAA), adsorbed at a magnetically controllable oil-water interface under different local environmental condition is manifested from the Bragg peak shifts in the reflected light, after the droplets are assembled into a periodic 1D array with the aid of a weak magnetic field. This new spectroscopic approach offers promising applications in probing macromolecular conformation at interfaces and to obtain new insight into colloidal stability.

New insights into the effect of orientation ordering and texturing of droplets, immobilized in a tissue mimicking agar matrix, on the field induced heating efficiency is obtained. A higher specific absorption rate is observed for droplets orientated parallel to the direction of the alternating magnetic field because of the enhancement of effective uniaxial anisotropy energy density and increased effective relaxation time. For identical and non-interacting MNP oriented parallel to the external DC magnetic field, a threefold increase in the effective uniaxial anisotropy energy density and 20–30% increased specific absorption rate are observed as compared to those oriented perpendicular to the magnetic field.

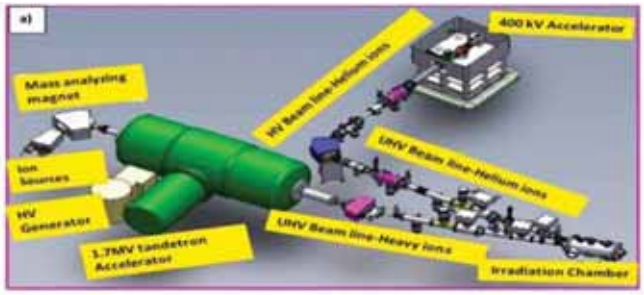
Cellulose capped magnetite nanoparticles in the size ranging from 21 to 41 nm have been synthesized for cationic dye removal. The particle size is tuned by using appropriate amount of carboxymethyl cellulose at the nucleation stage, by controlling steric hindrance.

The cellulose capped particles were found to be efficient for methylene blue dye removal due to physisorption of methylene blue on cellulose capped nanoparticles



(Top) Methylene blue (MB) mixed with MC nanoparticles before and after dye removal. (Bottom) schematic showing MB captured by MC nanoparticles

Among the irradiation effects on structural materials void swelling and helium embrittlement limit the lifetime of nuclear reactor components. To investigate them, a dual beam irradiation facility which is the first in the country has been set up at the centre. This facility provides co-implantation with heavy ion beams from an existing 1.7 MV accelerator along with gaseous ions from an indigenously built 400 kV accelerator. This facilitates simulation of irradiation conditions of materials in nuclear reactors. This arguably mimics the actual conditions of reactor, viz atomic displacements due to neutrons, transmutation product generation as well as inert gas decoration of vacancy clusters to form stable void nuclei.



(a) Schematic of a dual ion irradiation facility

(b) Experimental beamline station of dual beam irradiation facility

A High Resolution Rutherford backscattering spectrometry (HRBS) system with an energy resolution of 1.6 keV at 400 keV, corresponding to a depth resolution of 2 to 3 Å and improved mass resolution is installed. It consists of a Toroidal Electrostatic energy Analyzer (TEA), Microchannel Plates (MCP) and a 1D-position sensitive detector and associated nuclear instrumentation modules. It is a unique facility in India for studying ultra-thin films and composition of samples containing elements of nearer by mass.

Structural stability studies of boron doped 40:60 iron phosphate glasses under humid storage conditions, using Raman spectroscopy is reported. Raman measurements indicate that increased boron doping in these glasses maintaining oxygen/phosphorous ratio constant serves to strengthen the parent glass network, while for samples with iron/phosphorous ratio a constant, a systematic weakening of the network, was observed with increased boron content. Raman measurements on glasses exposed to ambient laboratory conditions for three years reveal excellent structural stability against atmospheric corrosion.

Impulsive photo-excitation of solids results in a travelling strain pulse which manifests itself as coherent acoustic phonon oscillations which have been extensively studied using time-resolved pump-probe spectroscopy. The generation of extremely long-lived, coherent longitudinal acoustic phonon oscillations in intrinsic GaAs (100), with clear and unambiguous evidence of Fano interference between these oscillations and the continuum of electronic states close to the bandgap has been reported. Fanoresonance arises from quantum interference between a continuum of quantum states and a discrete quantum state. In the present work, Fano resonance in coherent phonon oscillations generated without the aid of any capping

layer, dopants or substrate/interface effects has been investigated. Since Fano resonance is sensitive to changes in electronic structure, doping and defects, these observations are important to the field of picosecond ultrasonics which is used for non-destructive depth profiling of solids and for carrier diffusion studies.

A ground based Time Domain Electro-Magnetic induction (TDEM) system is under development with an extremely sensitive SQUID sensor to probe the conductivity of the earth in order to locate the conductive minerals buried in deep surface of the earth. The performance of the system has been tested in the field near the AMD camp, MC Palle, Cudappah (Dt), AP. The central loop sounding measurements have been performed by using a transmitter loop in the form of square with size of 100 m x 100 m and 400 m x 400 m and the decay of the secondary magnetic field has been recorded at the centre of the loop by using the SQUID system. The recorded decay profile shows the layered structures of the earth. The decay profile indicates from top to bottom the upper weathered conductive layer, a highly resistive layer, another conductive layer and another resistive layer. This establishes unique sensitivity of SQUID based TDEM system and further detailed studies are planned.

The microstructural parameters in pure Nb, irradiated with 5 MeV proton beam have been characterized as a function of dose in a reliable manner using X-ray diffraction line profileanalysis. In order to compare the microstructural changes in the homogeneous region with the peak damage region of the damage energy deposition profile, X-ray diffraction using two different geometries (Bragg-Brentano and parallel beam geometries) has been carried out. X-ray line profile analysis like Williamson-Hall analysis, Simplified breadth method, Double-Voigt analysis, Modified Rietveld technique and Convolutional multiple whole profile fitting have been employed to extract the microstructural parameters like coherent domain size, microstrain within the domain, dislocation density, types and arrangement of dislocations. The coherent domain size decreases drastically with increase in microstrain in the first dose for both the geometries and remains almost unaltered as a function of dose. The dislocation density is also found to increase by more than an order of magnitude with irradiation. No significant difference is observed in the microstructural parameters between the homogeneous and the peak damage region of the damage profile

The changes in the microstructure of 3.5 MeV proton irradiated T91 Ferritic-Martensitic steel samples with dose have been evaluated using detailed X-ray diffraction line profile analysis of the data collected using both laboratory and the synchrotron source. Different line profile analysis techniques like Williamson-Hall, modified Rietveld method and convolutional multiple whole profile fitting have been applied to evaluate the microstructural parameters such as domain size, microstrain, dislocation density and the character of the dislocation from both the data.

The ion-induced depthwise damage profile in 35 MeV α-irradiated D9 alloy samples with doses of 5×10^{15} He^{2+}/cm2, 6.4×10^{16} He^{2+}/ cm2 and 2×10^{17} He^{2}+/cm2 has been assessed using X-ray diffraction technique. The microstructural characterisation has been done along the depth from the homogeneous damage region (surface) upto the Bragg Peak region, as simulated from SRIM (Stopping and Range of Ions in Matter). The parameters such as domain size and microstrain have been evaluated using two different X-ray diffraction line profile analysis techniques. The results indicate that at low dose, the damage profile shows a prominent variation as a function of depth but, with increasing dose, it becomes more homogeneous along the depth. This suggests that enhanced defect diffusion and their annihilation in pre-existing and newly formed sinks play a significant role in deciding the final microstructure of the irradiated sample as a function of depth.

At RRCAT, an experimental facility has been established for doing terahertz (0.1– 2 THz) time domain spectroscopy using a laboratory based source at low temperatures (5-300 K) and in high magnetic fields (up to 7 T). The complex optical conductivity of a Fe_3O_4 film, deposited on Si substrate (Fe_3O_4/Si), was studied as a function of temperature and frequency using this facility. Both the dielectric constant ($\tilde{o}_1$) and the dynamic conductivity ($\acute{o}_1$) of Fe_3O_4/Si were found to be larger than those of the single crystals by an order of magnitude. The frequency dependence of $\acute{o}_1$ deviates from the metallic behaviour below 220 K, which is much higher than the high temperature metal to low temperature insulator transition in Fe_3O_4. The plasma

frequency above 220 K is found to be smaller than that of the single crystal samples. Analysis suggests that these observations are related to the substrate induced strain in the film.

***Experimental set-up for terahertz time domain spectroscopy* at low temperatures and in high magnetic fields**

A Variable Temperature Insert (VTI), along with a resistivity probe, has been designed and fabricated using thin walled, non-magnetic stainless steel tubes to work in the presence of a superconducting magnet in liquid helium environment. The temperature range of the VTI is 3K to 350K. A temperature stability of nearly 10 mK has been achieved to track a narrow superconducting transition in niobium with a width of about 0.08K. The electrical noise was brought down to less than 30nV to enable the measurement of very low residual resistance of 5.7 x $10^{-10}\Omega$-m in the normal state of niobium at 9.4K, and the determination of the Residual Resistivity Ratio (RRR) 298. Magnetoresistance and magnetostriction were also measured on very pure samples of SCRF cavity grade niobium.

Investigations have been done for the determination of the role of different tailor-made additives and conformers of resorcinol on the mechanism of unidirectional vapour growth of á-resorcinol crystal.

The important role played by the environment and the effect of spin-orbit interaction of each atom in Heusler alloys on their magnetic properties has been established.

Transparent Er, Nd co-doped Y_2O_3 ceramics with a transparency 78% (in 500-2000 nm range without Fresnel's correction) have been fabricated and characterized. The up-conversion luminescence and downshifting luminescence mechanisms involving energy transfer and non-radiative relaxation have been analysed. The observed emissions at both 563 nm (Er^{3+}:$^4S_{3/2}\rightarrow{}^4I_{15/2}$) and 1064 nm ($Nd^{3+}$:$^4F_{3/2}\rightarrow{}^4I_{9/2}$) with excitation at 822 nm (Nd^{3+}:$^4I_{9/2}\rightarrow{}^4F_{5/2}$) establishes the potential of the ceramic material as an efficient dual mode emitter at room temperature.

Raman spectroscopy of (1-x)NBT–x$BiCrO_3$ ceramic has been carried out at room temperature, and two extra bands have been observed near 770 cm^{-1} and 835 cm^{-1}, in addition to the Raman modes, The existence of these extra bands is attributed to the presence of oxygen defects in the crystal lattice, and the intensity of these bands is observed to increase with an increase in oxygen defect concentration. Raman spectroscopy could be a useful tool for the detection of oxygen defects in $Na_{0.5}Bi_{0.5}TiO_3$ based ferroelectrics.

Integration of GaP on group IV semiconductors like Si and Ge is an area of intense research for its application in multi-junction solar cells. Wavelength dependent Raman spectroscopy has been used to investigate inter-diffusion at the interface of GaP/Ge (111), and the spectra confirms the presence of a disordered germanium layer of thickness 20 nm at the hetero-interface, due to phosphorous diffusion. These results are very useful for understanding the role of the nucleating layer for the integration of group III-V on group IV semiconductors.

Semiconductor-insulator-metallic surface modifications have great potential in nano-micro-electronic device applications. The correlation of surface modification processes using laser irradiation with both, temperature and the nanowire orientation, has been investigated for differently oriented InAs nanowires (in plane) using polarized Raman spectroscopy. The study elucidates that laser irradiation leads to the formation of oriented crystalline oxide films on InAs nanowire surface.

[001] and [100] oriented laser elements of dimension 3-4 x 3-4 x 6-8 mm^3 have been fabricated from the in-house grown Nd:$GdVO_4$ crystals. Their lasing performance has been evaluated using plane-plane mirror geometry with 808 nm pumping, after anti-reflection coating of the elements. The laser output power obtained at 1064 nm was 4.57 W at 11.94 W of pump power (slope efficiency 49.7%) for the [100] oriented elements, and 2.7 W at 11.2 W of pump power

(slope efficiency 39%) for the [001] oriented elements. The beam profile of the output laser beam was nearly Gaussian.

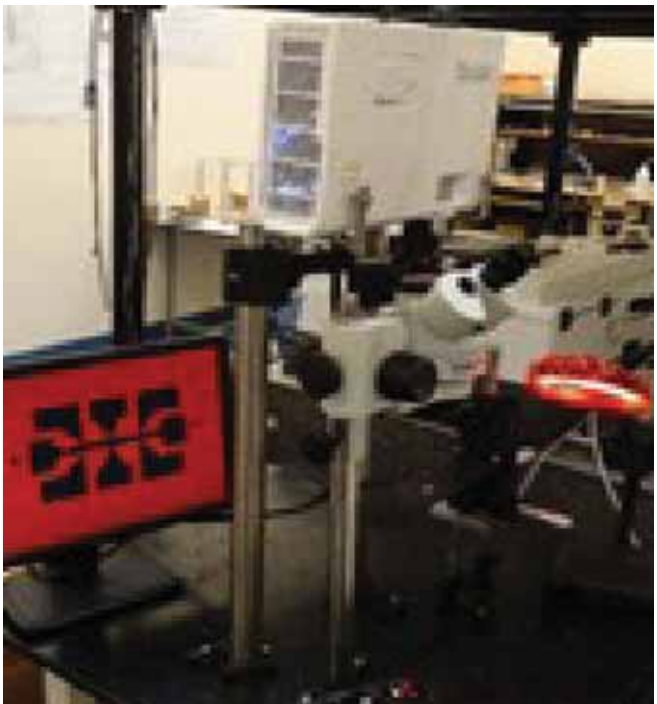
Platinum loaded carbon aerogel (Pt-CA) based Dixon ring catalyst is being explored in collaboration with HWD, BARC for Combined Electrolysis and Catalytic Exchange (CECE) based heavy water decontamination process. A set of Pt-CA based Dixon ring catalyst (2000 numbers) have been synthesized at LFMD, RRCAT and tested in LPCE (Liquid Phase Catalytic Exchange) setup at HWD, BARC. The catalyst showed higher activity in terms of Height of Transfer Unit (HTU), as compared to the existing 4.1 m for the Raschig ring catalyst.

In-house synthesized Au-ZnO nano-composites have been used for efficient photocatalytic degradation of various organic dyes. The effectiveness of the technique was demonstrated for complete degradation of an effluent from a textile industry. The technique holds promise for its application in the treatment of effluents in textile industries.

Development of high speed non-volatile memory based on resistive switching is currently of great research interest. In this regard, a new scheme has been devised to achieve fast reset process with switching time of 400 ns (comparable to set switching time of 180 ns) in Au/TiO_2/Pt devices. Observation of fast resistive switching (100's of ns) in TiO_2 thin films may find applications in development of next generation high speed resistive switching memories.

A simple, compact and inexpensive mask-less photolithography system has been developed indigenously by using a commercial projector and an optical microscope. Many patterns have been developed with a minimum feature size of 20 μm. The setup has been used for developing various semiconductor devices like laser diodes and photo detectors. The system is extremely useful for applications where feature size requirements are rather moderate and frequent changes in size/shape of patterns are expected.

Radiation hard GaAs detectors with high responsivity of 0.58 A/W at 869 nm have been developed indigenously. The developed detectors have been coupled with a preamplifier for measuring the



Mask-less photolithography system

degree of circular polarization of light emitted due to the spin polarized electrons in a AlGaAs/GaAs quantum well. Subsequently, electron spin relaxation time of 50 ps (± 3.5 ps) has been measured for GaAs/AlGaAs quantum well sample.

An experimental set up has been developed for quasi-simultaneous measurement of the photo-induced ISHE voltage (V_{ISHE}) and degree of circular polarization of photo-luminescence in III-V semiconductors. A spin Hall device has been fabricated in heavily doped n^+ GaAs using an indigenously developed mask-less lithography set up, and V_{ISHE} has been observed to be enhanced by several times, as compared to what is generally obtained in low doped samples under identical conditions.

GaN metal-oxide-semiconductor ultraviolet photodetectors with high k dielectric (ZrO_2) insulating layers have been developed. The dark current of Au/ZrO_2/GaN photodetectors has been reduced by an order of magnitude, while their photo response is clearly enhanced in comparison to Au/GaN based devices, implying a superior performance.

At TIFR, experimental demonstration of bandwidth enhancement was done in Josephson parametric amplifiers, with quantum-limited noise, beating the

standard gain-bandwidth limit. Functioning of a fully programmable three-qubit superconducting quantum processor with all-to-all coupling was demonstrated. First truly broadband, plasmonic quasicrystal was demonstrated. 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 also demonstrated. Tunable graphene superlattice was fabricated and studied. InAs nanowires were studied to probe their electrical, mechanical and thermal properties. Extreme Magneto Resistance (XMR) was observed in $MoSi_2$ single crystals approaching almost 10^7% at 2 K in a 14-T magnetic field without appreciable saturation. Performed growth of large high-quality single-crystal (100)-oriented beta-Ga2O3 by the optical floating-zone technique. An optical tweezer based technique to understand weakly adhering systems was developed. The first-ever observation of bulk SC in pure Bi single crystals below 0.53 mK was made under ambient pressure with an estimated critical magnetic field of 0.0052 mT at 0 K. 'Exotic' magnetism was reported in a distorted kagome lattice, based on metals, viz., $Tb_3Ru_4Al_{12}$. Particle size study was reported for the first time for a Eu-based mixed valent compound.

INTERDISCIPLINARY AREAS

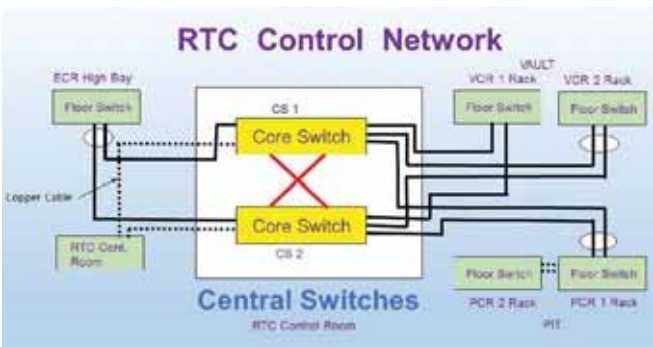
Cyclotron Control & Instrumentation

Installation of optical fiber based cyclotron control network

The operation of the Room Temperature Cyclotron (RTC) is based on a network based distributed control system. An Ethernet based control network is used as the backbone of the RTC control system and the network is spread over various areas of the cyclotron such as control room, vault, pit, caves, ECR, electrical substation and LCW plant. Therefore high reliability and 24 hours availability of the control network are the key requirements to ensure round the clock operation of the cyclotron.

To meet the above requirements, a dedicated fiber-optic Gigabit reliable Ethernet LAN is installed as the backbone of the RTC Control system. This LAN is designed to cater to single switch/link failure. The architecture of the LAN is shown in Figure 1. The Central switch configured as Fail-safe stack mode is located in the main control room. There are floor switches at different locations in the RTC building. These floor switches are connected to the Central switch by laser optimized multimode fiber cable with operating bandwidth 4Gbps backbone designed as Distributed Multilink Trunking configuration.

The Installation and commissioning of the RTC control network are completed successfully within the planned shutdown period of the cyclotron. The RTC control system is being operated using this network at present.

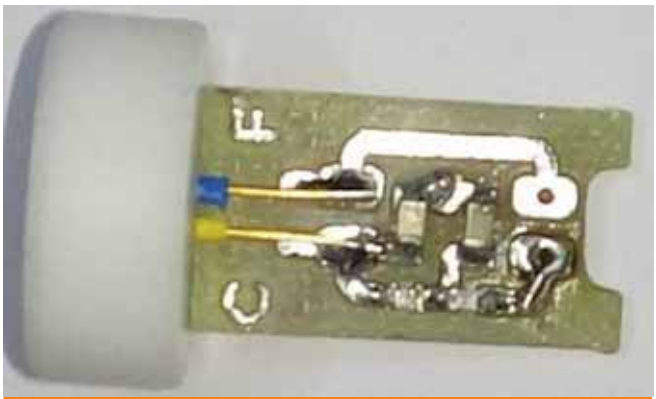


The architecture of the optical fiber based RTC control LAN

SiPM based desktop beam phase measurement system

Measurement of central phase of the ion beam with respect to RF is required to tune the cyclotron for maximum energy gain per turn and efficient extraction. A beam-phase measurement system is developed for the cyclotrons for this purpose. The measurement system is comprised of a front-end detector assembly, a fast timing amplifier, data acquisition system and application software.

The detector assembly consisting of a SiPM (Silicon Photo-Multiplier) coupled with Plastic scintillator (BC-418), Figure 3, is designed and fabricated in-house. The Plastic scintillator is chosen for its fast rise time (0.5 nS). The fast output pulse from the SiPM is amplified using a fast amplifier. The fast amplifier having a rise time around 10 nS, shown in Figure 4, is also developed in-house using high speed OPAMP (Gain Bandwidth product of 1.6 GHz). The RF signal (6 MHz) is converted to a square pulse using in-house developed comparator module and it is used for triggering time measurement.



Detector assembly

Fast timing amplifier

The phase information of the ion beam is measured as the precise time difference between the processed SiPM output signal and RF zero-crossover. A high-speed digitizer (sampling rate of 1GS/s) with digital CFD (Constant Fraction Discriminator) is used for measuring the precise timing information. An application software comprising of a GUI, shown in Figure 5, for displaying the phase information and a back-end process for acquisition and processing of raw data is developed in-house. The system is tested in laboratory and a time resolution of less than 1nS (i.e. less than 3 degree for 8 MHz RF) is achieved.

EPICS based ALARM annunciation system

Alarm annunciation system plays a crucial role in the control systems of complex machine like cyclotrons during commissioning and routine operation. It provides discrete state information of important machine parameters to the operators as audio-visual alarms. The time stamped discrete state e.g. faulty or healthy information of various machine parameters with time stamped operators' message is a useful tool for fault analysis in such machines. The existing annunciation systems of RTC and SCC are not equipped with inbuilt facility for event driven logging of time stamped alarms into centralize control database. In view of the above, an ALARM annunciation system with embedded EPICS interface has been designed and developed.

Indigenous development of 16-channel CSA ASIC (Application Specific Integrated Circuit) for nuclear physics applications

VECC has indigenously designed and developed its first ASIC (Silicon No: VECC-001) for in-house nuclear physics applications. The design, fabrication and testing of the 16-channel Charge Sensitive Amplifier (CSA) was undertaken to support the front-end electronics of three different detectors for CPDA and GMDA to be used in the nuclear physics experiments using cyclotrons.

VECC has indigenously designed and developed its first ASIC

ASIC is handed over by Director, SCL to Director, VECC

The ASIC has been handed over by Director, SCL to Director, VECC on May 18, 2018 at SCL, Chandigarh after successful fabrication and packaging. Semiconductor Laboratory (SCL), Chandigarh, under the aegis of Department of Space, is the only deep sub-micron CMOS fabrication facility in our country and this successful effort of design and fabrication of ASIC is done indigenously and it truly marks the spirit of Make-in-India campaign.

Software for dose evaluation and report generation

The software development for dose evaluation and report generation was carried out to bring harmonization among the TLD Laboratories responsible for external personnel monitoring for radiation workers. It is also aimed to implement the revised dose evaluation algorithm and generate the dose report for various institutions. This development was carried out by the Computer Division of VECC with the inputs from BARC. The software generates dose reports of personnel, for the specified time period in HTML, PDF. It also generates reports in SBAT data format, used by NODRS (National Occupational Dose Registry System) for dose monitoring. The software also can be used to check basic dosage statistics of institutions during a given time frame.

At TIFR Centre for Interdisciplinary Sciences, Hyderabad**,** in Biological Sciences, a microscopy-based assay was developed for determining cell cycle stages over large cell numbers. It was found that the Golgi apparatus changes its polarity from apico-basal to front-to-back orientation, with respect to nucleus. It was observed that the cells migrating out of a tumour are in a cluster of 5-8 cells or as single cell. In NMR Spectroscopy, asynchronous recoupling schemes in solid-state Nuclear Magnetic Resonance (NMR) under Magic-Angle Spinning (MAS) were introduced exploiting the symmetry of the internal spin interactions. In Material Sciences, researchers have grown Bi2Se3, a 3D TI material, in the Molecular Beam Epitaxial growth chamber. Under Theoretical Physics, systematic computer simulation studies elucidated that apart from long time relaxation processes (á relaxation), short time dynamics of the supercooled liquid, known as â relaxation, plays an important role in controlling the stability of the model polymer. In Theoretical Chemistry, the MolDis big data analytics platform was launched and had been made publicly accessible in May 2018. The project strives to generate and collect datasets relevant for experimental/synthesis research activities across the TIFR centres. In Synthetic Chemistry, a study elucidated the synthesis and molecular structures of various magnesium (II)-phosphate monoesters. The planning, indenting, construction, instrument installation and validation of the Specific Pathogen Free (SPF) mouse facility at TIFR Hyderabad was initiated and successfully completed.

INTERNATIONAL RESEARCH COLLABORATION

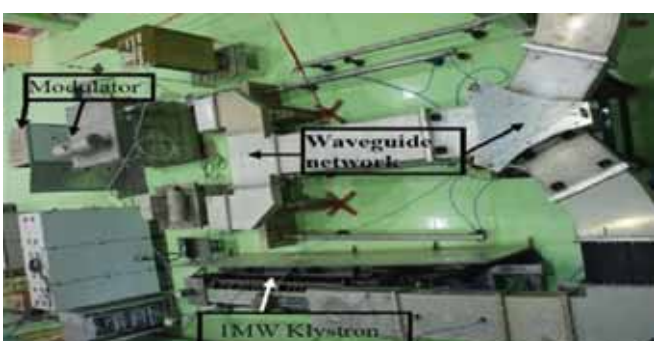
TIFR scientists participated in all aspects of the CMS experiment: data collection, monitoring, analysis, detector hardware construction and grid computing. The TIFR grid computing facility has played a major role in processing both collision and Monte Carlo data sets. Members of the CMS collaboration at TIFR participated in precision SM measurements to study properties of jets and vector boson production, single top production in association with Higgs, diHiggs production, b-physics related measurements and the landmark measurements of Higgs boson coupling to top quarks. The TIFR-Belle group continued to play a leading role in the analysis of e^+e^- collision data recorded near various Ò(nS) resonances with the Belle detector at the KEK B-factory in Japan. In Belle II (an upgrade of the former), during its Phase II or 'commissioning' phase between April and July 2018, the experiment collected about 500 pb^{-1} of data. The group was closely involved in the analysis of the Phase-II data of Belle II. A complete set up for the first atom-interferometer in the country employing laser cooled Rubidium atoms was implemented and is ready to be tested in precision measurements.

At TIFR's International Centre for Theoretical Sciences, Bengaluru the works carried out in the Astrophysical Relativity includes development of Bayesian model selection method to identify strongly-lensed gravitational-wave signals from binary black holes. It performed the first search for strongly lensed gravitational-wave merger events in LIGO-Virgo data. This resulted in null detection. It produced the combined constraints on deviations from General Relativity using the binary black hole events detected in the second observation run of LIGO and Virgo. The

centre also continued its work in other areas such as Complex Systems; Fluid Dynamics and Turbulence; Statistical Physics and Condensed Matter Physics; Mathematics and String Theory and Gravitational Physics.

At VECC, the Photon Multiplicity Detector (PMD) has been made ready to take data in Pb-Pb collisions at LHC, about 65Million events have already been collected by PMD. Two GEM chambers after successful test have been sent to FAIR-Germany for integration in the mini-CBM experiment.

At RRCAT, a 100 kV, 20 A, 1.6 ms converter type, long pulse, solid state modulator has been designed and developed for energizing a 1 MW, 352.21 MHz CERN LEP klystron. The klystron has been successfully tested using this indigenously developed pulsed modulator, and 1 MW RF power has been extracted from the klystron at 352.7 MHz. The droop and variation of the RF pulse was within ± 1%, and the phase stability of the RF output power within the pulse, and pulse-to-pulse, was less than ± 2.5 %.



Top view of the RF test stand of 1 MW LEP klystron

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.

Construction and commissioning activities are moving fast at ITER site. Several contractors are working at present for the completion of civil works, piping network and plant-systems. Live webcam is relaying updated information continuously. Tokamak complex has reached up to its 'movable roof' level and installation of piping and HVAC inside will start soon. The ITER Council met in Nov'18 to review the progress of the project, which reported 58% physical progress by the end of October 2018. Following CCS approval, a discussion was taken up by India's IC members with DG, ITER on how to reduce Cash contribution by making additional in-kind contributions. This seems possible as per the provisions of the ITER Agreement.

From the beginning of the project in 2007, a total of 14 Procurement Arrangements (PA) have been signed. Eleven major contracts for the manufacturing of ITER components have been signed till date. Significant progress has been made by ITER-India for delivery of Cryostat, cooling Water System Components & Cryogenic Distribution Lines to the ITER Project at Cadarache, France. Site acceptance test of one 100 kV High Voltage Power Supply, made in India by M/s ECIL, has been completed at Padova, Italy. Other systems are reporting good progress in works.

Largest capacity chillers ever made in India for ITER

7.2MW, 100kV Power supply at RFX, Podova, Italy

CHAPTER

6

RESEARCH EDUCATION LINKAGES

Signing of MoU between HBNI and J.B.Joshi Research Foundation

ATI Workshop on Mentoring: Faculties with Participants & ATI Staff

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 Development and knowledge management is done 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 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. During the year 2018-19, 231 PhD degrees and 176 M.Tech degrees were awarded by HBNI. Till March 2019, HBNI has awarded 1363 Ph.D degrees in a variety of disciplines and 1236 M.Tech Degrees. While the PhD degrees have, so far, been awarded mainly in science and engineering, PhD programs have also been initiated at NISER in the domains of statistics and humanities, and these will make HBNI even broader based in terms of research. Similarly, MSc programs in Nuclear medicine & Molecular Imaging Technology, as well as Hospital Radio Pharmacy are being started. All the academic programs of HBNI have the approval of the concerned statutory authorities and their guidelines are scrupulously followed.

The academic programs of HBNI are leading to Human resource development not only in core areas of nuclear science and engineering but also in several other areas of societal importance such as medical and health sciences. During 2018-19, HBNI awarded 66 MD, 21 DM and 23 MCh degrees. Till March 2019, HBNI has awarded a total of 332 MD, 106 DM and 122 MCh degrees, contributing significantly to the number of specialists in oncology in the country.

In the 2019 NIRF (National Institute Ranking Framework) exercise, HBNI was placed in the 17th position among 303 Universities, and 30th position among 1479 institutions in the overall category. The number of publications in reputed journals by HBNI faculty and students registered a healthy increase. The total number of journal publications with HBNI affiliation during calendar year 2017, as indexed by Web of Science, was 930, whereas the corresponding figure for 2018 was 1391. Based on high quality publications in Nature Group of Journals, the Nature Index, in 2018, placed HBNI in the third position among the academic institutions in India.

During the last year, a thorough review of the HBNI ordinances was undertaken, and the Ordinances were updated to incorporate a number of guidelines that had been evolved by the Academic Council to address various academic issues and also to introduce more clarity regarding certain aspects. Ordinances were also formulated for certain new courses that have been started.

HBNI continued to make sustained efforts to enhance interactions between students of various CIs and OCC, and make the students aware of the details of the academic Governance system. A number of other student-friendly measures have also been introduced.

The soft copy of PhD thesis submitted by HBNI students are made available on the HBNI website. PhD degree certificates awarded until Dec.2018 have been uploaded onto the web server of M/s Central Depository Services (India) Ltd., as per MHRD guidelines, and these can be downloaded by students after necessary registration process. Verification of degrees can also be undertaken by CDSL. The quantum of financial support for participation in international conferences has been enhanced, and the number of students who participated in international conferences during 2018-19 with HBNI financial assistance was 87, as compared to 61 for the earlier year. Towards providing self-study materials for the students that would augment or partly substitute the course work, a set of NPTEL lecture courses covering a large number of subjects in various disciplines has been obtained from NPTEL and hosted on the Anunet website of HBNI, the Pathshala. This website also hosts videos of colloquia and technical lectures organized by Central Office.

Signing of MoU between HBNI and J.B.Joshi Research Foundation

Dr. R. Chidambaram, DAE Homi Bhabha Chair Professor and former Secretary, DAE & Chairman, AEC,addressing the audience during the Theme meeting to commemorate 125th birth years of Bose and Saha

Towards promoting excellence in academic activities in HBNI and its CIs/OCC, HBNI signed a Memorandum of Understanding with J.B.Joshi Research Foundation, to create an Endowment that would institute awards for innovative research and also Endowment lectures by eminent scientists and technologists.

HBNI organized a theme meeting to commemorate the 125th birth year of S.N.Bose and Meghnad Saha on Sep. 10th, 2018, in association with BARC. In addition to a large number of faculty and research fellows, over 100 students from various schools participated in the program. A one-day meeting to commemorate the International year of Periodic Table was organized in association with BARC, on Feb.16th 2019. The program was attended by faculty and researchers of HBNI and in addition, over 500 students from various colleges in and around Mumbai participated in the program and engaged in lively discussions. HBNI also continued the program of colloquium and technical lectures. While the colloquia deal with various academic issues, technical lectures deal with specific scientific or engineering topics. Two colloquia and four technical lectures were organized by the HBNI Central office.

Training School

Human Resource Development Division (HRDD) of BARC provides highly skilled human resources to DAE through two flagship programmes–OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). Under OCES, the 1-year academic programme at each BARC TS is designed to fulfill course requirements for an MTech, MPhil or PhD degree of HBNI (Homi Bhabha National Institute). This linkage of BARCTS programmes with HBNI ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various units of DAE, and thus helping it to fulfill its main

mandate to enhance share of nuclear power in the country and to contribute to national security.

A total of 65 graduating TSOs (41 engineering+ 6 physics + 5 chemistry + 3 bioscience + 10 RSE), after successful completion of the training, were placed in various units of DAE. There were 10 Trainee Defence Officers (TDO) who passed out with this batch and they were assigned to different Divisions/Units for undertaking project for MTech. Seven fellows of OCDF 2017 scheme, after successful completion of the training, went back to their respective Divisions in BARC.

In order to promote DAE activities and thereby attract best talent to our fold, visits to as many colleges and universities as possible have been conducted during October 15, 2018 to January 20, 2019 under the outreach programme. The Online examination is planned during March 9 - 13, 2019 in about 50 cities/towns with multiple venues in cosmopolitan cities.

The 4th and 5th Training course under National Uranium Project (NUP) to Principal Investigators (PI) and Junior Research Fellows (JRF) from various universities / Colleges across the country was organized during Aug. 28-31, 2018 and Sept. 26-27, 2018. In the training course, lectures and practical training on uranium and other water quality parameters were covered for uniform methodology and quality data.

Health, Safety and Environment Group of BARC conducts One-year Diploma in Radiological Physics Course (post M.Sc. programme) under the aegis of Homi Bhabha National Institute (HBNI). It also conducts various training cum certification programmes on radiation safety in medical, industrial and research applications of radiation sources for societal benefits. The HS&EG also conducts Workshops and Exercises aimed at training of various organizations such as Defence, Paramilitary, NSG, Forensic, Civil Defence, Police, and Fire Services on Preparedness and response for Nuclear Disaster and Radiological Emergencies.

Twenty-nine Trainee Scientific Officers of the twelfth batch of BARC Training School at IGCAR have completed training in four disciplines and were placed in various DAE units. In the present academic year, twenty-three Trainee Scientific Officers are undergoing training at the Training School in five disciplines, including an additional discipline, (viz.) Fast Reactor Engineering, which has been introduced from this year. Along with the current batch of Trainee Scientific Officers, 26 Research Scholars and 6 Employees, pursuing higher studies under the aegis of Homi Bhabha National Institute, continue to do their coursework at the Training School.

BARC Training School AMD Campus, Hyderabad continued its activity wherein 15 Trainee Scientific Officers (TSO) of the eight batch (OCES-2017) completed induction training on 31-07-2018. Seventeen TSO's of the ninth batch (OCES-2018) are undergoing induction training.

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. 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.

NPCIL has strong and dedicated workforce of 11,292 employees as on 31.12.2018 consisting of Engineers, Technicians and Supervisors, Non-Technical Executives, Staff and Auxiliary support staff who spearhead the activities of the organisation. During the year 2018, as a part of annual induction program 161 young talents were recruited in Group A, B & C through direct recruitment process. In Persons with Benchmark Disabilities Category, total 26 young talents were recruited through direct recruitment process. The NPCIL (High Performers Annual Award) Scheme goes a long way in encouraging employees to push and work towards achievement of organizational goals in efficient and effective manner.

Training and Development initiatives covered competency development for fresh as well as experienced manpower across hierarchy. Besides, well developed internal training programs, customized management development programs with the involvement of professional training institutes and experts were organized for higher levels. Harmonious Employee Relations were maintained across NPCIL. 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). NPCIL has decided that the People's Capability Maturity Model (PCMM) equivalent implementation is to be initiated from one of its Stations, which contains all processes of an organization, and to gain experience for expanding it to other units in a phased manner. Accordingly, Gap Assessment was done for Narora Atomic Power Station (NAPS) and was selected to initiate implementation of PCMM equivalent for Level-2. Based on the assessment and reassessment, NAPS has largely achieved the Level-2 of PCMM equivalent.

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. 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

TMC continued to churn out trained and qualified cancer specialists who practised oncology globally. All doctoral and post-doctoral courses from 2008, were conducted under the Homi Bhabha National Institute (HBNI), a deemed university established under DAE.

The first batch of 30 students was enrolled in April 2018 for the first of its kind in India, the one-year Advanced Diploma in Patient Navigation called “Kevat”. TMC started this course in collaboration with the Tata Institute of Social Sciences (TISS) and with the support of Tata Trusts. The aim of initiating this program is to create a specialized workforce of trained professionals that would help patients manage their medical experience, co-ordinate their care and assist them to navigate through the complicated and multi-step medical system. The navigators would also be empowered to address multitude of patient needs including communication and counselling.

The beneficial TMC training of African, Sub-Saharan country doctors and nurses under the Indo-African Forum Summit III was extended for another period of 3 years. The annual fellowship and exchange programs for cancer research and education continued between King's College, London and TMC. TMC was accepted as 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).

Human Resources Development activities at RRCAT revolve around imparting training to Trainee Scientific Officers, Ph. D. Scholars, and M. Tech. students from various Indian institutes.

Administrative Training Institute

Administrative Training Institute, started functioning on 2nd July, 2007 with the motto “Prashikshaneshu Dakshprayate – Training Empowers”. ATI has been able to organize over 1000 programmes for over 27,300 participants, till date. Another major achievement of ATI is “training at doorstep” of different units. 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.

Administrative Training Institute (ATI) offers wide range of programmes starting from induction to post retirement and periodic in-service programmes and subject specific workshops ensuring depth and range.

Against 75 programmes scheduled for the

financial year 2018-19, ATI has conducted 78 programmes. This includes two programmes on Gender Sensitization & Equal opportunities in Govt. Service, Three Mandatory Induction Programmes for Work Assistants, Two Mandatory Induction Programmes for JPA/JSK, one for Administrative Staff and Seven Computer Programmes in MS Excel, MS Office, MS Access, etc.

Some of the major highlights of the ATI training programmes include one programme on GST (Goods and Services Tax), one workshop on RTI through ISTM faculty, 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 Changes, Panchgani. All the programmes were well received. Under the Management Development Programme, a one week programme for Group-A & B Officers was conducted at MCHRD Institute, Hyderabad.

The ever changing work environment has to be met not only with knowledge and skills but also with attitude. In order to bring in a holistic approach to training, new training programmes such as Workshop on Innovation, Workshop on Mentoring, MDP for Group B and C officials were also introduced. A special computer training programme for the Divyangjan (Hearing impaired) was also introduced during the year. These programmes were very well appreciated.

Workshop on Mentoring: Faculties Mr. Ashok Rao, NCBS, Bangalore, Smt. Saroja Gopal, Director, ATI & Mr. Achleashwar Singh, JD(OL), DAE with Participants & ATI Staff

Professional training for the Security Staff of the Department is another important aspect which includes induction and refresher programmes. These programmes involve field visits to DAE units.

Professional liaison and coordination by ATI has helped in strengthening network with the premier training institutes and faculty members. This helped in ensuring quality, variety and freshness in the programmes.

It has been the endeavor 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 extending the financial & technical support to various universities and research institutes across the country in the form of sponsored projects. Proposals for research projects, in the areas of interest of DAE programmes, are invited, scrutinized by expert committees and selected through a competitive process for implementation. In most cases a collaborating scientific group from one of the DAE research centres is identified for each of the projects. Over the years, sponsoring such projects has promoted research activities in various academic and research institutes in the country and has established strong academic linkages with them. Recently, in order to orient such collaborative research programmes more strongly towards the DAE mandates, the Board has been reconstituted with experts representing different themes as defined in the DAE vision document. The new BRNS Board is supported by nine focused BRNS Committees on DAE Programmes (CDPs) who are selecting and monitoring BRNS funded projects in the areas of nuclear power programme (NPP), Uranium and rare metals exploration & mining (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, 104 new research projects were sanctioned, and a total grant of ₹ 4835 Lakhs have been released for pursuing new and on-going research projects, supporting scientific publications/workshops and

financing the Olympiad Programme of training the Indian student's 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 ₹ 224 Lakhs was extended for conducting 147 scientific events. Out of these, twenty 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 Graduate Fellowship Scheme (DGFS), the former being a post-doctoral and the latter a graduate research fellowship. During the current year 19 new students were inducted under DGFS-Ph.D programme, bringing the total number of Ph.D. students enrolled under this scheme to 153. Total 63 number of students have completed their Ph.D., since the inception of this scheme. This year nine students have been awarded Ph.D degree by HBNI. The Raja Ramanna Fellowship of BRNS is intended to utilize the expertise of the retired eminent scientists for various ongoing programmes of the Department. The Homi Bhabha Chair is instituted to avail the services of Scientists and Technologists who have distinguished themselves at national and international levels. Under the Raja Ramanna Fellowship scheme, a grant for 64 scientists was disbursed, besides supporting four Homi Bhabha Chair professors.

Map indicating the country wide presence of BRNS

State-wise distribution of total 104 numbers of BRNS funded research projects during the year 2018-2019, to various Indian universities and institutions, indicates the country wide presence of BRNS.

Promotion of Mathematics

The National Board for 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.

Major activities of NBHM includes 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, Postdoctoral Fellowship (PDF); Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes.

The headquarters of the NBHM is 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 committeess 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.

Attractive scholarships have been instituted 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 / interviews. In 2018, about 50 students were benefitted from NBHM M.Sc. Scholarship. The selection of the Ph.D. scholars is based on academic records and the result of a Selection Test / Interview by a selection committee constituted by the NBHM. In the year 2018, 39 students were awarded NBHM Ph.D. Scholarship. NBHM continued to offer Postdoctoral Fellowships to selected young mathematicians who have completed their Ph.D. degree in Mathematics. During the year 2018, about 44 candidates were awarded with NBHM PDF.

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. About 10 such mathematicians were benefitted under this scheme during the year 2018.

NBHM operates a scheme to extend financial support to the libraries of various Universities and Institutions. A total of 25 such universities/institutions were provided with NBHM grant-in-aid for the year 2018. And about 85 such universities/institutions are recommended for the grant during 2019.

Under the Book Distribution Scheme, NBHM supplied selected books to Mathematics/ Statistics departments of universities/ institutes/ postgraduate centres.

NBHM provides assistance for selected research projects on the recommendations of the Committee of NBHM. The committee approved 21 fresh projects under this scheme during the year 2018.

Partial or full travel assistance to mathematicians for attending conferences, symposia, summer schools etc. within the country or abroad is provided NBHM. About 26 such applications were recommended by the committee during 2018.

NBHM provides financial assistance for holding national and international conferences/ workshops/seminars. About 30 such applications were approved during the year 2018 by the committee.

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, Mumbai. One main purpose of this activity is to support mathematical talent among high school students in the country. Indian National Mathematical Olympiad (INMO), 2018 had 939 participants and the Madhava Mathematics Competition took place in 23 regions across the country. In all 6701 students of undergraduate classes appeared for the competition.

NBHM continued to support the Visitors programme, Conferences and Mini-workshops for the Indian Women in Mathematics (IWM).

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.

During the summer vacation, active training programmes called Mathematics Training and Talent Search were also organized by NBHM outside the regular educational framework at the undergraduate level.

NBHM approved funding requirement of 45 candidates from India to participate in the International Congress of Mathematicians (ICM) 2018 held at Rio de Janeiro, Brazil during August 2018. Out of these 45 candidates, 32 attended the 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 they are Tata Institute of Fundamental Institute (TIFR), Mumbai; Tata Memorial Centre (TMC), Mumbai; National Institute of Science, Education & Research (NISER); Institute of Physics (IoP); Saha Institute of Nuclear Physics (SINP); Harish-Chandra Research Institute (HRI), Allahabad; Institute of Mathematical Sciences (IMSc); Institute of Plasma Research (IPR); Atomic Energy Education Society (AEES); Homi Bhabha National Institute (HBNI) and University of Mumbai – Department of Atomic Energy – Centre for Excellence in Basic Sciences (UM-DAE-CBS). These institutions are growing at a faster pace in terms of the projects undertaken by them.

Hon'ble Prime Minister of India inaugurated Mahamanna Pt. Madan Mohan Malaviya Cancer Centre in BHU Campus in Varanasi, Uttar Pradesh on 19.02.2019. The proposal of Tata Memorial Centre (TMC), Mumbai for 'Establishment of Homi Bhabha Cancer Hospital & Research at Muzzafferpur, Bihar has been approved by the Department on 31.07.2018. TIFR has started an ambitious new campus in Hyderabad, the capital of the newest member in the family of Indian states, Telangana. The site of the 200 acre campus, adjacent to the University of Hyderabad, has been generously made available by the state government, to nurture research and higher education in the region.

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 2018-19 for such partial financial assistance is to the tune of 2.65 crore.

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

In February 2019, HBCSE was approved as a "Centre for Excellence in Science and Mathematics Education" (CESME) under the Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching (PMMMNMTT), a scheme under the MHRD. All students selected and trained by HBCSE's Science and Mathematics Olympiad programme won awards (12 gold, 13 silver and 4 bronze medals, and 1 honourable mention) at the International Olympiads in Astronomy, Biology, Chemistry, Junior Science, Mathematics and Physics. In the International Physics Olympiad (IPhO) 2018, all 5 students bagged gold medals, enabling India to top the medals tally. This performance is the best by an Indian team in IPhO since participation began in 1998. More than 42 workshops were conducted at HBCSE and elsewhere, for around 2392 participants, which included science and mathematics teachers, teacher educators, and resource persons from identified groups of schools, and teacher education institutes.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

New web portal for online recruitment launched

A new web portal has been deployed to conduct the online recruitment for various posts at VECC. The main web portal has been developed by computer division BARC. The original portal has been customized for VECC, and additional features were added as per the VECC requirement. The web portal has been launched. The portal is currently being used for recruitment of Upper Division Clerk and Staff Car Driver (ordinary grade). The candidates can register themselves in the portal and can fill and submit the application form through their account. The forms are screened online. The portal also generates the call letters online.

Augmentation and Upgradation of IT & Computing Infrastructure

A new E-mail infrastructure with 3 rack servers and 10 TB SAN storage has been installed and commissioned with proper security safeguards and updated version of e-mail server software. E-mail service has been migrated to new setup and deployed in production. Hardware and software infrastructure of various IT services such as WWW, DNS, DHCP, Proxy server which are deployed in the Internet, have been upgraded with the introduction of virtualisation environment, HIDS solution, backup and centralised logging arrangement to ensure higher security and better disaster recovery. New symposium web server has been deployed with current version of INDICO and sufficient storage. The new symposium server (events.vecc.gov.in) has been deployed on HTTPS with SSL certificate issued by authorized CA. GPS based NTP server has been interfaced with the external DMZ through separate network port to deliver time-stamp to all the public servers (such as WWW, DNS etc.). All the servers in the external DMZ have been configured to synchronize with the GPS time server. An open-source based SNMP server with monitoring facility has been developed and deployed for IT assets. This facility is being used as a centralized server to handle the SNMP traps generated from various systems, display the reported incidents in a user-friendly graphical interface and also notify the critical events to the designated officials through e-mail. Time server and e-mail server & storage have been configured to send SNMP trap to this centralized SNMP based monitoring and reporting facility. Two new video conferencing facilities have been set up and an existing facility has been modernized and upgraded. An integrated library management system that was developed based on open-source software ("Koha") earlier was upgraded. A new HPC cluster named Himalaya, having a theoretical peak performance of 92 TFLOPS was released to the users after its successful installation and commissioning.

Installation of VECC fibre back bone and VPN connectivity to other campuses

It was decided to distribute all the critical IT services with redundancy among the Main building, C&I building and ANUNET building as a part of the disaster management plan for VECC IT infrastructure. High-speed fibre connectivity among the buildings have been established as an initial step for implementation of the plan. This fibre backbone will be used to extend the fibre connectivity to the other buildings of the VECC, Saltlake Campus. The activities of the Medical Cyclotron Project (MCP) at Chakgaria and second Campus of VECC at Rajarhat have been going on in full swing. It was required to extend the IT services and Internet connectivity to these campuses as well. The secure VPN access over the 10Mbps leased lines have been established to VECC branch offices like MCP and Rajarhat campuses.

Fibre backbone at VECC Campus

High speed outdoor fibre connectivity with Main building, C&IG building and ANUNET building has been established with 24 core armored single mode outdoor fibre cable. The fibre has been laid in a ring architecture to ensure availability of alternate path of the ring in case of either the cable discontinuity or failure of transit nodes.

Design, development & commissioning of IT security mock drill setup at RRCAT

An IT security mock drill setup to be used for conducting mock security drill exercises has been designed, developed and commissioned at RRCAT. This setup provides tools to simulate security compromising scenarios on a replicated network setup for verification of the readiness of the network security devices, and a monitoring setup for detecting/preventing possible attacks. This has helped the centre in improving its information security posture by enabling the centre to participate in the CERT-IN organized national level mock security drills, and proving its readiness at the national level.

Design, development and deployment of proactive network management portal

An authenticated network services administration dashboard for monitoring complete status of RRCATNet, including critical network, internet DMZ security servers and security applications, has been developed and deployed. This has helped in the proactive management of various network and security

components and services, thereby ensuring 99.98% uptime of the various network services and security applications.

Design, development and deployment of various information management systems

Various software systems have been developed and deployed on RRCATInfonet. These include the RRCAT Information portal and internet, which have helped to automate the application / requisition process, and the integration of centralised SMS based alert system for sending informative messages to stake holders of various information management systems on intranet and internet. The various workflow based software systems include which have been deployed include DSC enabled paperless applications like air ticket booking requests and approval processing, vehicle requisition and approval integrated with the SMS gateway, online booking and approval of RRCAT facilities, and software for online preparation and printing of PART-I and PART-II of promotion proposals. Employee related messages (salary, supplementary payments etc.), cash box, vehicle booking details, alerts for applicants for recruitment and various training programmes etc. have also been integrated with the SMS gateway. Software systems have been developed and deployed on internet for online applications like Trade Apprenticeship Scheme at RRCAT, online submission of Attestation form and Special Security Questionnaire form for selected candidates against various RRCAT recruitment advertisements. The digital dashboard on RRCATInfonet was developed and deployed as an information management tool by providing single electronic interface with consolidated data from various workflow based applications.

Commissioning of IAAS (Infrastructure As A Service) based Computing Cloud

An IAAS based computing cloud setup has been commissioned to meet the short term computational requirements of users of RRCAT. It has been deployed on RRCAT network, which has enabled scientists and engineers to quickly establish computing environments as per their requirements by simply using a web browser on their desktop machine.

RRCAT Computing Cloud hardware setup

Design, development and commissioning of SMS setup at RRCAT

The design, development and commissioning of a Short Messaging Service (SMS) gateway for sending SMS to employees, applicants etc. on their registered mobile numbers has been completed. This has helped the centre in providing instant status messages of various processes, useful information and reminder about events (meetings etc.) to concerned officials for convenient access and timely action.

Upgradation and segregation of networks in the Guest House and Hostel Complex (GHHC) and HBNI buildings at RRCAT

Computer networks in the GHHC, along with the network in the HBNI building, have been upgraded and segregated. This has helped the centre in providing controlled and hassle free internet and RRCATNet access at the GHHC, HBNI and Convention Centre buildings with necessary IT security and logging mechanisms in place.

Commissioning of a plagiarism check portal 'iThenticate'

The Scientific Information Resource Centre (SIRC) of the Computer Division (CD) has commissioned access to 'iThenticate', a plagiarism checking portal. This software is a folder-based originality checking software for research & academic documents. The facility is used to detect & prevent plagiarism in various documents being submitted by scientists and engineers for publications in journals, conferences etc., and for the submission of theses, dissertations, project reports etc. by students at RRCAT.

CHAPTER

7

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES

Compact Alkaline Water Electrolyser for production of Hydrogen

Technology knowhow and license Agreement signed by IPR & RUBAMIN Ltd., Vadodara

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 37 technologies have been transferred to 64 parties. Eleven technologies were introduced into public domain during the year. Out of these the nine new technologies were Onco Diagno Scope, Raman probe Vision Enhancement Module (VEM); Production of Tungsten metal powder and fabrication of Tungsten (W) and Tungsten Heavy Alloy (WHA); Low Temperature (10-300 K) Semi-adiabatic Heat Pulse Calorimeter; Production of Turmeric Based Nutraceutical – TURBOVITA" ; De-bittered Bitter Gourd (Karela) juice with high anti-diabetic activity; A post-harvest technology for development of Intermediate Moisture Shrimp; Banana Health Drink; Flame Retardant Cotton Cloth and RF/Microwave Substrates. Licences for 2 technologies that were renewed during the period were On-line Domestic Water Purifier based on Ultrafiltration Polysulfone Membrane and Auto TLD Badge Rader.

On the medical application front, a process to identify cancer cells using the extracellular acidity as a marker has been developed. The sensor is based on changes in the electrical conductivity of a conjugated polymer thin film upon contact with cancerous tissues has been developed. Portable sensors were developed for detection of H_2S and SO_2 gases. Synthetic diamond thin film based sensor technology for detection of H_2S was transferred to M/s Innovative Material Technologies Pvt. Ltd., Jaipur. Ultrathin SnO_2 based resistive sensors were developed for toxic gas monitoring.

A turbine blade health monitoring system has been developed in BARC. Software solution for data acquisition and signal processing related to blade health monitoring system was given to BHEL for detailed evaluation.

Compact Alkaline Water Electrolyser for production of Hydrogen

Technology for compact, low temperature alkaline water electrolyser capable of producing high purity hydrogen up to 10 Nm^3/hr and 5 Nm^3/hr oxygen has been developed. The technology was transferred to Industry.

The technology for production of tungsten metal powder in kg scale batches was developed. The process parameters were optimized for fabrication of tungsten by hot pressing and tungsten heavy alloy via liquid phase sintering. The developed technologies were transferred to M/s. R. S. Enterprises, Pune.

Technology for the 12 channel Tele-ECG (6 Vendors), Peripheral Pulse Analyzer (1 Vendor) & Body Composition Analyzer (2 vendors) was transferred.

CsI:Tl is a scintillator crystal used in gamma ray spectrometers, X-ray baggage scanners, etc. Growth of

these crystals of 50 mm size has been perfected by BARC and the technology for the growth of these crystals and fabrication of radiation detectors was transferred to M/s ANTS Innovations, Thane.

Technology of Table Top Static Gas Sensing Unit was transferred to two private firms namely M/s Theta Controls, Pune and M/s ANTS Innovations Pvt. Ltd., Thane. M/s ANTS Innovations Pvt. Ltd has received Micro, Small and Medium Enterprises (MSME) award for this product from Technology Development Board (TDB), DST on National Technology Day at Vigyan Bhavan, Delhi.

The technology for Extra-Cellular Acidity Analyzer (ECAA), a portable electrochemical sensor developed to differentiate between cancer cells and normal cells was transferred to M/s Genuine Biosystems Pvt. Ltd., Chennai. The sensor is being validated using human breast tissue samples under a MoU between BARC and Tata Memorial Centre. The cancerous human breast tissue samples show an increase in current response and higher extracellular acidity values whereas the normal tissue samples show a decreasing current with time. Further validation of ECAA is in progress using cancerous human tissue samples of different grade and stage.

A nanocrystalline SnO_2 thin film based sensor has been developed for SO_2 (range 1-100 ppm) and H2S (range 1-40 ppm) gases. This sensor is being tested for the last 6 months at ONGC, Uran plant with field samples containing various hydrocarbons (98%), CO_2 (2%) and H_2S in the 10-200 ppm concentration range. Field sample data indicated very good repeatability and reliability of the sensor response with satisfactory performance

Technologies made available through Technology Transfer Cell, VECC for commercial production includes The RFID based embedded Issue/Return System for Library Management; The RFID based Hand Held Reader for Attendance Recording; The Digital Nano-ammeter and The Digital Pico-ammeter

IPR has transferred innovative technologies to various private entrepreneurs and to some government organizations as well. The details are given below:

Technology knowhow and license Agreement signed by IPR & RUBAMIN Ltd., Vadodara

A technology knowhow and license agreement was signed between IPR & RUBAMIN Ltd., Vadodara on 5th March 2019 at IPR. The agreement covered the license of patented knowhow on 'Metal oxide nano powder production technology' on non-exclusive basis to M/s Rubamin Ltd. Zinc oxide nano powders have immense applications in the field of pharmaceuticals, paints & chemicals, fertilizer & agri-nutrients, animal health, etc. Since this technology will foster production of zinc oxide nano powders in India, this agreement contributes directly to the 'Make-in-India' programme of Government of India.

MoU between IPR & Saurashtra University for development and supply of experimental plasma systems for academic purpose, signed in July 2018. The agreement deals with the development of an experimental plasma systems for academic use. MoU between IPR & VSSC for development of electro magnet module for structural analysis software package was signed in July 2018.

COLLABORATIVE PROGRAMMES

Collaboration with industry under MoU for "Development of Radio-protector" technology, To Incorporate Segmental Impedance in Body Composition Analyzer along with Connectivity to Host PC, Incubation of production of nickel-cobalt-manganese based active cathode battery materials Development MoU of advance robotic prosthetic limbs.

A Centre for Computational Engineering and Sciences (CCES) has been created under BRNS umbrella at IIT-Bombay to support development,

maintenance and up-gradation of computational mechanics software packages and provide human resource development and education on a continuing basis. Major thrust of the centre is to provide robust quality software packages, advanced computational and visualization tools necessary for sustained development of academic programmes at IIT-B and Indian nuclear energy programme in the new millennium.

A turbine blade health monitoring system using non-intrusive technique is developed in BARC to measure the blade vibration from turbine casing. The system has been successfully used in Tata Power plant, Trombay, and Singareni Thermal Power Plant in Telangana. Software solution for data acquisition and signal processing related to turbine blade health monitoring system was given to BHEL for detailed evaluation.

SOCIETAL INITIATIVES

In order to promote technologies developed by BARC for rural populace, 6 DTDDF (DAE Technology Display & Dissemination Facility) centres were established. A total of 11 awareness meetings were held in different places. Ten agreements were signed with different organizations and individuals to promote rural entrepreneurship using BARC technologies under Advanced Knowledge & RUral Technology Implementation (AKRUTI) Tech Pack.

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 2018-19, five DAE-IPR cell meetings were held, which reviewed twenty-four new patent proposals. DAE filed twenty nine new patent applications which includes; two applications under PCT (Patent Co-operation Treaty), thirteen in India, six in USA, five in Europe and one each in Germany, Japan & China.

During this period, twelve of the previously filed patents were granted to the Department. These includes; two each in India & USA and one in Europe. Following are the list of patents granted:

A Method and System for Non-Intrusive on line Detection of Turbine Blade Condition – by BARC (in India): This invention relates to on-line detection of incipient cracks in turbine blades to serve as early warning system for turbine blade failure. It is a simple, cost effective and non-intrusive detection for assessing the health of the turbine blade during plant operation, which is important for the safe operation of the turbine in an operating power plant.

A wound dressing capable of in-situ NO_x release and a process for manufacturing the same – by BARC (in India): This invention is a wound dressing capable of in-situ NO_x (nitrogen oxides) release for treating a variety of wound conditions. The dressing when wetted by a sterile solution of sodium nitrite, releases gaseous NO_x, which has powerful antimicrobial properties. It is a cost-effective and affordable wound dressing which can be stored at ambient temperature and humidity up to 24 months and remains inactive until hydrated.

High Voltage DC Power Supply with full range 24 pulsed input and ripple free output for RF Amplifiers – by RRCAT (in USA): This invention relates to a high voltage regulated DC power supply with 24 pulse input for ripple free output for high power RF amplifier. The input system is 24 pulsed for the entire range of the operation of the power supply and input & output control system are made independent by introducing a circuit in between, making the input stored energy lower thereby avoiding the use of crowbars and input ripple filters. It could find wide industrial applications in areas where high voltage power supplies and RF amplifiers are extensively used, as in radio broadcast transmitters, fusion research, plasma heating research applications, etc.

Optical Rare-Earth doped fibre long period grating based ionizing radiation dose Sensor device – by RRCAT (in USA): This invention relates to a sensor device consisting of long period gratings made of rare-earth doped double clad fibre, for gamma dose measurement in the range of 150 Gy-2.5 kGy, in real-

time from remote locations. The sensors are passive and immune to electro-magnetic interference (EMI) and could find application in the food, fruits or seed processing industry.

A method and device for tuning Superconducting Radio Frequency (SCRF) Cavity – by RRCAT (in Europe – validated in France, Germany & Switzerland): 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 Producing Body Centered Cubic (B2) Nickel Aluminide (NiAl) Coating of Controlled Thickness on Nickel-base Alloy Surfaces – by IGCAR (in Europe – validated in France): The invention relates to a nickel aluminide (NiAl) coating of controlled thickness on nickel-base alloys surfaces with high hardness of 800-1100 Vickers Hardness Number (VHN) and dimensional tolerance of 80 ± 30 microns coating thickness. The process has minimum environmental emission of toxic chemical fumes and is thus environment friendly. The invention could find application in aluminizing nickel based alloys as a protective coating and for high temperature applications in nuclear, aircraft and gas turbine industries.

A polymer composite for extracting cesium from Nuclear waste and / or other inorganic wastes / solutions – by BARC (in Europe – validated in France): The invention relates to a polymer composite with superior properties for the extraction of active and non-active cesium (Cs) from high-level radioactive nuclear waste. The void volumes of the polymer composite is varied to obtain the desired Cs ion exchange kinetics wherein the composite material is radiation resistant, thermally stable and stable in highly acidic and alkaline medium.

Novel plasmodium protein as malarial vaccine and drug target – by TIFR (in India): The invention relates to a recombinant vaccine and pharmaceutical composition for detection and treatment of malaria for Plasmodium infection P. falciparum antigen. A diagnostic kit is also provided for in vitro detection of Plasmodium infections.

Thermal Plasma process for 'inflight' Dissociation of Zircon Mineral – by BARC (in India): The present invention relates to a one-step process to dissociate zircon in a thermal plasma reactor, using air as the plasmagen gas. The unique feature of the system is that it uses air as the working gas to generate the thermal plasma. The use of air and addition of carbon in the process ensures in-flight removal of silica thus doing away with the secondary chemical leaching step. The process yields zirconium oxide (ZrO_2), a ceramic, that is practically free from silica, and finds application in welding processes, insulating rings (in thermal processes), in dentistry as crowns, etc.

Charged thin film composite nanofilteration membranes and process of its production – by BARC (in India): The present invention relates to a negatively charged thin film nano filtration membrane(s), exhibiting differential solute rejection capacity against ionic solute(s). The invention also provides a process for the preparation of membranes with exclusive negative charge which allows the charge to be introduced during the fabrication stage. The invention could wide applications which includes; removal of partial salinity and hardness from brackish water and other usable water by removal of permanent hardness.

A Method of adjuvant treatment with Chlorophyllin containing therapeutic preparation including for Radioprotection of normal tissues during radiation therapy and kit thereof – by BARC (in USA): The present invention relates to a therapeutic kit containing chlorophyllin preparation, for preventing γ-radiation induced hematopoietic syndrome and toxicity of the lung epithelial cells in-vivo against whole body irradiation induced mortality. The invention can protect normal hematopoietic stem cells and / or sensitizes radio-resistant cancer cells to gamma radiation thereby lowering the risk of normal tissue radiation toxicity when administered to the prior the radiotherapy for treating cancer.

Process of Solvent Extraction for Separation of Rare Earth Elements (REEs) through Partial Reflux of Rare Earths in Solvent based on Separation Factor – by IREL (in USA): The present invention relates to a process of solvent extraction for separation of rare earth elements (REEs) based on multiple contacts of the REEs with a suitable solvent along with a REE as a partial reflux thereby reducing the number of stages of separation by increasing the separation factor between the REEs. The invention can help separation of REEs more economically by eliminating the need for chemical separation process for cerium separation prior to solvent extraction process.

During the same period, the following 3 patented technology were licensed to 8 companies in India.

- Online domestic water purification based on polysulfone membrane (BARC)
- Arsenic removal filter for domestic water purification (BARC)
- A purely organic, seed dressing biofungicide formulation of an improved Trichoderma Virens mutant stain with toxicological and environment safety data (BARC)

Among the new patent applications that were filed, the following were published during the year.

1. Synthesis of Fibrous Nano-Silica Spheres with controlled Particle Size, Fibre Density, and Various Textural Properties – by TIFR (in USA – App. No. 16/064,898 dated 21-Jun-2018).
2. Process of Solvent Extraction for Separation of Rare Earth Elements (REEs) through Partial Reflux of Rare Earths in Solvent based on Separation Factor – by IREL (in USA – App. No. 15/649,902 dated 14-Jul-2017).
3. A method and device for tuning SCRF Cavity – by RRCAT (in Europe – App. No. 15712694.7 dated 05-May-2015).
4. A process for the removal of 99Tc from liquid intermediate level waste of spent fuel reprocessing – by BARC (in Europe – App. 17742862.0 dated 29-May-2018).
5. A System, a Device and a Method for Passive Decay Heat Transport – by BARC (in Europe – App. No. 16704275.3 dated 15-Mar-2017).
6. An improved Method of Manufacturing Actively Cooled Accelerator Grid with full penetration Weld Configuration – by IPR (in Europe – App. No. 17188542.9 dated 30-Aug-2017 & USA – App. No. 15/709,706 dated 20-Sep-2017)
7. Multifunctional superabsorbent cotton and process for preparation thereof – by BARC (in India – App. No. 201821007235 dated 26-Feb-2018).
8. Flame Retardant Transparent liquid based on novel functionalized Graphene Quantum Dot – by BRNS Project (BARC & ICT, in India – App. No. 201821006525 dated 21-Feb-2018).
9. A Wideband Hybrid High Power MW Level CW Radio Frequency (RF) Combiner / Splitter – by IPR (in India – App. No. 201821011151 dated 26-Mar-2018).
10. MW Level CW Single Pole Double Throw (SPDT) Coaxial Radio Frequency (RF) Switch – by IPR (in India – App. No. 201821011443 dated 27-Mar-2018).
11. Splitted Plasma Anode Fire-ball based Ion Source for both nano-patterning and Thin Film deposition – by IPR (in India – App. No. 201821021321 dated 07-Jun-2018).
12. A Method for increasing the life of Cutting Tools – by IPR (in India – App. No. 201821022517 dated 15-Jun-2018).
13. Fixative Composition for Preservation and Recovery of Leucocytes of Biological Samples – by BARC (in India – App. No. 201821023662 dated 25-Jun-2018).

14. Leak Arresting Gripper for Pipes – by BARC (in India – App. No. 201821024273 dated 29-Jun-2018).

15. Displacement Decoupling Arrangement for Piping Systems – by IPR (in India – App. No. 201821029220 dated 03-Aug-2018).

16. A novel universal multinutrient soil extractant for assessing bio-availability of nutrients in soil – by BRNS – BARC & GB Pant University (in India – App. No. 201821031273 dated 21-Aug-2018).

17. A Novel Cryogenic Vacuum Producing System (CVPS) – by IPR (in India – App. No. 201821035710 dated 21-Sep-2018).

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 2018-19, about 128 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 workshop was conducted for scientists and engineers at Institute for Plasma Research Gandhinagar, and Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. Lectures on Intellectual Property Rights were also delivered at The Institute of Mathematical Sciences, Chennai, and at Sri Para Sakti College for Women, Courtallam, Tamil Nadu.

CHAPTER

8

INFRASTRUCTURE

Residential Quarters at Anushaktinagar, Mumbai

Kindergarten School at Anupuram Township

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 Facilities for Research in Experimental Nuclear Astrophysics (FRENA) Laboratories for SINP, at Bidhan nagar, Kolkata; Construction of Advanced Radiation Technology Laboratories (Iodine-125 Seed Manufacturing Plant, Low Counting Lab) for RPL, BRIT at Vashi, Navi Mumbai; Construction of Electrical Substation at Rajarhat, Kolkata; Construction of Ancillary Structure for Sewage Treatment Plant at western sector and near Brindhavan building at Anushakthinagar, Mumbai; Construction of four Stand-alone Toilets in DAE Housing colony at Anushakthinagar, Mumbai (under Swatchta Action Plan); Compost pit for Wet Garbage Waste Treatment for DAE Housing colony at Anushakthinagar, Mumbai (under Zero Waste output Programme); Cleaning Activities of DAE premises at Anushakthinagar; Construction of Substation for 312 Type VE at Anushakthinagar and Construction of Under Ground Water Tank for 312 Flats Type VE.

Frena building front & back point view

Construction of Advanced Radiation Technology Laboratories for RPL, BRIT at Vashi, Navi Mumbai

Construction of Electrical Substation at Rajarhat, Kolkata

Construction of Ancillary Structure for Sewage Treatment Plant 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 24 Flats Type IIB Building at RMP Yelwal, Mysuru, Karnataka; Construction of 48 Flats Type I & II flats for SMF at Chellakare, Chitradurga, Karnataka; Construction of

Residential Quarters at Anushaktinagar, Mumbai

Radio Therapy Block of 100 Bedded Hospital Complex at Visakhapatnam, Andhra Pradesh

Layout of LIGO India Project

100 Bedded Hospital building complex at Aganampudi, Visakhapatnam, Andhra Pradesh; Pre Project Activities of LIGO (India) Project at Hingoli, Maharastra and Construction of Buildings for AMD-AERB, UGC-DAE-CSR, RMRC & Diamond Jubilee Guest House for VECC at Kolkata.

DCSEM is also involved in the maintenance of residential flats (10169nos.) and Institutional buildings viz. DAE Secretariat, Dispensaries, AEES Schools, Community Centres, DAE Guest House etc. in Anushaktinagar, Mandala & City area, including execution of upgradation works required for these buildings. It is also responsible for operation & maintenance and up gradation 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 offices, shopping centres, community centres, etc. within the residential colony. DCSEM Security Staff continued to provide the overall Security Services for DAE residential colonies & V.S. Bhavan at Anushaktinagar, Mumbai.

PURCHASE & STORES

The Directorate of Purchase & Stores (DPS) is a service Organisation unit under DAE with a mandate to carry out the Material Management function of DAE. It has the mandate to procure the right material at the right price from the right source at the right time adopting the right procedure for Research and Development units as well as Industrial units.

Vendor development

During the year, five Vendor Meets were conducted at various units of DPS. 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 were arranged for the vendors.

Implementation of NIC e-office

To ensure that DPS is in compliance with the digital initiative taken in various Government offices, NIC e-office was introduced and implemented in DPS. Sale tender files at Central Stores Unit were converted into e-files and thereby reducing considerably time and effort for movement of files and this increased the efficiency. A

number of mails/correspondences were processed under e-office mode in CPU, DPS.

Software integration

To ensure, smooth, seamless, speedy processing of various activities in DPS the different existing software used by Central Purchase Unit (CPU), Central Stores Unit (CSU) and CAU were integrated to an extent that retrieving of data becomes easy.

Item Codification

The complete inventory of all zonal stores at BARC, Mumbai comprising of over 70,000 items were codified in the new 11-digit material codification system. The staff and officers of DPS were trained for its usage. Stores Unit RMC, 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.

Cleanliness and maintenance

Committees were formed in each group to carry out regular inspection on Cleanliness and to submit report after inspection. The said committees conducted review of cleanliness on regular intervals, carried out necessary action wherever and whenever required and prepared reports on quarterly basis. In order to maintain cleanliness especially in stores located at different places, different types of scrap were collected and disposed-off, thereby resulting in removal of waste material such as debris, garbage, waste/spoiled wood pieces. Swatchta Abhiyan programme was conducted in all units, with special cleanliness drives.

Monitoring of contracts

To ensure speedy processing of purchase files as well as timely execution of contracts monitoring of high value cases were carried out by officers of DPS at various levels. The review of files resulted in considerable reduction in lead time.

Consolidation of procurement of common stock items

To avoid duplication of work, derive economies in bulk procurement and to have better inventory management, procurement of common stock items like paper, printer cartridges were consolidated across all DAE units. The requirement of computers was consolidated at Mumbai. Medicines were consolidated at Mumbai and Kalpakkam. Rate contracts for medicine, paper and printer cartridges were operated at major DAE units covered by DPS.

Extension of e-sale

Activities relating to e-sale was extended to NRB, Tarapur and Stores Unit, IGCAR. Users and vendors were trained for the new application. The participation in e-sale tenders was more than that of conventional mode.

DAE User Meet

To sort out the issues related to procurement, regular user meetings were arranged. The issues 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

Due to experience gained over the years on procurement of various categories of items by DPS, Department entrusted the responsibility of procurement of uranium in various forms to DPS. During the calendar year, DPS has procured uranium from Canada and Kazakhstan. Discussions were also held with prospective uranium suppliers from Canada, Australia, Japan Uzbekistan and Kazakhstan for negotiation of new contract.

GENERAL SERVICES ORGANISATION

General Services Organization (GSO), 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 Schools and accommodation for the CISF personnel. GSO attends to liaison works with State Government Departments for supply of water and with BSNL for telecommunication network to the Township.

Some of the significant achievements of the Engineering Services Group, during the year 2018-19 include the following:

Signing of MoU by GSO & Tamilnadu State PWD and commencement of work for Construction of Check Dam across Palar river; Completion of first phase of Security Isolation fencing at Sadras area, Kalpakkam Township; Installation of CCTV network at salient road junctions, vulnerable locations and at the Sadras, Pudupattinam and Kuppam entry/exit gates in the Kalpakkam Township; Construction of two Tower blocks (116 Nos. Type IIB quarters) for CISF personnel; Integrated Radiation Monitoring Services Building, Kindergarten School at Anupuram Township and Additional Classrooms with provision of lift facility at AECS Anupuram; Provision of storage facility and additional output points at the Nisargruna technology based Biogas Plant; In-house Architectural and Structural Design of the second phase of proposed 100 bedded hospital at Anupuram Township; Establishing OFC cable network for networking all the Electrical substations in North PDPM and Sadras; Creation of Master Services Group multi layered drawings (Both hard and soft copies) for Anupuram Township showing all the details of the buried services like Power cables, Communication cables, BSNL cables, OFC, drinking water lines, sewage lines, fire water lines, position of chambers and valves, earth pits; Conversion of Load Break switch panel with draw out type vacuum circuit breaker panel in Master Service Substation - 2 in Kalpakkam Township; Erection, Testing and Commissioning of Fire Hydrant main for KV-1 and AECS-1 Schools and IIB Tower blocks at Kalpakkam; Introduction of Safe Street light pole climbing system for reducing the manpower requirement for street light maintenance; Introduction of online important water

Security Isolation Fence at Sadras, Kalpakkam Township

Kindergarten School at Anupuram Township

parameters monitoring system for Water Treatment Plant at Kalpakkam Township; Installation of Computerized wheel alignment facility at Autoshop.

The Medical Group of GSO effectively handled medical needs of about 30,000 CHSS beneficiaries. In addition to the regular duties, the medical officers completed the following case based analytical studies which give insight to the disease profiles of our population and throw light on specific health issues in the community:

- Comparative analysis of efficacy of desensitizing agents and other treatment modalities in the treatment of dentin hypersensitivity.
- Comparative study of the clinical outcome of patients undergoing cataract surgery by two different modalities of surgical procedures; phaco emulsification procedure and small incision cataract surgery
- Role of Steroids in Management of Chronic Rhinosinusitis and Sinonasal Polyposis.

- Clinical and biochemical profile in patients presenting with acute coronary syndrome under age 55 years in DAE Hospital.
- Incidence of fatty liver among obese children and clinical correlation with BMI, LFT and lipid profiles.
- Screening of female GSO employees above 40 years for the early detection of breast lesions.
- Incidence of new asthma cases in Kalpakkam
- Studying the pattern of lipid profile of 50 children in the age group of 11 - 18 years and the prevalence of dyslipidemia among them
- Clinical case study of the treatment of diabetic ulcers and complicated acute and chronic wounds with VAC therapy (Negative pressure and wound therapy).
- Eosinophils and Urticaria a study of correlation.
- Efficacy of Lignocaine Losengesin patients of 16 to 50 years undergoing upper GI Endoscopy

CHAPTER

9

PUBLIC SECTOR UNDERTAKINGS
(FINANCIAL PERFORMANCE)

Electronic Voting Machine with VVPAT

Smart Energy Meter

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 operational performance of ECIL is given here.

NUCLEAR POWER CORPORATION OF INDIA LTD.

The profit (Total Comprehensive Income) for the year 2018-19 is ₹ 2779 Cr. The profit for previous FY 2017-18 was ₹ 3614 Cr. NPCIL bonds continued to be rated as AAA (Highest Safety) by CRISIL and CARE.

URANIUM CORPORATION OF INDIA LTD.

The total income of the Company during the year 2017-18 was ₹ 1791.95 Cr as against ₹ 1272.7 Cr in the previous year. In terms of performance of the Company for the year 2017-18, UCIL has been rated as "Excellent" by Department of Public Enterprises (DPE) as per Memorandum of Understanding (MoU) signed by the Company with Department of Atomic Energy. The MoU targets for production of U_3O_8 for FY 2018-19 has been successfully achieved.

INDIAN RARE EARTHS LTD.

During the financial year 2018-19, the Sales Turnover achieved is ₹ 762.65 crore (Provisional) against ₹ 573.88 crore of the corresponding period of previous year and Profit Before Tax (PBT) for the financial year 2018-19 is ₹ 203.96 crore (provisional) compared to PBT of ₹ 123.85 crore of corresponding previous year.

ELECTRONICS CORPORATION OF INDIA LIMITED

Electronics Corporation of India Limited (ECIL) is engaged in the design, development, manufacture, supply, installation and commissioning of Electronic Equipment for Atomic Energy, Defence, Aerospace, Security, Information Technology and e-Governance sectors. The company has emerged as a leader in providing total solutions in Strategic Electronics and has varied multi-disciplinary competencies. ECIL has been consistently paying dividends over the past few years and is poised to leverage consistent growth in strategic electronics.

ECIL supplied Electronic Voting Machines (EVM) and Voter Verifiable Paper Audit Trail (VVPAT) to Election Commission of India for General Election 2019. The in-house developed software, secure manufacturing and strict quality control resulted in smooth conduct of elections. In addition the company has also supplied Multi post EVMs for State Election Bodies.

ECIL has been continuously investing in upgrading existing products and developing new products to meet the ever changing requirements because of the extremely high rate of obsolescence in electronics. Due to strong multi-disciplinary R&D foundations of the company, reinforced by collaborations with nation's leading R&D laboratories and academic institutions, it has been possible to achieve success in many areas of its operations.

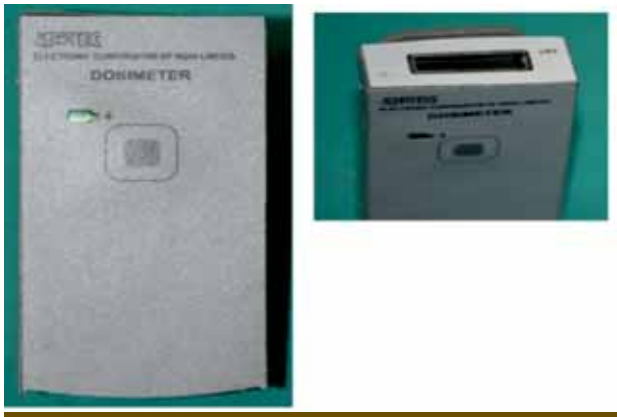
Performance

Against the MoU target of Rs.1800 crore each for production and Net Sales, the Company achieved a production of ₹ 2751 crore and a net sale of ₹ 2728 crore upto March 2019.

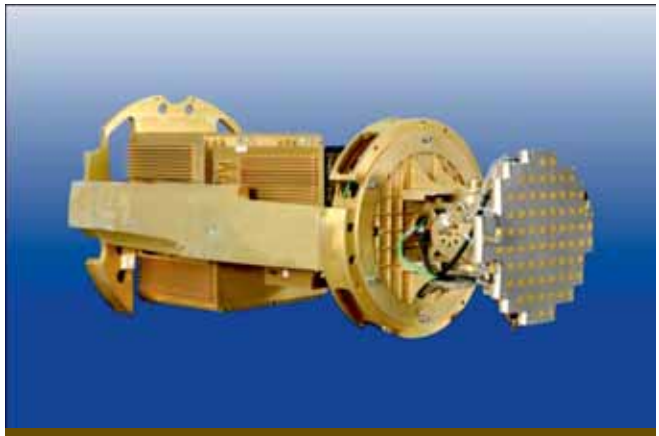
The sector-wise significant achievements during the year 2018-19 are as follows:

Atomic Energy

- Nuclear Instrumentation Package (NIP)
- Radiation Detection Equipment
- Control & Instrumentation and SCADA Systems
- Safe and Secure 32 node PLCs



Pocket Dosimeter



RF Seeker

Aerospace

- Antennas with control systems for various space programmes
- Secured Communication Network
- Rate Gyros

Antennas for various space programmes

Defence

- M7 Multimode Digital Radios
- TR 2400 Radios
- TR 3060
- Seeker
- Universal Electronic Fuzes
- Various Crypto solutions for Defence networks

Security

- Cell Phone Jammers
- Vehicle Mounted Jammers

- Online Flight Plan Management System
- CCTV
- Access Control System
- Integrated Security Solutions
- IED detectors

CCTV System

Class Room Jammer

IT, e-Governance & OTHERS

- Electronic Voting Machines (EVM) and Voter Verifiable Paper Audit Trail (VVPATs) for both ECI and State Election bodies.
- Smart Energy Meters
- IT Education

Smart Energy Meter

Electronic Voting Machine with VVPAT

Research & Development

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.

New Products Introduced

- Flash X-Ray System
- NUCON Programmable Logic Controllers (PLC)
- Pocket Dosimeters
- Portable Gamma Survey Meter
- Area Gamma Monitor with CsI/SiPM
- Class Room Jammer (EC-CrJ-6B5)

Flash X-Ray System

Area Gamma Monitor with CsI/SiPM

Portable Gamma Survey Meter

Tie-ups and Agreements

The company has entered into the following strategic tie-ups / MoUs to strengthen its activities:

- AVRORA, Russia to carry out joint project on Integrated Platform Management System (IPMS).
- Paschim Banga Society for Skill Development (PBSSD) for IT Training in West Bengal for economically weaker sections.
- C-MET & MietY for development of Super Capacitor for VVPAT application.

CHAPTER

10

OTHER ACTIVITIES

Visit of MoS General Dr.V.K. Singh at Pravasi Bharitya Divas, Varanasi

Journalist's interaction with Senior Scientists during Media Meet

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 addresses the requirements for new radiation installations in BARC.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), a standing Committee of senior officials of the Department of Atomic Energy (DAE), to oversee the Department's emergency preparedness and coordinate the response activities in case of any radiation emergency in the public domain. The cause of such an emergency could be an event taking place either within a nuclear facility or at other facilities handling radioactive materials such as hospitals or industries, an accident during transport of nuclear material or even an attempt to create chaos in public domain by malicious acts using a radioactive material.

The Crisis Management Group (CMG), which is the standing Committee of senior officials of the Department of Atomic Energy (DAE), carried out its 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 2018-19, India participated in all the five IAEA conducted International Convention Exercises, known as “ConvEx”, 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 carry out variety of emergency exercises. The numbers of such exercises monitored / participated by CMG during the year 2018-19 are Communication Exercises – 539 nos.; Fire Emergency Exercises – 88 nos.; Plant Emergency Exercises – 57 nos.; Site Emergency Exercises – 20 nos. and Off-Site Emergency Exercises – 04 nos.

CMG participated as observer and provided feedback for improvements when off-site emergency exercises were carried out at the nuclear power stations. A new template for 'Off-site emergency preparedness and response plan' for nuclear power plant sites was developed jointly with NPCIL and AERB. The plan was tried with AERB concurrence for conducting off-site emergency exercise at Rawatbhata-Rajasthan site and found more effective and satisfactory.

The “Standard Operating Procedure (SOP) for DAE officials to respond to any report / information received about suspected / unauthorized presence of radioactive material in public domain” and the

"Guidelines for public officials to handle cases of reported or suspected presence of radioactive material in the public domain" were revised based on experience feedback and issued during the year.

The 'Disaster Management Plan of DAE' prepared following the template provided by NDMA; was revised and approval was obtained from NDMA as mandated in DM Act (2005) during 2018.

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 2018, 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 62nd General Conference which was held at Vienna, Austria from 17-21 September 2018. Chairman, AEC had a number of bilateral meetings on the sidelines of the conference.

Bilateral meetings

Pursuant to the IGA signed with Japan which came into force on 20.07.2017 the first and the second Working Group meetings between Japan and India were held at DAE, Mumbai on 26/03/2018 and 06.09.2018 respectively with discussions held on possible areas of cooperation in nuclear energy.

The third Joint Technical Working Group and second Joint Committee meeting were held in Canberra Australia from 11/04/2018 to 13/04/2018 under the IGA between India and Australia.

Pursuant to the IGA signed with Bangladesh, the first Joint Committee Meeting (JCM) between India and Bangladesh was held during July 25-26, 2018 at VECC, Kolkata

Second meeting of the Joint Working Group under the MoU between GCNEP and U.K. was held during 3-5 July 2018.

The 6th Indo–US Joint Working Group Meeting was held at Sandia National Laboratories, Albuquerque, US from 6th to 8th August 2018 under the MoU signed between GCNEP, DAE and Department of Energy (USA).

First Joint Committee Meeting under the IGA signed on 9th December 2016 between DAE and Vietnam took place on 12th December 2018. There were presentations on Research Reactors, Nuclear Medicine & Equipments, Industrial Applications, Agriculture applications, cooperation in rare earths, minerals and metals by the Indian side. The Vietnamese side also gave a presentation on the Research Reactors in Vietnam. Discussions were held on scope for further cooperation in human resources training in radiation oncology, nuclear medicine and radiology. Subsequently, the Vietnamese delegation visited TMC, BARC and BRIT.

A two member delegation from Ghana visited DAE on 28.01.2019 and discussed bilateral issues. There were presentation from DAE, BARC, BRIT and NPCIL. Discussions were held on scope for further cooperation in human resources training in radiation oncology, nuclear medicine and radiology. Subsequently, the Ghana delegation visited BARC, NPCIL, AERB, ACTREC, BRIT and TAPS.

First Joint Coordinating Committee Meeting with Argentina under the Inter-Governmental Agreement signed on 23rd September 2010 was held in DAE, Mumbai on 20.02.2019. Both sides agreed for further cooperation in human resources training in radiation oncology, nuclear medicine and radiology.

The Indian side informed that Tata Memorial Centre in principle is agreeable to capacity building and training of medical staff at all levels of nuclear medicine, subject to mutually acceptable modalities to be worked out. The Delegation members also visited Global Centre for Nuclear Energy Partnership, Bhabha Atomic Research Centre, Board of Radiation and Isotope Technology, Nuclear Power Corporation of India Ltd. and Nuclear Fuel Complex.

India signed the following MoU's and Agreements during the year 2018:

An MoU between the Department of Atomic Energy of the Republic of India and the Department of Natural Resources of Canada concerning cooperation in the fields of science, technology and innovation was signed with Canada on 23.02.2018.

An MoU between the Department of Atomic Energy of the Republic of India, the State Atomic Energy Corporation "Rosatom" (Russian Federation) and the Ministry of Science and Technology of the People's Republic of Bangladesh on Trilateral Cooperation in Implementation of the Rooppur Nuclear Power Plant Project in Bangladesh signed on 01.03.2018.

An MoU was signed with VINATOM, Vietnam and GCNEP, DAE on 03/03/2018. The MoU strengthens capacity building and technical capabilities of VINATOM and co-operation in the field of atomic energy for peaceful purposes.

Nuclear Power Corporation of India Ltd (NPCIL) a Government of India Enterprise under the Department of Atomic Energy signed the Industrial Way Forward Agreement with Électricité de France S. A. (EDF), France on 10th March 2018. The Agreement prescribes a way forward for the implementation of the Jaitapur Nuclear Power Project. The Agreement was exchanged by Secretary DAE with CEO & Chairman, EDF.

An Arrangement for Exchange of Information and Cooperation in the Area of Regulation of Safe Nuclear Energy use for Peaceful purposes between the Office of Nuclear regulation (ONR) of Great Britain and the Atomic Energy Regulatory Board (AERB) was signed on 17.04.2018.

India and US signed the Project Annex II to the Implementing Agreement on 16/04/2018 at New Delhi. The Agreement opens the way for jointly advancing cutting edge neutrino science projects under way in both countries.

An MoU was signed between the Global Centre for Nuclear Energy Partnership (GCNEP), Department of Atomic Energy and The Institute for Nuclear Research and Nuclear Energy of the Bulgarian Academy of Sciences (INRNE-BAS), Bulgaria on 5th September, 2018. The MOU mainly envisages for cooperation in the fields of nuclear security and physical protection system, radiological safety studies, destructive and non-destructive assay, advance nuclear energy systems, nuclear safety and safety analysis, applications of radioisotopes and radiation technologies, radiation protection and environmental radiation monitoring and human resource development

An Action Plan for prioritization and implementation of co-operation areas in the Nuclear Field identified jointly by India and Russia was signed on 5th October, 2018. The Action Plan ensures due allocation of resources, scheduling of activities and preparation of technical and commercial proposals and further enables functioning in a more focussed manner on speedy implementation of priority areas.

An MoU was signed between the Global Centre for Nuclear Energy Partnership (GCNEP), Department of Atomic Energy and Atomic Energy Regulatory Authority (AERA), Government of Malawi on 5th November, 2018. The MoU facilitates organizing training, seminars, workshops and lectures by research experts from both sides on topical issues to develop a pool of trained human resource in the areas of peaceful uses of nuclear energy.

A renewal of MoU was signed between the Department of Atomic Energy and Commissariat Al'energie Atomique at Aux Energies Alternatives France (CEA) concerning cooperation Global Centre for Nuclear Energy Partnership (GCNEP) of India on 22.01.2019.

An MoU was signed between the Global Centre for Nuclear Energy Partnership (GCNEP), Department of Atomic Energy and the National Atomic Energy

Commission of Argentina (CNEA) on 18th February, 2019. The MoU was exchanged in the presence of the Hon'ble President of Argentina and the Hon'ble Prime Minister of India. The MoU facilitates organising training, seminars, workshops and lectures by research experts from both sides on topical issues to develop a pool of trained human resource in the areas of peaceful uses of nuclear energy.

Apart from the above the following events/exhibitions were organised by the External Relation Division, DAE:

The 15th Pravasi Bharatiya Divas Convention was held from 21 to 23 January 2019 at Varanasi, Uttar Pradesh. Constituent Units of DAE viz GMRT (TIFR), VECC, BRIT, BARC, RRCAT, ECIL, IPR, TMC and NPCIL participated in the exhibition which was organised during the occasion. Minister of State (External Affairs) General Dr. V.K. Singh visited the exhibition. The exhibition's theme this year was "Role of Indian Diaspora in building a New India".

The Department of Atomic Energy and the Ministry of External Affairs jointly organized a Conference "ParmanuTech-2019" on 6th February 2019 at Pravasi Bharatiya Kendra, New Delhi, for the foreign Diplomats based in India to showcase the activities of the Department and technologies developed for the peaceful uses of Atomic Energy. During the event, an exhibition was also organized. Constituent units of DAE participated in the exhibition along with one of the private partners. The key note address was delivered by Dr.Jitendra Singh, the Hon'ble Minister of State in the Prime Minister's Office. Apart from Heads of Foreign Missions, senior officials of DAE and its constituent units, Officials from the Ministry of External Affairs and the Prime Minister's Office graced the occasion. As a part of "ParmanuTech-2019", site visits to Bhabha Atomic Research Centre (BARC), Board of Radiation and Isotope Technology (BRIT) and Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) were arranged on 08.02.2019.

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. Following five schools that are operational at the at the Centre are School of Advanced Nuclear Energy System Studies (SANESS); School of Nuclear Security Studies (SNSS); School of Radiological Safety Studies (SRSS); School of Nuclear Material Characterization Studies (SNMCS) and School on Applications of Radioisotopes and Radiation Technologies (SARRT).

In September 2018, a MoU with Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences was signed for technical cooperation in the field of atomic energy for peaceful purposes. Also, a MoU with The Ministry of Natural Resources, Energy and Mining, Republic of Malawi was signed for cooperation in the field of atomic energy for peaceful applications, in Nov 2018. In further strengthening of the technical cooperation in the field of atomic energy for peaceful purposes, a MoU has been signed with the National Atomic Energy Commission of the Argentine Republic in February 2019.

GCNEP Phase-II construction has been planned in four packages. Under one of the packages, construction of residential complex has started in November 2018. The tendering process of remaining three packages is in Work Order approval stage. Under

Tree Plantation at GCNEP Residential Complex

Concrete pouring at Residential Complex

these packages, construction of Central Building, School Building 2 (GCNEP laboratories), Service Building and Gate House are being taken up at GCNEP Campus. At GCNEP Township, Guest House Block-B along with Dining & Recreation facilities, Service Building, Gate House, Crèche cum pre-school and Dispensary shall be constructed.

While Phase II construction activities are in progress, GCNEP continues to deliver its commitment to promote safe, secure and sustainable nuclear energy by conducting specialized programs in the domain of Nuclear Safety, Security, Safeguard and societal applications. During the Year 2018 – 19, GCNEP conducted 10 International and 2 national programs, meeting similar mandate of more than 45 countries who participated in these programs.

RTC on "Phenomenology and Numerical Simulations of Severe Accidents in Advanced Water Cooled Reactors (WCRs)"

International Training Course on the "Control of Nuclear Material in Use, Movement and Storage"

The facilities and infrastructure under operational Phase I of the Centre have also been augmented during this period to meet the functional requirements. A state of the art Sensor Evaluation Test Bed Facility (SETBF) is also being established to facilitate the participants with hands on experience during various training programs.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and CANDU Owner's Group (COG) and participating in programs organized by these agencies for enhancing the safety and reliability of Nuclear Power Plants. NPCIL is one of the founder members of WANO and its nuclear power plants are affiliated with two WANO regional centres located at Tokyo and Moscow. WANO was established in 1989 and all the nuclear power plants operating in the world are its members. NPCIL representatives are in the governing board of WANO Tokyo Centre (WANO TC) and WANO Moscow Centre (WANO MC). During the year, WANO Peer Review of NAPS and KKNPP-1&2 and WANO follow-up reviews of TAPS-1&2 and RAPS-5&6 were conducted. These reviews provided the opportunity to learn international best practices.

WANO organized eight 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. In addition, WANO conducted a training program on Design Informed Review. WANO also conducted Operating Experience Caravan back to back at NPCIL-HQ, TAPS-1&2 and KAPS for one and half day duration at each place. In the year, three 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. Some experts from NPCIL participated in peer reviews of overseas NPPs/other WANO members and had the opportunity to discuss various issues related to improvement in plant performance with experts from other countries. NPCIL continued to submit Performance Indicator data and WANO Event Reports (WERs) to WANO for IAEA safeguarded reactors. NPCIL successfully conducted Emergency Response drill exercise with WANO. NPCIL participated in some of the COG meetings held thru' audio conferences. In addition, COG representative visited NPCIL and discussed issues of mutual cooperation. Two experts participated in COG workshop held in Canada. NPCIL participated in the information exchange programme of COG and had

WANO MSM on Single Point Vulnerability and System Performance Monitoring held at NPCIL, HQ during November 12-16, 2018

access to its website which contains large database of useful operating experience information related to PHWR plants. Many persons from NPCIL participated in various meetings, workshops, seminars organized by International Atomic Energy Agency (IAEA). NPCIL continued to provide information for IAEA Power Reactor Information System (PRIS) database.

COMPUTER AND INFORMATION SYSTEMS DIVISION (CISD)

Raja Rammana Fellowship (RRF) Scheme utilises the services of active retired scientists, engineers and technologists, with experience in high quality research in specialized areas, who wish to contribute further in field of their expertise and of interest

DAE - RR Fellow (RRF) Portal: https://rrf.dae.gov.in/RRF/pc.php

TaskPro: http://10.0.1.44/TaskPro/pc.php

to the DAE. The Computer and Information Systems Division (CISD) of DAE has implemented the web-based portal rrf.dae.gov.in for online processing of applications. The portal supports nomination by Head of host Institute. List of Institutes eligible as per the requirements of RRF Scheme is also maintained on the portal. The submitted online applications are received at the DAE Secretariat for further processing.

CISD has implemented an online system - Anusankalak for collecting the periodic reports online from all the constituent Units of DAE including PSU and Grant-in-aid Institutions. Anusankalak is a role-based application which provides a user access to specific data and applications based on his role. The system is being used by SCS and Vigilance sections of DAE for collecting the data online from various Units and Institutions of DAE.

CISD has implemented TaskPro - a web-based application for a periodic monitoring of progress of a task. It enables an authorised senior-level user to create a task, attach documents or multimedia, define its peridicity for progress monitoring, and assign it to one or multiple persons. The system sends the auotmatic reminders if reports are not submitted on schedule. The system also allows to the user to search the the task and its progress reports submitted by the users.

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 27 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 16 new Disciplinary cases of Group 'A' officers. About 58 complaints were downloaded from CVC portal and 8 complaints were received through PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides, 4 complaints from CBI have also been processed. Thirty two cases have been closed with the approval of Competent Authority after necessary investigation and status has been uploaded onto the CVC portal. Fifty six complaints have been received directly in the Department. After confirming the authenticity of the complainant, necessary investigations were carried out and with the approval of Competent Authority 50 complaints were closed. Vigilance clearances were given for various purposes to 3249 Group 'A' officers of Units, Aided Institutions and PSUs as well as to the staff of 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 of CTE (Chief Technical Examiner) examination was maintained.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2018" was observed in DAE during October 29th to November 03rd, 2018 on the theme of "Eradicate Corruption – Build a New India". The week commenced with administering integrity pledge by Secretary, DAE and Joint Secretary (A&A) to all officers and staff on 29.10.2018. During the week, a workshop for Vigilance Officers/HR officials dealing with vigilance/disciplinary

Vigilance Awareness Week 2018 Observed in DAE Secretariat with the theme "Eradicate Corruption – Build a New India"

matters was held in DAE Secretariat on 31.10.2018. 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 Ganesh V. Sawaleshwarkar, Postmaster General (Mails & Business Development), GPO, Mumbai delivered a talk on 02.11.2018. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 02.11.2018. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance strives to promote integrity and eradicate corruption with the active support of all the stakeholders and believes that public participation plays an important role in fighting corruption and in nation building. As a preventive vigilance measure and to spread vigilance awareness 8 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 "Eradicate Corruption- Build a New India" was observed in NPCIL Headquarter in Mumbai and all the Units located outside Mumbai, during the Week from 29th October to 03rd November, 2018. As per directives of Central Vigilance Commission (CVC), NPCIL conducted outreach activities in 14 colleges and 42 schools. Total 4594 students from colleges and 5784 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, Wall paintings (photograph enclosed), Street play (photograph enclosed) & Speech competition etc. were held at NPCIL HQs & its sites. A short film competition was conducted at Kaiga Site. Total five groups participated in the competition. The prize winning films were 'Mithai', 'Sathya' and 'Machhar'. These documentaries were produced in-house by employees of NPCIL. These films were screened at all units. It is very effective to communicate anti-corruption message.

The CVC had envisaged a web based system of e-Integrity Pledge for citizens as well as corporates in the year 2016. Around 11,370 employees of the organization have been persuaded to take Integrity Pledge. Also 4333 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 418 contracts workers at various sites. 'Chetna' – Annual edition of Vigilance Magazine was released by Vigilance Directorate. Vigilance Report Management System (VRMS) was implemented last year. All the reports relating to inspections and complaint investigations are being submitted online through web based VRMS application. CVO and Vigilance Officers carried out 179 inspections at all NPCIL units. Seven Chief Technical Examiner (CTE) type inspections were also carried out.

Total 434 complaints were disposed of, out of which 12 complaints were investigated. Several 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 29/10/2018 to 03/11/2018. The Vigilance Awareness Week began by administering Integrity Pledge to the employees by Director, IGCAR on 29/10/2018. The theme for the year "Eradicate Corruption-Build a New India" was adequately brought out by holding Essay, Poster, Slogan and Quiz competitions. Registrar, NIT, Warrangal and Superintendent of Police, Special Investigation Cell, Directorate of Vigilance and Anti-Corruption, Chennai were invited to deliver lectures on 29.10.2018 and 02.11.2018 respectively to sensitize the employees on the dos and don'ts to eradicate corruption from public life and set a road map for New India.

OFFICIAL LANGUAGE IMPLEMENTATION

DAE and its Constituent Units, PSUs and Aided Institutions continued to carry out their activities to promote the use of Rajbhasha Hindi in various disciplines of Nuclear Science and Technology. Some of the efforts made in this direction are highlighted below:

The total strength of Hindi staff in DAE and its constituent Units, PSUs, and Aided Institutions is 133.

DAE have inspected 12 nos. of its Units/Public Sector Undertakings/Aided Institutes. The Parliamentary Committee on Official Language have inspected NAPS, Naraura; AMD, Banguluru; NPCIL, New Delhi; RRCAT, Indore.

The meetings of Joint Hindi Advisory Committee (DAE-DOS) were held on 07.05.2018 and 21.12.2018 in New Delhi.

19th All India Official Language Sammelan was held on 2nd February, 2019 in National Institute for Science Education and Research (NISER) at Bhuvneshwar. The Administrative Heads and In charge of OL from Units, Undertakings, Aided Institutions spread all over India participated in the Sammelan.

In view of promoting the use of Hindi in the Department and its Units/PSUs/ Aided Institutions, 229 Sections have been specified under Rule 8(4) of the Official Language Rules, 1976. Action is also being taken to specify some more Sections under the said Rule. Under the Official Language Rule 10(4) of OL Rules, 1976, 41 offices of the department have been notified so far.

A total 43 Seminars/Talks in Hindi on various subjects, mostly related to Nuclear Science were organized and the Souvenirs in Hindi on the proceedings of the Seminars/Talks were also brought out.

All Gazette Notifications, Cabinet Notes, Annual Reports and other documents furnished to the various

Shri Satish Iyer and Shri Y. Kamlakar being awared with mementos on World Hindi Day-2019 by Joint Secretary (R&D), DAE and Joint Secretary (I&M), DAE respectively

Committees of the Parliament, and the Agreements and MOUs were prepared bilingually.

About 2234 officers and employees were imparted training in Hindi Noting and Drafting in Hindi Workshops (106 workshops were organized). About 347 officers and employees under the Incentive Scheme for doing original noting and drafting in Hindi, 37 Typists under the Incentive Scheme for Hindi Typing and 33 Stenographers under the Incentive Scheme for Hindi Stenography were awarded.

About 154 Officials, 17 Stenographers were imparted training in Hindi, Hindi Stenography respectively & eligible candidates were given cash awards and other incentives for successfully passing Hindi, Hindi Stenography examinations.

Hindi books worth Rs. 8,43,187/- were purchased.

Department of Atomic Energy, Secretariat, Mumbai was awarded with “Rajbhasha Shield and Appreciation Letter” for doing excellent work in Rajbhasha Hindi for year 2017-18 by Town Implementation Committee (TOLIC), Western Railway.

Quarterly meetings of OLICs were held regularly and the progress of implementation of Hindi was monitored regularly through Departmental OLIC meetings. The Quarterly Progress Reports and Minutes of the meetings of OLICs of all Units/PSUs/Aided Institutions were also reviewed regularly. Hindi Week/Fortnight/ Month was organized in all offices.

DAE and its 25 establishments have their Websites in bilingual form and these are updated from time to time. Presently, there are 29,311 bilingual computers in the Department.

24 House Magazines and 10 News Letters were brought out by various establishments of DAE.

For the year 2018-19, BARC, Mumbai has received "Rajbhasha Shield" from Navi Mumbai-TOLIC for the excellent implementation of the Official Language Policy.

"Technical Translation Training Workshop" was organized for 35 Scientific Officers of BARC. Three

Shri P. Goverdhan, Controller, BARC and other delegates releasing BARC Hindi Magazine “Urjayan” in TOLIC Meeting on 26.11.2018

Shri P. Goverdhan, Controller, BARC presenting a momento to Shri S.A. Bhardwaj, Ex. Chairman, AERB on the occasion of World Hindi Day – 2019

articles in the technical and scientific category were published in Hindi BARC Newsletter. A scientific seminar was organized in Training School hostel, Multipurpose Hall on 20th February, 2019, for about 180 officials of Navi Mumbai-TOLIC member offices and Mumbai based DAE offices. BARC visit was also included in the programme. In the inaugural session of this program, the Controller, BARC, representatives of Department of Official Language and the Chief Engineer, Konkan Railway Corp. Ltd released the boolet"Standard Notings" prepared by the Hindi section of the Center. The Hindi Day-2018, World Hindi Day-2019 programme was organized successfully. A total of 8 Hindi workshops were organized during the financial year. For the excellent implementation of the Official Language Policy in the year 2018-19, BARC, Mumbai was awarded "Rajbhasha Shield" by Navi Mumbai-TOLIC on 20th June, 2019 at Training School Hostel, BARC, Mumbai.

Hindi Vigyan Sahitya Parishad is a voluntary organization of BARC, which is working to bring science to the people through the official language Hindi. The Parishad continued publication of the popular quarterly magazine "Vaigyanik". The Parishad organized National Science Seminar in Jhansi, Uttar Pradesh and Patna, Bihar. The Parishad also organized a "Health Symposium" and a scientific talk in excellent way. Pamphlets on various subjects related to DAE's activities were also prepared in bilingual form. A booklet on Swachch Bharat was prepared in Hindi.

The Kendriya Sachivalya Hindi Parishad is also a voluntary body of BARC. The Parishad organized a total of 10 competitions and official language talks during Hindi Day Celebrations. The "Hindi Sugam Sangeet Gayan Contest" organized by Parishad was liked very much.

NPCIL complies with the Official Language Policy and instructions/orders issued from time to time by Government of India. Every year Hindi Workshops are conducted by NPCIL HQ as well as at its all sites. In this financial year 4 nos. of one day Hindi workshops were conducted in NPCIL 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. One quiz competition'ABC' was organised as a part of Hindi Day Celebration on 14 September 2018.

A Rajbhasha Sammelan evam puruskar Vitran Samaroh was organized at HQ to encourage healthy competition for implementation of OL Policy. This function is organized every year at HQ and the region wise winner units are honoured with “CMD Rajbhasha Shield”. Every Month a Hindi competition is organized at NPCIL as well as at its all sites. During the year, 12 competitions were organized. The personnel of NPCIL participated enthusiastically in the competitions.

Hindi Scientific Seminars were organised at HQ as well as at its sites on World Hindi Day Celebration, 2019. The members of Joint Hindi Salahakar Samiti of the department were invited as guest faculty in these seminars.

NPCIL was honoured with DAE Rajbhasha Shield consecutively for tenth year (2008-2018). The house magazine of HQ “Urjasvi” was honoured with best Hindi Magazine among the PSUs category by DAE. NPCIL was honoured with the award for the year 2017-18 for its excellent implementation of Official Language in the category of large enterprises from Town Official Language Implementation Committee for Mumbai based Enterprises. NPCIL has been honoured with Special Award in the category of large enterprise for the year 2017-18 by an NGO “Ashirwad” which has been working for promoting and propagating Rajbhasha Hindi in Mumbai since four decades.

Rajbhasha Shield for the house magazine is being received by the NPCIL officials

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resource Division (SIRD) manages the bi-lingual official website of BARC,

Library Information Systems that includes IT infrastructure, Internet Cafe, Integrated Library Management System, Library RFID System, Digital Library (Saraswati), Retrospective Repository (D-space) Online Information Gateway (Lakshya), Remote Access Facility HOoA (Home Office or Anywhere) and Content Management System for creation & management of Information content. SIRD publishes the bi-monthly BARC Newsletter.

Under Apex project R&D - XII- N- 49 two projects are under progress viz., "Enhancement of Digital Knowledge Resources and Human Resource Development" and "Archival Centre for BARC and Enhancement of Infrastructural Facilities".

The division is the nodal agency for all activities related to INIS in India. Amongst many other services, it also provides translations of French, German, Russian, Spanish, Portuguese and Japanese scientific and technical documents as well as interpretation services and language courses for all the units of DAE.

Home Office or Anywhere (HOoA) facility continued to provide access of online subscribed library resources to BARC patron's preferred devices. More than 1000 scientists and engineers have been enrolled for this facility.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of public outreach 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:

105th Indian Science Congress at Manipur University, Imphal

DAE participated in the 105th Indian Science Congress (ISC) –Pride of India Expo-2018 exhibition held at Manipur University, Imphal during March 16-20,2018. 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. Other units of DAE that included BARC, IGCAR, UCIL, ECIL, NFC, AMD, BRIT, IPR, HWB, RRCAT & NPCIL also participated along with DAE. The focal theme of 105th ISC was "Reaching the Unreached through Science & Technology". About 10,000 visitors : students, academicians, businessmen and general public visited the exhibition.

DAE took part in the Acharya Satyendranath Bose Smarok Bigyan O Prajuct Mela from January 11-14, 2018 at Hedau Park, Kolkata. Students from around 80-90 schools of Kolkatta and its suburbs, 15 colleges and 5 universities participated in the above Science Fair.

Public Awareness Division, DAE organized the second series of Journalist's Workshop at IGCAR, Kalpakkam during March 26-28, 2018. 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 up and wherein Scientist-Journalist meet was also organized. The workshop ended with a Panel discussion and feedback from the journalists.

A National Seminar cum Workshop on the theme: Atomic Energy & Radiation for Societal Development was held during May 09-10, 2018 at Dhanamanjuri Community College, Imphal. The event was well received by students, scientists and other members of the general public. Talks on Nuclear Power, Safety, Cancer Prevention, Applications of radioisotopes in the field of food, agriculture, industry were delivered.

DAE participated in the DAE-BRNS SESTEC-2018 held during May 23-29, 2018 at BITS Pillani, KK Birla Goa Campus, Goa. The event was a platform for encouraging young students to solve real world challenges by applying science and technology.

In the 6th Indian National Exhibition cum Fair 2018 during July 26-29, 2018 DAE exhibited all the peaceful uses of atomic energy. The event was well received by the students.

To bridge the gap between Science and Society, DAE participated in the Agro Food Expo-2018 during July 27-29, 2018 at Pragati Maidan, New Delhi. DAE exhibited its activities and contributions in the areas of agriculture and food processing and provided information to several farmers, members of the rural public, scientists and private entrepreneurs who visited the exhibition.

DAE participated in 21st National Science Exhibition August 24-27, 2018 at New Barrackpore, Kolkata Achievements in the field of healthcare, agriculture, food processing and biotechnology were exhibited by DAE. Members of the academia, scientists, general public benefitted from the exhibition.

DAE-NUJ Journalist Workshop at Kaiga, Karwar, Karanataka

DAE organized the third DAE-NUJ Journalists Workshop during August 27-30, 2018 at Kaiga, Karnataka. 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. An exhibition on various technologies for better quality of life was set up wherein a Scientist-Journalist meet was also organized. The workshop ended with a Panel discussion and feedback from the journalists. The event went a long way in changing the perception of the participants.

A two day Seminar by National Association for Application of Radioisotopes in Industry (NAARRI) was held during September 10-11, 2018 at St. Aloysius College, Mangalore. Experts of DAE addressed the participants on the peaceful applications of atomic energy contributing to societal welfare. Financial assistance was also by DAE.

As desired by Honourable MP (Rajya Sabha) Shri Amar Sable, DAE put up an exhibition on the various R&D technologies in `Shining Maharashtra' 2018 a mega exhibition in Heritage Gardens, Solapur during September 25-28, 2018, organized by Sansa Foundation. The exhibition was designed to highlight and help in popularizing Science & Technology. The exhibition was witnessed by more than ten thousand visitors (students, farmers and other visitors).

DAE Exhibition at` Shining Maharashtra' at Solapur

A three day Public Outreach Programme on DAE Technologies was organized in the "International Conference on Science, Technology & Applications of Rare Earths (ICSTAR-2018) September 23-25, 2018 Tirupati. IREL participated in this event and showcased their technologies which was well received by the visitors.

India International Science Festival 2018 (IISF 2018) organised by Ministry of Science & Technology and Earth Science and Vijanana Bharati during October 05-08, 2018 at Lucknow. DAE participated by putting up an exhibition. The event was well received by students and the general public. The DAE pavilion witnessed over 20,000 visitors, mostly students.

As a part of its Public Awareness Programme, Public Awareness Division has been organizing, “DAE All India Essay Contest” for undergraduate students on topics relating to “Nuclear Science & Technology". With a view to continue this fruitful exercise, DAE organised the 30th DAE All India Essay Contest. The topics for the essay contest were: Evolution of Nuclear Power in India, Radioisotope Production and Radiation Technology Applications & Lasers and Their Impact on Mankind. The announcement was given wide publicity by contacting over 10000 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 to Mumbai to visit various facilities of DAE and to make an oral presentation of their essays. In order to generate a competitive spirit, selected students were being awarded with cash prizes.

DAE participated in the 14th Jatiya Sanhati Utsav-o-Bharat Mela - 2018 organised by Bangiya Seva Samity during December 12-16, 2018 at Sonarpur, Kolkata. An exhibition was put up on `Applications of radioisotopes in Food Processing & Agriculture'. The event proved to be a phenomenal success in evoking interest about applications of atomic energy among students and the public.

DAE participated in the 19th World Congress of Food Science and Technology during October 23-27, 2018 at CIDCO Exhibition Centre, Navi Mumbai. DAE provided information about its contributions in the areas of agriculture and food processing. Several farmers, members of the rural public, scientists and private entrepreneurs visited the exhibition.

A bi-annual Fusion Energy Conference (FEC) under the aegis of the International Atomic Energy Agency (IAEA) was held during October 22-27, 2018 at Gandhi Nagar, Gujarat. Institute of Plasma Research (IPR) was the local host for this event. DAE participated in this event and exhibited relevant technologies.

DAE participated in "Rise in Jammu and Kashmir 2018 during November 01-03, 2018 at Jammu. The event was well received by students and other members of the general public.

A three day workshop-cum-exhibition was organized by DAE at Graphic Era Hill University, Dehradun during November 13-15, 2018. Exhibition on various technologies of DAE (Bhabha Kavach, Tele ECG, Radiation Processed food, Irradiation of pulses and other spices, Water Purifier, Bhabhatron, Minerals of AMD & Non-Nuclear applications of Heavy Water Board) were put up and explained to the students. Nine talks were also delivered on various activities of DAE. B.Tech /B.Sc students of two Universities of Graphic Era and XII std. science students of neighbouring schools in

Dehradun attended the exhibition. Students interacted with the scientists and a question and answer session followed after each lecture. On the whole it was a fruitful exercise. Around 450 to 500 students attended the lectures and around 2500 students attended the exhibition on all three days. Officials from BARC, Heavy Water Board and AMD, Delhi (Northern Region) were also present to interact with the visitors.

10th Agrovision was held during November 23-26, 2018 at Nagpur 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.

Visit of Farmers during 10th Agrovision, Nagpur

DAE put up an exhibition in Ujjwal Himachal Pradesh - 2018 during December 14-16, 2018 at HPCA Stadium, Dharamshala. The event was well received by the student community and general public.

A Conference and Exhibition on Non-Destructive Evaluation was held during December 19-21, 2018 at CIDCO Convention & Exhibition Centre, Navi Mumbai. DAE gave financial assistance and put up an exhibition. BARC, IGCAR, RRCAT & BRIT participated and showcased their technologies. The event was a platform to solve real world challenges by applying science and technology.

Sunderban Kristi Mela 'O' Loko Sanskriti Utsab had organised by Kultani Milan Tirtha Society during December 20-29, 2018 Kultani, West Bengal. DAE participated in the event and provided financial assistance. The event was well received by students and general public.

The 106th session of the Indian Science Congress (ISC) was held from 03-07 January, 2019 at Lovely Professional University, Phagwara, Punjab. The Hon'ble Prime Minister of India Shri Narendra Mody inaugurated the Indian Science Congress on 3rd January, 2019. The occasion was graced by Eminent Scientists, Nobel Laureates, Dignitaries, former ISCA General Presidents, Industry Leaders, Policy Makers, Innovators, Academicians and thousands of

106th Indian Science Congress at Phagwara

national/international delegates. DAE took up 354 sq.mtrs and put up a five day exhibition along with the following units 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. Other units of DAE that included BARC, IGCAR, UCIL, ECIL, NFC, AMD, BRIT, IPR, HWB, RRCAT & NPCIL also participated along with DAE. 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 DAE under one roof. Various queries from students were attended to during the five day exhibition. The exhibition was witnessed by 1500 to 2000 visitors per day (students and other visitors).The award ceremony was held on 7th January, 2019 wherein Vice Chancellor, Chancellor amongst other dignitaries graced the function. DAE was awarded the Best Informative Pavilion by the Indian Science Congress Association and the exhibition benefited students' community and masses.

Pravasi Bhartiya Divas Jan 21-23, 2019

The 15th Pravasi Bharatiya Divas Convention was held from 21 to 23 January 2019 at Varanasi, Uttar Pradesh. Constituent Units of DAE viz GMRT (TIFR), VECC, BRIT, BARC, RRCAT, ECIL, IPR, TMC and NPCIL participated in the exhibition which was organised during the occasion. Minister of State (External Affairs) General Dr. V.K. Singh visited the exhibition. The exhibitions theme this year was “Role of Indian Diaspora in building a New India”.

Visit of MoS General Dr.V.K. Singh at Pravasi Bharitya Divas, Varanasi

Parmanu Tech 2019 – Conference on Nuclear Energy for Peaceful Purposes – February 6, 2019

The Department of Atomic Energy and the Ministry of External Affairs jointly organized a Conference “ParmanuTech-2019” on 6th February 2019 at Pravasi Bharatiya Kendra, New Delhi, for the foreign Diplomats based in India to showcase the activities of the Department and technologies developed for the peaceful uses of Atomic Energy. During the event, an exhibition was also organized. Constituent units of DAE participated in the exhibition alongwith one of the private partners. The key note address was delivered by Dr.Jitendra Singh, the Hon'ble Minister of State in the Prime Minister's Office. Apart from Heads of Foreign Missions, senior officials of DAE and its constituent units, Officials from the Ministry of External Affairs and the Prime Minister's Office graced the occasion. As a part of ParmanuTech-2019, site visits to Bhabha Atomic Research Centre (BARC), Board of Radiation and Isotope Technology (BRIT) and Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) were arranged on 08.02.2019.

DAE Media Meet at DAE Secretariat 27th February,2019

The first DAE Quarterly Media Meet was held on 23rd February, 2019. The media was invited through Press Information Bureau, Mumbai who identified and selected the senior and genuine science communicators from Mumbai and were briefed on the technology updates. The topic selected was Radioisotopes in Health Cate-Radiopharmaceuticals for

Journalist's interaction with Senior Scientists during Media Meet

Nuclear Medicine: DAE Roles and Contributions wherein Scientists (Experts) from BARC, BRIT & RMC gave a brief presentation on Radiopharmaceuticals and related Radioisotopes & Clinical Applications of Radiopharmaceuticals. This was followed by a lively interactive session. Around 14 Journalists from The Indian Express, Deccan Chronicle, The Asian Age, All India Radio, DD News, Maharashtra Times, Loksatta, Hindustan Times, Times of India, Navbharat & Lokmat, Mumbai including 2 Journalists from Rajasthan Patrika & Dainik Bhaskar,Indore attended the Meet. The meet was coordinated by PIB officials. Shri Rabindranath Mishra,IIS Director Genera (West Zone)I, PIB, Mumbai was also present on the occasion and addressed the journalists. The meet was covered by Indian Express, Hindustan Times, Maharashtra Times & Asian Age and Rajasthan Patrika. A detailed press release was put up on the website with photographs by PIB, Mumbai.

Conference on` Applications of Nuclear Energy in Food & Agriculture, Water, Industry and Sewage treatment' at PDPU, Gandhinagar, Gujarat – March 25-26, 2019

A two day conference at Pandit Deendayal

Shri K.N. Vyas, Chairman, AEC & Secretary, DAE in the Conference at Pandit Deendayal Petroleum University, Gandhinagar, Gujarat during 25th & 26th March 2019

Petroleum University, Gandhinagar, Gujarat, during 25th and 26th March,2019, was organized by Dr. R.J. Patel, RRF, DAE. Shri K.N. Vyas, Chairman, AEC & Secretary, DAE was the Chief Guest for the event. Additional Chief Secretary, Agriculture, Farmers Welfare & Co-operation Department, Principal Secretary, Higher and Technical Education, Government of Gujarat and many other dignitaries and senior scientists were present for the above event.

To communicate all aspects of nuclear power to various sections of the society, Nuclear Power Corporation of India Limited (NPCIL) has been executing series of public awareness campaigns on regular basis to convey factual and authentic information on nuclear power in a lucid, innovative and transparent manner with a multipronged communication strategy. NPCIL's public outreach

activities include regular interaction with the persons living in the vicinity of Indian Nuclear Power Plants (NPPs), organizing visits of villagers, students, opinion makers, officials from various organizations, media persons and other members of public to nuclear power plants, organizing awareness campaigns on nuclear power for various target groups like media personnel, policy and decision makers, people's representatives, state officials, students and teachers, medical professionals and the public at large. Apart from that, NPCIL is also involved actively in setting up of number of permanent nuclear galleries at the science centers across the country to provide factual information in an interesting and interactive way on multiple applications of nuclear energy. Use of exhibitions, seminars, lectures, scientific meets, distribution of public awareness publications, advertisements in print and electronic media, screening of documentary films in vernacular languages, interaction with press and media, professional tie-ups with expert communication agencies are some of the public awareness activities being carried out to promote various positive aspects of nuclear power. Use of digital and social media platforms as e-public awareness campaigns etc. are also being adopted to enhance the public perception at large, especially with young generation. NPCIL has been reaching out to an average of around 5 lakh people per month as a result of these multi-pronged initiatives.

Web based Public Awareness

NPCIL web site has been providing large amount of information on nuclear power and about the activities and achievements of the corporation.

Publications

Millions of informative & educative public awareness publications on multiple aspects of nuclear power are being distributed to general public, students, teachers, eminent persons etc. on regular basis. For maximum reach, these Public Awareness publications are being distributed in regional languages also in places where NPPs are located.

Halls of Nuclear Power

The permanent exhibitions, “Halls of Nuclear Power” have been setup at three science centers so far at Mumbai, Chennai and Delhi and became witness to millions of visitors annually. Fabrication and installation of similar galleries at other science centers located pan India are also under process.

Halls of Nuclear Power

Nuclear Power Plant Models

Five models of 220 MW Reactor unit are fabricated and installed at Jawahar Planetarium – Allahabad, Uttar Pradesh; Regional Science City, Lucknow, Uttar Pradesh; APJ Abdul Kalam Planetarium & Science Park, Sambalpur, Odisha; Solapur Science Center, Solapur, Maharashtra and District Science Center, Dharampur, Gujarat in the last fiscal. Similarly, models of 700 MW PHWRs are also fabricated and installed at NPCIL sites for public awareness activities.

Nuclear Power Plant Models

Over 54 lakhs persons, particularly students paid visit last year to these science centers located across the country.

A special documentary film "Rajasthan Parmanu Bijlee Ghar was produced and telecast in DD National Channel on 26th January

Films and Multimedia

A special short film made in association with Film Division, Govt. of India on world record of 962 days continuous operation of Kaiga Generating Station-1 was screened in English, Hindi and Kannada languages at Doordarshan (DD) News and Loksabha TV. A special documentary film "Rajasthan Parmanu Bijlee Ghar: Bharat Ki Pragati Ka Ujjaval Aadhar" on achievements of Rawatbhat, Rajasthan site was produced and telecast in DD National Channel on 26th January in Hindi and later on in other 13 regional DD Channels in total four languages, Hindi, English, Marathi and Gujarati subsequently.

The film received wide publicity through social and digital media also. Film was very well appreciated by the large number of audience.

Scientific Displays & Exhibitions

Last year, NPCIL participated in about 35 exhibitions of various levels with over 4 lakhs visitors to its pavilions. Some of the notable participations in the year were, 106th Indian Science Congress (ISC) held at Phagwara, Jalandhar, Punjab, ParmanuTech-2019 exhibition held at Pravasi Bhartiya Kendra, New Delhi, Kota Dusshera Mela at Kota including others exhibitions were also organized by various sites time to time. NPCIL participated in the 'Nuclear Reactor Technology' Exhibition on the occasion of National Technology Day organized by BARC in May, 2019 at Mumbai.

Scientific Displays & Exhibitions

Nationwide Public Relation (PR) and Media Facilitation Programme

With the view of long term sustainable nuclear power awareness program and to further enhance PA activities, series of programs have been organized at various schools and colleges of prominent cities across the 8 states i.e., Delhi, Uttar Pradesh, Rajasthan, Haryana, Gujarat, Madhya Pradesh, Maharashtra and Andhra Pradesh. Under this campaign, many activities on all aspects of nuclear power like painting competition, essay competition, debate, slogan competition, run for energy, talk shows, Question & Answer (Q&A) session, films screening, rally etc. are being organized in many schools along with massive media coverage. Besides, these activities, many articles on various applications of nuclear energy are published in various newspapers of the country under media facilitation program. Under this campaign, more than 500 positive news coverage and 100 articles on various applications of nuclear energy have been published so far with participation of around 25000 students and teachers during the FY 2018-19.

Other Programmes

The organization has also taken up many other structured programmes on public awareness on nuclear power. Significant among these is lecture series for All-India Kendriya Vidyalaya, engineering colleges, other students and faculty members. Slogan and essay writing, quiz and debate programs among others were also part of the students program. In the last fiscal 124 lectures have been delivered on nuclear power and

other useful applications of nuclear energy, covering 25 thousands students. During last fiscal 4 workshops were organized in Mumbai with association of Times of India group under Newspaper-In-Education (NIE) Programme. Special article on World Record of Kaiga Generating Station-1 achievement, was also published in Times of India's NIE Edition.

NPCIL's innovative campaign "Atom on Wheels" - a mobile exhibition - won international award under the category of "World's Best Public Communication Campaign" across the globe at 10th ATOMEXPO-2018 held at Sochi, Russia on May 14, 2018. Total 22 countries had participated in the event.

Every year, RRCAT conducts an eight week "Orientation Course on Accelerators, Laser and related Science and Technologies". The fourth edition 'OCAL-18' was conducted from May 21 to July 13, 2018. Forty post-graduate students (M.Sc., M.Tech., M.E.) from 15 states successfully completed the course, which comprised lectures, invited talks, hands-on experiments, visit to RRCAT laboratories, students' seminar and an industrial visit. The course is aimed at motivating the bright young students in the country to take up a career in science and technology in general, and accelerators and lasers in particular.

Inauguration of Fourth Orientation Course on Accelerators, Lasers and Related Science and Technologies (OCAL 2018).

Under the outreach programme, RRCAT participated in the Indian Science Congress ISC 2019, Phagwara, Punjab from January 3-7, 2019 and in the India International Science Festival at the Indira Gandhi Pratishthan, Lucknow from 5-8 October, 2018. Special events and visits were arranged for various schools, colleges and government institutes with interactive sessions and scientific experiments.

Public Outreach programs were organized by the HWP sites in nearby schools / colleges, villages, state government officials and others, to create public awareness about the peaceful uses of Atomic Energy by audio-visual presentations. Plant visits were also arranged for students in the neighborhood.

HWP, Baroda has conducted public awareness programme at Chemical Engineering department of M.S University, Vadodara.

HWP, Kota has organized lectures at Government ITI College, St. Paul's Secondary School, Shri Ram Bal Vidya Mandir Senior Sec. School, Charbhuja, Rawtbhata and in Tamlao village on heavy water production process, its various uses which included H2S safety systems & emergency preparedness, do's & don'ts during emergency situation.

HWP, Manuguru has organized public awareness programmes in Hanumat Konda, Ammagaripalli and Jaggaram villages located in the neighborhood of the plant site. Plant visits of nearby school / college students have also been organized.

At HWP, Talcher, plant visits for the Students and Teachers of of C.V.Raman College of Engineering, Bhubaneswar, Odisha's Electronics & Instrumentation Engineering and Chemical Engineering Department were arranged.

At HWP-Thal lectures were delivered & distributed pamphlets of HWB and HWP activities, to the students of different engineering colleges such as Dr. Babasaheb Ambedkar Technological University (DBATU), Lonere, National Institute of Technology, Surat; Jawaharlal Nehru Engineering College, Ahmedabad; MIT Academy of Engineering (MITAOE) Alandi, etc as a part of public awareness activities.

At HWP-Tuticorin, fire prevention lecture and demonstration was organized at St. Antony Saveriyarpuram School, Tuticorin. Various other public outreach programme were also organized for the benefit of school & college students, teachers & general public around the facility.

AMD conducted Public awareness programmes in various cities as well as in remote field

areas at 38 venues. A total of 124 events have been organised for students, teachers and general public.

VECC participated in 5 exhibitions and science fairs. Arranged 14 educational visits for the students from various schools and colleges in the vicinity of Kolkata to VECC labs since January 2018. Organized outreach seminars successfully at 12 different institutes spread across West Bengal, Bihar and Odisha with prior intimation by advertising through local newspapers in English, Hindi and Bengali.

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 is 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 major categories in which CSR projects have been taken up are: Education, Healthcare, Infrastructure development, Skill development, Sustainable development and other general projects.

Under education the projects like construction of school buildings, boys and girls hostel, class rooms, library building, balvikas sanstha, mid-day kitchen shed, boundary wall, development of anganwadis, assistance to schools like drinking water, toilets, science laboratories, play equipment, flooring in open area,

Construction of Girls Hostel at Ghata, Kakrapar site

Eye Camp at Kakrapar site

raised platform, furniture, deployment of teachers in schools, assistance to students like study materials, note books, sports kit, scholarship and sponsorship, free transport service, organising quiz etc. were taken up during this year.

Under healthcare, the CSR projects included running of primary health center, providing mobile medical van services; organizing medical, eye, ENT and special health care camps; providing medical treatment and medicines (OPD services) for villagers; training and education programme for children with special needs at Rawatbhata, funding extension of hospitals like Tata Memorial Hospitals, holistic school health care, distribution of assistive devices to disabled persons, Gym equipment for setting up gym, installation of water purifiers etc.

Cement concrete link road at Rawatbhata site

Skill development training in the field of Stitching,Kalpakkam site

Under infrastructure development, the projects like laying of approach roads, development of drinking water facility, construction of community hall, animal food storage building, RCC sheds, levelling of area, drainage, construction of bridges, installation of street lights, providing fishing facility, construction of toilets, financial assistance to fire accident and riot victims of Ranasthalam near Kovvada and Banswara respectively, baseline survey etc. were taken up.

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, poultry farming, tailoring, carpentry, welding, electrician, fitter, computers, fish pickles, farming and agriculture etc. were focused upon.

Some sustainable development initiatives were also undertaken this year. These included projects to rainwater harvesting, solid waste management facilities, installation of solar and LED Street lights, development of village ponds, ground/ underground natural water bodies, breeding of migratory birds and planting of tree saplings etc.

Roof top solar power plant at Vyara School, Kakrapar site

Swachha Bharat Mission

As per the directives of the Govt. of India, "Swachhta Pakhwada" was observed from Feb 16-28, 2019 at IGCAR, Kalpakkam. Cleaning of the office premises was carried out with special emphasis on e-waste. In order to provide a fillip to the swachhta activities of the various Divisions/Groups, a visit by the members of Swachhta Cell was organized and three best location were selected and Certificate of Appreciation were awarded during closing ceremony of Swachhta Pawkhwada. Competitions under various categories like slogan, essay and poster were conducted on the topic "clean and green environment" among employees / trainees of this Centre and prizes were distributed during the closing ceremony. On the last day of the pakhwada, guest lecture by Shri M.S.Premnath, Retired Suptd. Engineer, Chennai Corporation, Chennai on "Waste Management" highlighting the points regarding necessity of effective implementation of Waste Management was organized.

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.

BARC continued to provide the health care facilities to entire Mumbai based CHSS beneficiaries through its 390 bedded hospital, 13 zonal dispensaries, 3 occupational health centers and 24 hr. casualty facility. All the units are computerized with unique Hospital Information system.

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 wards of DAE employees 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 RTE category.

The government of India gives the right to free and compulsory education to children in the age group of six to fourteen years, under the Right to Education Act. The same is being implemented in AEES since 2015-16.

AEES has achieved significant results in its pursuit of excellence in curricular as well as co-curricular activities during the year. 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 Atomic Energy Central Schools (AECS) across the country for the safety, security and discipline related problems faced in the Schools/JCs.

Board (Xth and XIIth) Exam Results of AEES Students

About 2077 students appeared in the CBSE Board examination of Class X, in March, 2018. 26 out of 29 schools achieved more than 90% pass percentage, out of which 12 schools had a 100% result. The Quality Index is 7.19 (in 10 point scale). The overall Excellence Index is 75.49 (in 100 point scale).

About 1455 students from 16 AEC Schools and 1 Junior College appeared for the Class XII examination in March, 2018. The pass percentage is 90.79% and the overall Excellence Index is 66.74. The Quality Index is 6.34. The pass percentages of 11 Schools / Junior Colleges were above 90%, out of which AECS - Kudankulam produced 100% result.

Important achievements

Participation of Students in the Republic Day Parade at Delhi

Miss Aakruti Tiwari of AECS, Manuguru and Miss Menon Sumitha Sudheer of AECS-3, Tarapur had represented their respective NCC Directorates in the Republic Day Parade at Rajpath, Delhi and took part in the Cultural programme held on the lawns the Prime Minister's Residence on 26.01.2018.

Kum. Lakshita Manocha, Class X of AECS-2, Rawatbhata had participated in Republic Day Parade/Camp held in Delhi in connection with the Republic day celebration on 26.01.2019.

Participation in CBSE National Level Science Exhibition

Miss S. Jithya Das and Miss V. Manisha of AECS, Anupuram had participated in the CBSE Regional Level Science Exhibition from 4th January to 6th January, 2018, got selected to participate in the CBSE National Level Science Exhibition.

45th Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition (JNNSMEE)

AEES has been recognized as a separate entity by NCERT to participate at the Jawaharlal Nehru National Science, Mathematics and Environmental Exhibition, an annual event. AEES level exhibition was held at AECS, Kakrapar and the Projects from AEC Schools were selected at AEES level and the best 04 selected exhibits were sent for selection to Jawaharlal Nehru National Science, Mathematics and Environmental Exhibition organized by the NCERT held in November, 2018, out of which 03 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.

Rashtriya Kishore Vaigyanik Sammelan (Children Science Congress)

Among the 3 projects displayed at the JNSME Exhibition, 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.

19th Junior Science & Mathematics Olympiad – 2018

Atomic Energy Education Society in collaboration with Homi Bhabha Centre for Science Education (HBCSE) has been conducting the Junior Science & Mathematics Olympiad orientation programme for the meritorious students of Class X of AEC Schools located all over India. There were 60 enthusiastic participants who attended this programme from all AEC Schools across India. The toppers in the subjects of Physics, Chemistry, Mathematics and Biology were given the Sunil Mehta Memorial Awards. On the last day, an enthralling Quiz competition was conducted for the 16 students of this Olympiad programme. The students were selected through a written exam and were divided into 4 teams. The winners were awarded with Sandhya Gondhlekar Memorial Award. From this year onwards, the Quiz Competition was extended to Class IX students too which was held from 17-22 December, 2018.

AEES Excellence Examination

For the first time in the history of AEES, it has been decided to conduct an examination on the lines of NTSE for all the students of classes VII to X of all AEC Schools. The examination pattern of NTSE (National Talent Search Exam), MMS (Means-Cum-Merit Scholarship) examinations were studied and based on that the outlay of question paper and the syllabus were prepared. OMR sheets were provided to all the schools. The examination titled as "AEES Excellence Examination" was conducted on 2nd February, 2019 in all AEC Schools across the country. This has been well received by the parents.

All India AEES General Knowledge Quiz for Class VIII students

The objective of this quiz is to inculcate the temperament of reading and exploring various subjects and avenues including General Knowledge among the children. Two students were selected from Class VIII of each school. The Quiz was conducted on 24th & 25th January, 2018 at Mumbai. The winners and runners up were awarded with certificates and prizes on the occasion of common Republic Day function of AEES at Mumbai.

Dance performance in the Cultural Exchange programme with Kyrgyzstan

Cultural Exchange programme with Kyrgyzstan

Atomic Energy Education Society hosted a Cultural Exchange Event on 30th Jan 2018 at the DAE Convention Centre, Anushaktinagar. A troupe of dancers from Kyrgyzstan who were on a visit to the DAE Mumbai, were invited to showcase their talent. Each school of Mumbai also presented one cultural item to introduce our culture and dance forms to visiting foreigners.

Achievement of students in Art

All India Inter-AECS Art competition (School level) was held in AEC Schools all over India on 28th November, 2018. The selected paintings were displayed in the All India AEES Art Exhibition held on 26th January, 2019 at AEJC (Atomic Energy Junior College), Mumbai.

All India Inter AECS Science Quiz by Hindi Vigyan Sahitya Parishad and All India Inter AECS

English Debate for Junior and Senior Groups (National Level)

The preliminary round (Zonal level) of this contest was conducted at AECS, Narwapahar (East Zone), AECS, Narora (North Zone), AECS-1, Tarapur (West Zone) and AECS, Mysore (South Zone) on 24th August, 2018. The winners of Zonal level competitions participated in the National level competition held at Central Complex auditorium in BARC on 26th November, 2018. AECS-1, Mumbai were the top winners of the competition.

AEES conducts the All India Inter-AECS Debate in Hindi or English (on alternative year basis) for Junior (Classes IX & X) and Senior (Classes XI & XII) groups. The Zonal level Debate (English) was held along with the Science Quiz in Hindi at the places mentioned above. The National level debate was held in Mumbai on 27th November, 2018. AECS, Narwapahar and AECS, Mysore were the top winners for the junior and senior groups respectively.

All India Inter-AECS Cultural (Dance) Meet

All India Inter-AECS Cultural (Dance) Meet for Junior & Senior category of students was held in AECS-1, Tarapur from 3 to 7 December, 2018. Students from all the AEC Schools and Junior Colleges from across the country participated in the competition. Prizes were distributed to the winners of various events.

Workshops, Seminars and Orientation Programmes

Vigyan Pratibha Programme

'Vigyan Pratibha' is a major talent nurture programme in Science and Mathematics for high school students initiated by the Government of India. The Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research (HBCSE, TIFR) is involved in this initiative, which was formally launched on 31st July, 2017 at HBCSE, Mumbai. Follow-up workshops for Science & Mathematics teachers were held during January 15-18, 2018 at HBCSE, Mumbai and during January 8-11, 2019.

In-Service Training Programme

The concept of an In-Service training 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 Zonal Institutes of Education and Training (ZIET) and other KVs, for imparting training of quality and value to our teachers. In continuation of the successful completion of the First and the Second Spells held in the Academic Year 2017-18, the First Spell of Training was successfully held for PRTs, TGTs & PGTs at ZIET, Mumbai and at various other KVs starting from 14th May to 28th May, 2018. The second spell of the training was held between 23.12.18 to 01.01.2019. Total 76 number of teachers in various categories attended the programme.

Trophies and Awards

The Cluster level selection process for AEES awards for the staff of AEES was held at various centres and the final selection process was held in Central office, AEES in December, 2018. These awards (15 at Central level and 07 at Cluster level) for the outstanding teaching and non-teaching staff were conferred on the Republic day function on 26th January, 2019 in Mumbai. The trophies to the best AEC Schools and Junior Colleges in various categories like Dr. Homi Bhabha trophy for the best Overall performance, Dr. Vikram Sarabhai trophy for the best Scholastic performance, Dr. Raja Ramanna trophy for the best Co-Scholastic performance and Dr. Homi Sethna trophy for the best performance in Sports and Games were conferred on the occasion of the Republic day function on 26th January, 2019 in Mumbai.

Celebrations

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. Shri S. Sarkar, Chairman, AEES, the Chief Guest of the function hoisted the National Tricolour on the occasion.

Various awards given on this occasion were as follows:

AEES awards (National Level) for the outstanding teaching and non-teaching staff were conferred to 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 those who participated in the Republic Day Parade/Rally being held on 26th January every year.

"Souradip Ghosh Memorial Award" offered by Shri S.K. Ghosh, for the meritorious students who perform 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).

Swachh Bharat Abhiyaan (Cleanliness Drive in Schools)

For the past 3 years, there has been plenty of enthusiasm for the nationwide cleanliness campaign, 'Swachh Bharat Abhiyaan' in India. AEES too took lot of initiative and participated in this campaign. Various activities were conducted like Slogan writing competition, wall painting, swachh bharat rally, Painting & Essay writing competition, 'Say no to Plastic' campaign, Street play, fancy dress competition, plant a tree campaign, composing song/poem on swachhta and display of projects based on the theme 'Science and Swachhta' from 16th to 28th February 2018 in all the AEC Schools. Same activities were also conducted in February 2019.

Street play on "Importance of Swachhta" in the vicinity of the School by Students

4th International Day of Yoga

The 4th International Day of Yoga was celebrated with great enthusiasm in AEES, on June 21st, 2018. Yogasanas and Pranayam were performed under the guidance of learned yoga experts in which students of various age groups and staff members of the schools participated enthusiastically across the country in all the AEES Schools. A separate programme was arranged at the auditorium in AEJC, Mumbai where Chairman, Secretary and the administrative and academic staff of AEES participated. Renowned yoga experts conducted an interactive session on Yoga and its benefits for the staff members of AEES and the teachers and non-teaching staff of AECS / AEJC, Mumbai. The entire student, teaching and administrative fraternity showed great vigor and enthusiasm in practicing Yoga and the programme was a grand success in its mission of creating increased awareness and interest in Yoga.

Yoga day celebrations

Hindi Pakhwada - 2018

Hindi Pakhwada - 2018 for the AEC Schools of Mumbai and Central Office, AEES was celebrated from 17th August to 10th September, 2018 during which several Hindi competitions were conducted like Hindi Essay writing, Poster & Slogan, Hindi Kavya Path, Hindi Typing and Hindi Kavitha Lekhan.

AEES Goes Online

Training Need Analysis

Training needs analysis is the first stage in the training process and involves a procedure to determine whether training will indeed address the problem which has been identified. AEES has launched an online portal for assessing the Training Needs of its employees.

Online AIPR (Annual Immovable Property Return)

For the first time in the AEES, employees were enabled to file their Annual Immovable Property Returns online. All the employees of AEES used this facility.

On-line Recruitment: Application & Screening

The application process for recruitment in the AEES was made online. More than 2500 applicants applied through the Online Application & Screening portal launched by the AEES in March, 2018. This has been done through www.mahaonline.gov.in. Through individual log in, the candidates were able to check their results.

Tendering for Cosmetic Maintenance Online

The Notice Inviting Tender (NIT) for cosmetic maintenance of all the schools and the central office in Anushaktinagar has been executed online through www.tenderwizard.com.

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 years now. Special emphasis is being put for the overall development of school children and events & activities were also undertaken for the same. 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 2018-19 are as follows:

About 1000 employees participated in the Inter DAE meets which aim 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. are also selected during the meet.Participation of all DAE units are 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. Events of XXXIV Annual DAE Meet, namely Athletics,

Athletics' Meet

Badminton Tournament Winners

Swimming Competition Winners

Bridge Tournament Winners

Badminton, Cricket, Cultural (Poetry/Drama), Table-Tennis, Swimming, Ball Badminton, Hockey, Bridge, Carrom, Basketball and Volley Ball were completed successfully during the year 2018-19. 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.

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 preliminaries 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.

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 – 2018 was organised from 1st May to 31st May 2018 and total 370 people participated in this. Twelve regular Yoga Classes are conducted in Brindavan Yoga Hall. Total approx. 400 participants attend daily Yoga Classes. Programmes were arranged on 21 June-2018 to celebrate International Yoga Day on a Grand scale.

DAE S&CC and NPCIL Sports & Cultural Committee, TMS, Tarapur had successfully organised 4th National Yoga workshop on the theme "Yoga for Stress Free Life" on 10th and 11th February, 2018. This workshop was organised at TAPS residential colony and was a grand success. This two days workshop was focussed on understanding the causes of stress, symptoms, effect on human health and ways to remain stress free even in difficult situations in life.

Under Nature & Adventure related activities, Team Girisanchar of DAE S&CC has arranged various

Himalayan trekking expedition

Members of Bhagirathi-II - High altitude Himalayan Mountaineering Expedition

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. Girisanchar-30 (30th All India DAE Trekking Expedition) was held in Tamhini-Bhira region from January 12th to 25th 2019. Himalayan trekking expedition (Trek the Himalaya-10) was organized in Kuari Pass region. Also, Seven members (All members of Team Girisanchar), participated in Bhagirathi-II – High altitude Himalayan Mountaineering Expedition held in "'Gangotri Region of Garhwal Himalaya " from 12th May 2018 to 30th May, 2018. Four members (Shri Arjun Patil, Shri MangeshKhamkar, Shri Sandesh Palshetkar and Shri S. Jaiswal) has reached the altitude of 6270M close to Bhagirathi-II summit (6512M).

DAE Cultural Centre has initiated various activities like Dance, Drama, Music, Literature, Traditional Art, Films, photography workshops etc. Training initiatives in Hindusthani 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.Seminar titled "Jo baatTujhmein Hai" on Music Director Roshanwas held on 18th Feb 2018, at Training school hostel and was attended by 106 participants. Programmee was inaugurated by Dr R.K Sinha former Chairman AEC and secretary DAE.

India-Russia Cultural Fest

Under India-Russia Cultural Fest, the DAE Sports and Cultural Council hosted a 'Festival of Science and Culture' in collaboration with M/s ROSATOM, Russian State Atomic Energy Corporation, on 28th October 2018 at DAE Convention Centre. This grand extravaganza included arts festival, interactive hypothesis/quiz competition, extempore speech competition, interactive sessions with Russian cosmonaut, screening of edutainment documentaries. The evening witnessed a fabulous cultural show by DAE Cultural Centre (for India) and a mesmerising 60 minutes dance ensemble by the famous 'KALINKA' group from the Russian Federation.

DAE Cultural Centre successfully conducted 2nd Annual Concert Performances by 'Students & Faculty of DAE Cultural Centre'. The response for the event was overwhelming.

Taberik-Kauhar, a Dance ensemble by Troupes from Kyrgyztan was organized by DCC on 28th Jan, 2018 at New Committee Centre. The event received an overwhelming response.

DAE Cultural Centre organized a 'One Day Basic Digital Photography'Workshop at Multipurpose Hall, TSH, Anushaktinagar on 29th September 2018. The workshop covered basis aspects of digital photography by speakers Debmalya Mukherjee and Vilas Parab including some hand-on training on splash photography. This workshop was attended by 54 participants.

DAE Sports & Cultural Council & BARC Staff Club jointly conducted Anushakti Monsoon Marathon 2018 (AMM 2018) on Sunday 7/10/2018 and got overwhelming response.

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 Sports, fitness, cultural cum community centre (New Community Centre) at Anushaktinagar as a demonstration model community center on a self-supporting basis as an example to all other units; Support to district level promotional tournaments at Anushaktinagar to facilitate our 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 for Annual competitions SPLASH and financial grants to Special children for conducting sports camp Shoushilya at Anushaktinagar.

A friendly T-20 Cricket Match between Chairman, AEC-XI and Director, BARC-XI was played on 15th December 2018 at Anushaktinagar Cricket Ground. Match was organized by DAE Secretariat&Department of Atomic Energy Sports and Cultural Council (DAE S&CC).

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.

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, one APIO and one Appellate Authority at NPCIL Head Quarters, to deal with the requests received under the RTI Act 2005. 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/Training were organized in NPCIL for creating awareness about the importance and ways to implement the Act. During the FY 2018-19, 1093 RTI applications and 230 Appeals were received under the RTI Act, 2005 and disposed of. In the case of NPCIL, there were 24 cases (Second Appeal) heard by Central Information Commission, New Delhi. 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 fully complies with the provisions of RTI Act, 2005. In this regard, the Unit has suomoto declared information under the provision of Section 4 of RTI Act 2005. This suomoto declaration is updated regularly as and when there is any change. During the year 2018, 157 applications were received of which 17 applications were transferred to other PIOs. Information was provided to the applicants within the prescribed time limit. Similarly, 14 RTI Appeals were received during the same year which was disposed of within the prescribed time limit.

RTI related issues have been dealt with efficiently at AMD. A total of 171 RTI applications and 35 appeals for first appellate authority were received and replied. 7 CIC hearings on second appeal were attended and orders passed by CIC.

During the year, from January 2018 to March 2019, RRCAT received 219 RTI applications and out of these 210 applications were disposed of.

At IREL, during the period from 01.04.2018 to 31.03.2019, 143 RTI queries were received and 141 RTI queries were replied and reply to balance 02 RTI applications will be sent within prescribed period as per RTI Act, 2005.

DCSEM has received 196 nos. of RTI queries out of that 174 nos. are replied and 22 queries are under process.

SINP received 58 RTI applications and 10 RTI appeals and all of them were replied.

During Financial Year 2018-19, the Harish Chandra Research Institute under RTI Act, received 43 applications and all were replied.

AWARDS & PRIZES

Several awards in areas of safety and performance, Vigilance, Public Awareness (PA)

NSC safety award 2017 Suraksha Puraskar for TAPS-3&4

Certificate of appreciation from NSC of India in Group-C power generation sector for achieving the most outstanding in OSH for the Assessment Period of three years-2015 to 2017

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 under NSC Safety Awards-2017 received Suraksha Puraskar (Bronze Trophy and Certificate) for developing & implementing very effective management systems & procedures and achieving very good performance in Occupational Safety and Health (OSH) for the assessment period of three years - 2014 to 2016 in Group-C (Power Generation - Thermal / Hydel / Nuclear power plants). Under NSC Safety awards-2018 – TAPS-3&4 received “Certificate of Appreciation” for the assessment period 2017 in Group-C (Power Generation - Thermal / Hydel /Nuclear power plants) for implementing Occupational Safety and Health (OSH)

National Safety Award scheme 2016 of DGFASLI for MAPS- 1&2

NSCI 'Shreshtha Suraksha Puraskar' award 2017 for MAPS-1&2

management systems and procedures effectively and achieving outstanding performance in OSH.

MAPS-1&2 received 'Shreshtha Suraksha Puraskar' Safety Awards – 2017 under Group-C Power Generation category from National Safety Council of India. It also received National Safety Award scheme of DGFASLI for the performance year 2016, under Schedule-15: Miscellaneous Industry with more than One million man-hours working per year and won the “Runner-up” title under the Sheme-1: Lowest Average Frequency Rate in preceding three consecutive years including the performance year.

NAPS was awarded with "Certificate of appreciation" by National Safety Council, Mumbai in "NSCI Safety Awards 2018", for achieving the appreciable achievement in Occupational Safety & Health during the assessment period of three years from 2015 to 2017.

“Shreshta Suraksha Puraskar” (Silver trophy) NSCI Safety award-2018 from National Safety Council, Mumbai, for KGS-1&2

KAPS-1&2 received Gujarat State Safety Award-2015 as Winner in Category-V, Group-A organized by M/S Gujarat Safety Council and Directorate Industrial safety & Health, Gujarat state. It also received Certificate of appreciation from National Safety Council of India in Group-C -power generation sector for achieving the most outstanding performance in OSH for the Assessment Period of three years-2015 to 2017.

KGS-1&2, bagged "Shreshta Suraksha Puraskar" (Silver trophy) NSCI Safety award-2018 from National Safety Council, Mumbai.

KGS-3&4, bagged the prestigious National Safety Award "Sarvashreshtha Suraksha Puraskar-2018" (Golden trophy) from National Safety Council of India. This is third time in a row that Station has received this award. Three employees bagged prizes during 35th DAE Safety Professional's Meet (National Level Completion) held at VEC Centre, Kolkata from 27th to 29th November-2018 in Paper presentation, Poster and Cartoon competition.

NSC award 2018 Sarvashreshtha Suraksha Puraskar (Golden Trophy) for KGS-3&4

In Public Awareness, NPCIL's innovative campaign "Atom on Wheels" - a mobile exhibition - won international award under the category of "World's Best Public Communication Campaign" across the globe at 10th ATOMEXPO-2018 held at Sochi, Russia on May 14, 2018. Total 22 countries had participated in the event.

AMD officials have been conferred with two DAE – Group Achievement Awards -2017 and a Meritorious Service Award-2017 by DAE.

ECIL has received many awards these are Governance Now PSU Award 2019; SKOCH Order of Merit Awards 2018 for Linear Variable Differential Transformer; ELCINA EFY Awards for R&D 2018 for Point of Sale device and the IEI Industry Excellence Award 2018.

At SINP, Dr. Biswarup Satpati of Surface Physics and Material Science Division, SINP has been awarded the "Excellence in Microscopy" by Electron Microscope Society of India (EMSI) for the year 2018. Prof. Munshi Golam Mustafa of Theory Division has been named as a Fellow of National Academy of Sciences (FNASc). Dr. Chandrima Das of Biophysics and Structural Genomics Division has been awarded the SwarnaJayanti Fellowship under 'SwarnaJayanti Fellowships Scheme' 2017-18 in Life Sciences Group by Department of Science & Technology, Government of India. Dr. Oishee Chakrabarti has won the National Women Bioscientists Award (Young Category). Prof. Prabhat Mandal of Experimental Condensed Matter Physics Division has been elected as a "Fellow of the Indian Academy of Sciences". Dr. Biswarup Das, research fellow of HENPP division obtained the Prof. C.V.K. Baba Award for Best Thesis in "Nuclear Physics" for the year 2018. This award is given by Indian Physics Association.

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 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 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	7827	1	3	39	1	0	0	3	0	107	0	0	10	0	0	0	0	7	0	0	0	
Group B	7509	7	11	72	1	1	3	3	0	28	0	1	11	0	0	0	0	127	0	0	1	
Group C	8678	19	42	113	0	3	8	20	0	237	0	1	22	0	0	2	3	149	0	0	0	
TOTAL	**24014**	**27**	**56**	**224**	**2**	**4**	**11**	**26**	**0**	**372**	**0**	**2**	**43**	**0**	**0**	**2**	**3**	**283**	**0**	**0**	**1**	

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 ON 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 IN RESPECT OF **AIDED INSTUTUTIONS**

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	927	3	2	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Group B	1791	6	4	23	1	0	2	1	0	1	0	0	1	0	0	0	0	2	0	0	2	
Group C	1310	4	11	24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
TOTAL	**4028**	**13**	**17**	**54**	**1**	**1**	**3**	**2**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**	**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 ON 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 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	7256	9	7	74	0	3	9	6	1	89	0	1	14	0	0	0	0	9	0	0	3
Group B	5300	12	10	71	0	1	3	2	0	13	3	2	5	0	0	0	0	0	0	0	0
Group C	4467	20	10	47	1	15	11	8	0	72	0	0	4	0	0	0	0	31	0	0	2
TOTAL	**17023**	**41**	**27**	**192**	**1**	**19**	**23**	**16**	**1**	**174**	**3**	**3**	**23**	**0**	**0**	**0**	**0**	**40**	**0**	**0**	**5**

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'S 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;
- 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 I.D. 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 SPEHERES OF LIFE. WE SHALL REMAIN VIGILANT AND WORK TOWARDS THE GROWTH AND REPUTATION OF OUR ORGANISATION. THROUGH OUR COLLECTIVE EFFORTS, WE SHALL BRING PRIDE TO OUR ORGANISATIONS AND PROVIDE VALUE BASED SERVICE TO OUR CONTRYMEN. WE SHALL DO OUR DUTY CONSCIENTIOUSLY AND ACT WITHOUT FEAR OR FAVOUR.

THIS OFFICE IS THUS COMMITTEED 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.

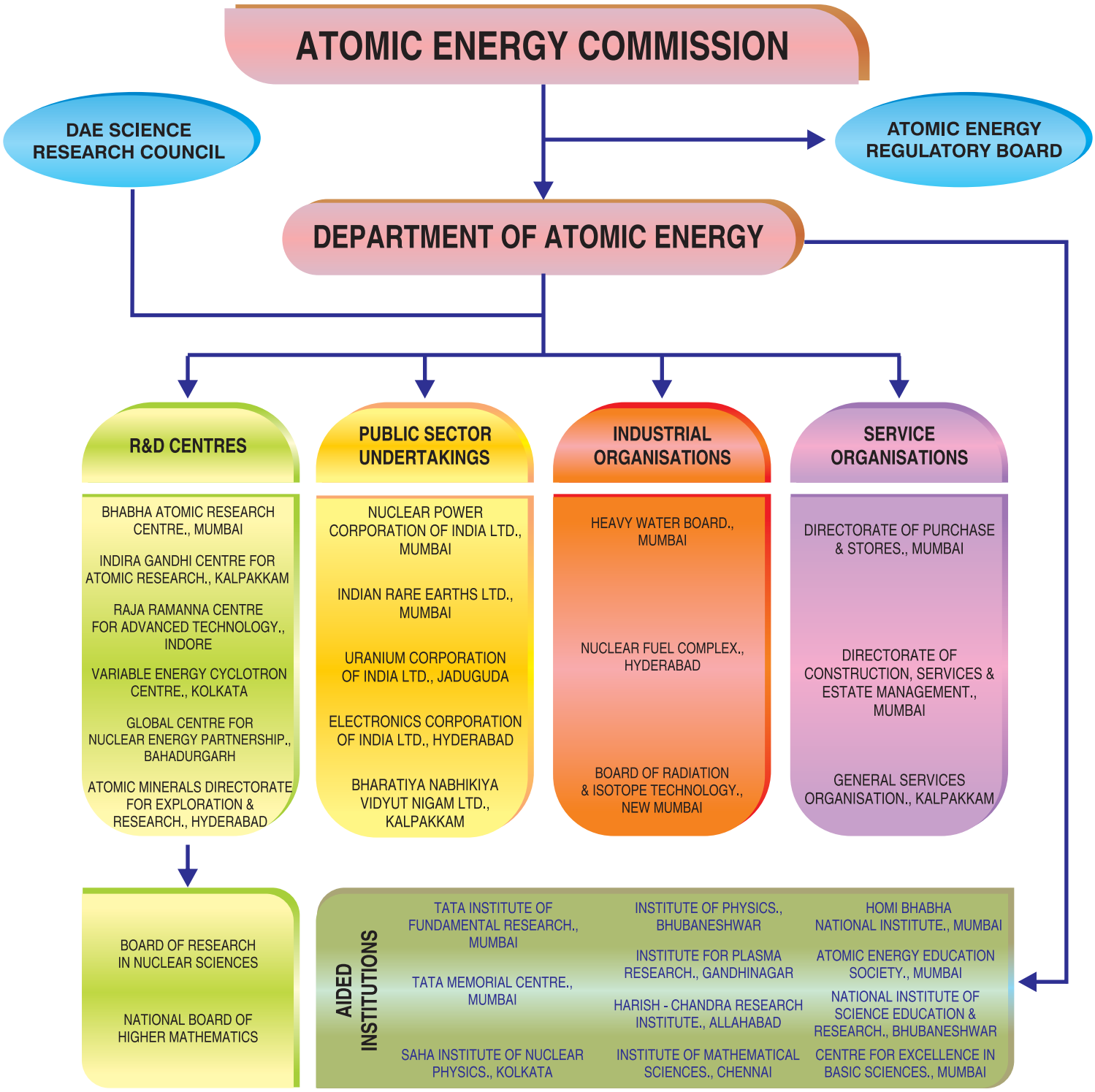
ANNEX-I

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.

An 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 2018, Chapter-III : Compliance Audit, Union Government, Scientific and Environment, Ministries / Departments.

Para 3.1 - Activities of Heavy Water Board

Delay in decision making for dismantling and disposal of the closed Heavy Water Plant at Baroda and delay in closure of the Heavy Water Plant at Talcher by the Heavy Water Board resulted in avoidable expenditure of Rs.68.26 Crore on their maintenance. There was time overrun of one month to more than seven years in 29 projects and cost overrun of Rs.12.32 Crore in five projects. Oxidation system established at a cost of Rs.8.66 Crore could not be utilised due to lack of feeder gas.

Action Taken:

Revised ATN under submission.

Para 3.2 - Short-realisation of ground rent

Directorate of Construction Services and Estate Management was unable to renew license agreements and revise ground rent in respect of land leased to oil companies due to lack of decision by Department of Atomic Energy which resulted in short realisation of rent and interest of Rs.12.78 Crore. Besides, an amount of Rs.50.39 lakh towards interest on delayed payment of ground rent was also recoverable.

Action Taken:

Revised ATN under submission.

Para 3.3 - Outstanding dues pending for recovery

Board of Radiation and Isotopes Technology failed to take timely action to establish proper mechanism for realising payments towards sale of radioactive material and allied products which resulted in outstanding dues of Rs.10.71 Crore.

Action Taken:

For private customers, BRIT was issuing a warning once the outstanding amount reaches to Rs.2 lakhs and stopping the supply once the same reaches to Rs.4 lakhs. To bring down the outstanding dues now it has been modified to 2 months running average for warning and 4 months running average for stopping the supply. A note regarding interest on delayed payment is also included in the invoice. The outstanding has been reduced from Rs.10.71 crore to Rs.8.70 crore.

Para 3.4 - Irregular Leave Concession Claims

Nuclear Fuel Complex, Hyderabad, did not exercise stipulated checks before passing Leave Travel Concession bills of its employees which resulted in payment of Rs.40.11 lakh towards irregular claims.

Action Taken:

Revised ATN under submission.

ANNEX-III

REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2019)				Number of appointments made during the calendar year 2018									
					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	8572	1083	276	1291	263	2	2	15	391	47	44	6	3	29
Group B	8643	1575	782	2286	76	7	2	11	213	43	35	13	2	15
Group C	10402	2126	944	3455	360	64	19	149	236	41	40	9	4	15
TOTAL	**27617**	**4784**	**2002**	**7032**	**699**	**73**	**23**	**175**	**840**	**131**	**119**	**28**	**9**	**59**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2018)				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	1332	80	5	104	31	0	0	2	13	2	0	0	0	0
Group B	2947	446	66	553	143	12	10	47	47	8	3	0	0	0
Group C	1757	365	198	396	50	1	6	14	30	4	1	0	0	0
TOTAL	**6036**	**891**	**269**	**1053**	**224**	**13**	**16**	**63**	**90**	**14**	**4**	**0**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2019 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2018 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2018)				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	7256	839	281	1315	96	13	16	22	1116	127	44	3	0	0
Group B	5300	911	420	1463	120	16	7	41	1153	239	69	0	0	0
Group C	4467	744	326	1130	71	13	2	36	512	139	58	3	0	0
TOTAL	**17023**	**2494**	**1027**	**3908**	**287**	**42**	**25**	**99**	**2781**	**505**	**171**	**6**	**0**	**0**

ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADF	Alpha Demonstration Facility
AECS	Atomic Energy Central School
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AHWR	Advanced Heavy Water Reactor
AIIMS	All India Institute of Medical Sciences
AKRUTI	Advanced Knowledge & RUral Technology Implementation
ALARA	As Low as Reasonably Achievable
ALIP	Annular Linear Induction Pump
AMD	Atomic Minerals Directorate for Exploration & Research
APO	Alkyl Phosphine Oxide
APW	Active Process Water
ARPF	Agricultural Radiation Processing Facility
ASSSB	Additional Spent Subassembly Storage Bay
ATI	Administrative Training Institute
ATTF	AHWR Thermal Hydraulic Test Facility
AUSC	Advanced Ultra-Super Critical
BARC	Bhabha Atomic Research Centre
BBCI	Dr. B. Barooah Cancer Institute
BBS	Barium Borosilicate
BCD	Bleed Condenser
BCU	Brine Concentrator Unit
BDB	Beyond Design Basis
BET	Bacterial Endotoxin Test
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BNHS	Bombay Natural History Society
BoG	Board of Governors
BOMAB	Bottle Mannequin Absorber
BOTIP	Balance of Turbine Island Package
BPI	Beam Position Indicator
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BSOI	Beach Sand and Offshore Investigations
BWR	Boiling Water Reactor
CBP	Catalytic Bearing Plate
CBS	Centre for Excellence in Basic Sciences
CCE	Centre for Cancer Epidemiology
CCES	Centre for Computational Engineering and Sciences
CFD	Computational Fluid Dynamics
CFFP	Ceramic Fuel Fabrication Plant
CISD	Computer and Information Systems Division
CIWH	Condensation Induced Water Hammer
CMB	Cosmic Microwave Background
CMG	Crisis Management Group
CMR	Custom Made Sources
CNT	Carbon Nanotubes
CoARs	Cobalt Absorber Rods
COD	Crack Opening Displacement
COG	CANDU Owner's Group
CORAL	Compact Reprocessing facility for Advanced fuels of Lead cells
CPCB	Central Pollution Control Board
CRDM	Control Rod Drive Mechanism
CRZ	Coastal Regulation Zone
CSR	Corporate Social Responsibility
CSR	Certificate Signing Request
CSRDM	Control & Safety Rod Drive Mechanism
CSS	Core Support Structure
CTRJD	Calandria Tube Rolled Joint Detachment
CTS	Cobalt Teletherapy Sources
CVC	Central Vigilance Commission
CVO	Chief Vigilance Officer
DAE	Department of Atomic Energy
DAE S&CC	DAE Sports and Cultural Council
DAQ	Data Acquisition
DCSEM	Directorate of Construction Services & Estate Management
DFRP	Demonstration Fast reactor fuel Reprocessing Plant
DGFS	DAE Graduate Fellowship Scheme
DGFT	Directorate General of Foreign Trade
DIC	Digital Image Correlation
DMRL	Defence Metallurgical Research Laboratory
DMW	Dissimilar Metal Welds
DND	Delayed Neutron Detector
DPS	Directorate of Purchase & Stores
DPSS	Diode Pumped Solid State
DPR	Detailed Project Report
DRDO	Defence Research Development Organisation
DRS	Disaster Recovery Setup
DRS	Digital Recording System
DTD	Directorate of Technology Development
ECAA	Extra-Cellular Acidity Analyser
ECCS	Emergency Core Cooling System
ECD	Electron Capture Detectors
ECIL	Electronic Corporation of India Limited
ECR	Emergency Control Room
ECRIS	Electron Cyclotron Resonance Ion Source
ECT	Eddy Current Testing
EDF	Électricité de France
EMCCR	En-masse Coolant Channels Replacement
EMFR	En-masse Feeders Replacement
EMS	Environmental Management System
EMSI	Electron Microscope Society of India
EOT	Electric Overhead Traveling
EPA	Electrical Penetration Assembly

EPR	Emergency Preparedness and Response
ERM	Environmental Radiation Monitor
ERM	Extended Reach Manipulator
ESL	Environmental Survey Laboratory
ESP	Environment Stewardship Programme
ETF	ECCS Test Facility
EVM	Electronic Voting Machine
FBTR	Fast Breeder Test Reactor
FBR	Fast Breeder Reactor
FCCU	Fluidized Catalytic Cracker Unit
FCG	Fatigue Crack Growth
FCT	Fast Current Transformer
FCVD	Fluidization based Chemical Vapor Deposition
FDG	Fluorodeoxyglucose
FFLM	Failed Fuel Location Module
FHCS	Fuel Handling Control System
FIDWS	Flow Instability Detection and Warning System
FMTF	Fuelling Machine Test Facility
FOFB	Fast Orbit Feedback
FPC	First Pour of Concrete
FPGA	Field Programmable Gate Array
FPS	Fire Protection System
FRENA	Facilities for Research in Experimental Nuclear Astrophysics
FRFCF	Fast Reactor Fuel Cycle Facility
GCNEP	Global Centre for Nuclear Energy Partnership
GDWP	Gravity Driven Water Pool
GHAVP	Gorakhpur Anu Vidyut Pariyojana
GMRT	Giant Metrewave Radio Telescope
GPC	Geo Polymer Concrete
HBCH	Homi Bhabha Cancer Hospital
HBCSE	Homi Bhabha Centre for Science Education
HBNI	Homi Bhabha Nationa Institute
HCDA	Hypothetical Core Disruptive Accident
HDG	High Density Graphite
HEP	Horizontal Extrusion Press
HFS	Hyperfine Structure
HLLW	High-Level radioactive Liquid Waste
HPGC	High Performance Green Concrete
HRTF	Hydrogen Recombiner Test Facility
HAS	Human Serum Albumin
HSAR	Hydraulically Suspended Absorber Rod
HWB	Heavy Water Board
HWP	Heavy Water Plant
IAEA	International Atomic Energy Agency
ICCM	Integrated Centre for Crisis Management
ICF	Irradiation Creep Facility
ICIS	Integrated Control and Information System
ISC	Indian Science Congress
IDCT	Induced Draught Cooling Tower
IFFF	Integrated Fuel Fabrication Facility
IGA	Inter-Governmental Agreement
IGCAR	Indira Gandhi Centre for Atomic Research
IHTR	Innovative High Temperature Reactor
IHX	Intermediate Heat Exchanger
IISF	India International Science Festival
IIT	Indian Institute of Technology
ILRT	Integrated Leak Rate Test
IMO	International Mathematics Olympiad
IMSc	Institute of Mathematical Science
IMSBR	Indian Molten Salt Breeder Reactor
INGA	Indian National Gamma Array
INMO	Indian National Mathematics Olympiad
INO	India-based Neutrino Observatory
INDRA	Indian Network for Detecting Radon Anomaly
INPRO	Innovative Nuclear Reactors and Fuel Cycles
INRP	Integrated Nuclear Recycle Plant
IOCL	Indian Oil Corporation Ltd.
IOP	Institute of Physics
IPR	Intellectual Property Rights
IPR	Institute for Plasma Research
IPHWR	Indian Pressurized Heavy Water Reactor
IREL	Indian Rare Earths Limited
ISBU	Integrated Spacer pad Bearing pad Unit
ISI	In-service Inspection
ISM	Induction Skull Melting
ISNS	Indian Spallation Neutron Source
ISRO	Indian Space Research Organisation
ITER	International Thermonuclear Experimental Reactor
ITL	Integral Test Loop
IWFA	Industrial Way Forward Agreement
IWM	Indian Women in Mathematics
JCM	Joint Committee Meeting
JNPP	Jaitapur Nuclear Power Project
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
LBE	Lead-Bismuth Eutectic
LCTF	Liquid Tunable Filter
LEBT	Low Energy Beam Transport
LEHIPA	Low Energy High Intensity Proton Accelerator
LESS	Liquid Effluent Segregation System
LEU	Low Enriched Uranium

LHC	Large Hadron Collider
LLLW	Low Level Liquid Waste
LLNL	Lawrence Livermore National Laboratory
LMBF	Longitudinal Multi-bunch Feedback
LOCA	Loss of Coolant Accident
LRP	Large Rotatable Plug
LSTB	Large Scale Test Bed
LVDT	Linear Variable Differential Transformer
LWR	Light Water Reactor
MAA	Macro Albumin Aggregates
MACE	Major Atmospheric Cerenkov Experiment Telescope
MCF	Medical Cyclotron Facility
MCR	Main Control Room
MDA	Minimum Detectable Activity
MFFF	Metal Fuel Fabrication Facility
MHD	Magneto Hydro Dynamic
MJPJAY	Mahatma Jyotiba Phule Jeevandayee Aarogya Yojana
MLC	Multi Leaf Collimator
MoEFCC	Ministry of Environment, Forest and Climate Change
MoU	Memorandum of Understanding
MPL	Mobile Purification Loop
MPMMCC	Mahamana Pandit Madan Mohan Malaviya Cancer Centre
MRL	Mobile Radiological Laboratory
MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
MSBR	Molten Salt Breeder Reactors
MSNCL	Molten Salt Natural Circulation Loop
MSR	Molten Salt Reactor
NABL	National Accreditation Board for Testing and Calibration Laboratories
NBHM	National Board of Higher Mathematics
NDCT	Natural Draught Cooling Tower
NET	Neuro Endocrine Tumors
NFC	Nuclear Fuel Complex
NISER	National Institute of Science Education & Research
NIT	Notice Inviting Tender
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NTPC	National Thermal Power Corporation
NTTF	NPCIL Thermal Hydraulic Test Facility
NUFAP	Natural Uranium Fuel Assembly Plant
NUJ	National Union of Journalists
NUOFP	Natural Uranium Oxide Fabrication Plant
NUP	National Uranium Project
OCES	Orientation Course for Engineering graduates and Science postgraduates
OCSP	Online Certificate Status Portal
ODS	Oxide Dispersion Strengthened
OHSMS	Occupational Health and Safety Management System
OLIC	Official Language Implementation Committees
ONERS	Online Nuclear Emergency Response Decision Support System
PAC	Project Appraisal Committee
PAS	Personal Air Sampler
PCB	Pollution Control Board
PCIS	Passive Containment Isolation System
PCL	Parallel Channel Loop
PCP	Primary Coolant Pump
PCPTF	Primary Coolant Pump Test Facility
PCRD	Passive Catalytic Recombiner Devices
PCT	Patent Co-operation Treaty
PDC	Personnel Decontamination Centre
PET	Positron Emitting Tomography
PFBR	Prototype Fast Breeder Reactor
PFN	Pulse Forming Network
PHT	Primary Heat Transport
PHWR	Pressurised Heavy Water Reactors
PIA	Pump Internal Assembly
PIE	Post Irradiation Examination
PIGE	Particle Induced Gamma-ray Emission
PIS	Plant Information System
PLC	Programmable Logic Controller
PLIS	Performance Linked Incentive Scheme
PLS	Partial Least Square
PMD	Photon Multiplicity Detector
PPIS	Passive Poison Injection System
PPRDF	Pyro Process R&D Facility
PRESAM	PREssure tube SAg Measurement
PRIS	Power Reactor Information System
PRTRF	Power Reactor Thoria Reprocessing Facility
PSA	Probabilistic Safety Assessment
PSI	Pre-service Inspection
PSMA	Prostate Specific Membrane Antigen
PTD	Pot Transfer Device
PCT	Patent Co-operation Treaty
QWR	Quarter Wave Resonator
RAL	Radioanalytical Laboratory
RAFM	Reduced Activation Ferritic–Martensitic
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RCM	Reactivity Control Mechanism
RFCTLARR	Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement
REE	Rare Earths Elements
RFEC	Remote Field Eddy Current
RFID	Radio Frequency Identification
RFQ	Radio Frequency Quadrupole

RIA	Radioimmunoassay
RMC	Radiation Medicine Centre
RMRE	Rare Metal and Rare Earth
RPh	Radiopharmaceuticals
RPP	Radiation Processing Plant
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RRF	Raja Rammana Fellowship
RTC	Room Temperature Cyclotron
RTD	Residence Time Distribution
RTI	Right to Information
RWB	Rad Waste Building
SAMG	Severe Accident Management Guidelines
SBC	Ship Building Centre
SBD	Singridungri-Banadungri
SBO	Station Blackout
SCC	Super-Conducting Cyclotron
SCP	Safety Control Plate
SCP	Supplementary Control Panel
SCQWR	Super-conducting Quarter Wave Resonator
SCRF	Superconducting Radio-Frequency
SDCP	Shutdown Cooling Pump
SDU	Sodium Di Uranate
SEM	Scanning Electron Microscope
SFR	Sodium cooled Fast Reactor
SGBD	Steam Generator Blow Down
SINP	Saha Institute of Nuclear Physics
SIS	Seismic Instrumentation System
SMA	Seismic Margin Assessment
SMS	Short Messaging Service
SNM	Special Nuclear Materials
SOP	Standard Operating Procedure
SPECT	Single-Photon Emission Computed Tomography
SPP	Solvent Production Plant
SPS	Spark Plasma Sintering
SQA	Software Quality Assurance
SRC	Safety Review Committee
SRP	Small Rotatable Plugs
SSFDC	Secondary Sodium Fill and Drain Circuit
SSP	Secondary Sodium Pump
SSTP	Stainless Steel Tube Plant
SSWF	Spent Subassembly Washing Facility
STE	State Trading Enterprise
SUT	Start-Up Transformer
SXP	Solvent Extraction Plant
TACTIC	TeV Atmospheric Cerenkov Telescope with Imaging Camera
TAPS	Tarapur Atomic Power Station
TARE	Trans Arterial Radio Embolization
TBM	Test Blanket Module
TBP	Tributyl Phosphate
TCDM	Trombay Chhattisgarh Dubraj Mutant
TCF	Technical Cooperation Fund
TFS	Tritium Filled Self-luminous
THM	Total Heavy Mineral
TIFR	Tata Institute of Fundamental Research
TIMOT	Two Isotope Magneto-Optical Trap
TIMS	Thermal Ionization Mass Spectrometer
TLAA	Time Limited Ageing Assessment
TLD	Thermo Luminescence Dosimeters
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TMIS	Training Management Information System
TMT	Thermo Mechanical Treatment
TNMB	Tamil Nadu Maritime Board
TOR	Terms of Reference
TSO	Trainee Scientific Officer
UCIL	Uranium Corporation of India Limited
UNPS	Uranyl Nitrate Pure Solution
UOP	Uranium Oxide Plant
USUS	Under Sodium Ultrasonic Scanner
UTOPA	Unprotected Transient Over Power Accident
VAR	Vapour Absorption-based Refrigeration
VDI	Virtual Desktop Infrastructure
VECC	Variable Energy Cyclotron Centre
VPP	Vertical Piercing Press
VRMS	Vigilance Report Management System
VTB	Virtual Tumor Board
VTL	Vertical Turret Lathe
VVPAT	Voter Verifiable Paper Audit Trail Printers
WANO	World Association of Nuclear Operators
WEC	Westinghouse Electric Company
WEST	Wet Scraping Technique
WASIF	Water and Steam Interaction Facility
WCM	Wireless Channel Monitors
WII	Wildlife Institute of India
WIP	Waste Immobilization Plant
WLIMS	Wet Low-Intensity Magnetic Separator
XBIS	X-ray Baggage Inspection System
XRD	X-Ray Diffraction
ZLD	Zero Liquid Discharge
ZOP	Zirconium Oxide Plant
ZSP	Zirconium Sponge Plant

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