



# 2017-18 ANNUAL REPORT



सत्यमेव जयते

**GOVERNMENT OF INDIA**  
**DEPARTMENT OF ATOMIC ENERGY**







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***Cover page front & back: Site view - Kakrapar Atomic Power Project KAPP-3&4***

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The page features a white background with decorative geometric elements. A solid purple horizontal bar is at the top. In the top-left corner, there is a parallelogram composed of a purple upper half and a teal lower half. In the bottom-right corner, there is a large triangular shape, also split into a teal upper half and a purple lower half.

# 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 2017-18, 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. Second unit of Kudankulam Nuclear Power Project (KKNPP-2) commenced commercial operation from 11:00 hrs. of March 31, 2017. With this, 1000 MW of nuclear power capacity was added to Southern Grid. 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) are under construction. In addition, First Pour of Concrete (FPC) for Reactor foundation slab of Kudankulam Nuclear Power Project Unit-3 (KKNPP-3, 1000MW LWR) was done on June 29, 2017, signifying the actual start of construction of the project. Administrative Approval and Financial Sanction from GOI exists for Gorakhpur Haryana Anu Vidyut Pariyojana Unit-1&2 (GHAVP-1&2, 2x700 MW PHWRs). Administrative Approval and Financial Sanction from GOI was received for construction of Ten indigenous 700 MW Pressurized Heavy Water Reactors (PHWRs) in Fleet Mode and for Kudankulam Nuclear Power Project Unit-5&6 (2x1000 MW LWRs) in June 2017. Various pre-project/ preparatory activities towards commencement of construction of these projects, are in progress. 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

During the Calendar Year 2017, NPCIL registered generation of 37180 Million Units (in addition, there was an infirm power generation of 1427 MUs from KKNPP-2 during 2017). In the previous calendar year 2016, the generation was 37881 MUs (in addition, there was an infirm power generation of 900 MUs from KKNPP-2 during 2016).

During the Financial Year 2017-18, NPCIL registered a power generation of 27744 MUs till December 31, 2017. The expected generation for the

Financial Year (FY) 2017-18 is about 38600 MUs. Actual generation during the previous FY 2016-17 was 37674 MUs (in addition, there was an infirm power generation of 2327 MUs from KKNPP-2 during 2016-17)

During the Financial Year 2017-18, the overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 67% and 70% respectively till December 31, 2017.

During the Financial Year 2017-18, four reactors i.e. KGS-1, KGS-4, RAPS-3 and RAPS-5 achieved continuous run for more than a year. As on December 31, 2017, KGS-1, RAPS-3 and RAPS-5 registered 597 days, 490 days and 430 days of continuous run respectively and are still continuing running. KGS-4 registered 550 days till 25.11.2017 after which it was shut down for carrying out planned BSD activities. So far, the continuous run of more than a year has been achieved 25 times by various reactors operated by NPCIL.

KAPS-2 is under shutdown since July 2015 and KAPS-1 since March 2016. In both units, major works relating to En-Masse Coolant Channel Replacement (EMCCR) and En-Masse Feeder Replacement (EMFR) have been undertaken in project mode since August 1, 2016. KAPS-2 is expected to start electricity production by December 2018 and KAPS-1 thereafter.

## Projects under construction

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

In Unit-3, concreting of Inner Containment (IC) dome is successfully completed and pre-stressing work is in progress. Construction of Natural Draft Cooling Towers (NDCTs), welding of Steam Generators (SGs)-Reactor Headers-Primary Coolant Pumps (PCPs) interconnecting piping, and erection of top half feeder pipes in both Fuelling Machine (FM) vaults are completed. The bottom half of feeder pipes installation is in progress. 400 KV switch yard and 6.6 KV switch gear are charged. The unit has entered commissioning phase and various systems of Electrical and Common Services are commissioned. Commissioning of Simulator is in progress and expected to be completed



Site view - Kakrapar Atomic Power Project KAPP-3&4

by February 2018. The physical progress of the unit is about 89% as on end December 2017.

In Unit-4, civil works are in progress. After erection of Inner Containment (IC) dome structure, further works are in progress. Erection of all SGs is completed. "Generator Stator", the heaviest single component of the 700 MW project weighing 336 MT, is erected. Coolant Channel Installation has commenced. The physical progress of the unit is about 75% as on end December 2017.

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

In Unit-7, civil works are in progress. Concreting of IC wall ring beam is completed. Control Building (CB) 111 Meter (M) Elevation (El) is released for Control & Instrumentation (C&I) works. Installation of Coolant Tubes has been completed and installation of Feeders is in progress. The physical progress of the unit is about 75% as on end December 2017.



Site View - Rajasthan Atomic Power Project (RAPP-7&8)



In Unit-8, civil works are in progress. Concreting of Reactor Building (RB) slab at 115.5 M El is completed and works for slab above 115.5 M El is in progress. Erection of Fuelling Machine (F/M) Bridge and columns is achieved. The physical progress of the unit is about 61% as on end December 2017.

400KV Switchyard, Line reactors for Sujalpur-I, Sujalpur-II and Jaipur lines have been charged and synchronized.

### **Kudankulam Nuclear Power Project (KKNPP) Unit-3&4 (2x1000 MWe LWRs)**

First Pour of Concrete (FPC) for Reactor foundation slab of Kudankulam Nuclear Power Project Unit-3 (KKNPP-3, 1000MW LWR) was done on June 29, 2017, signifying the actual start of construction of the project.



*Panoramic view of Main Plant – KKNPP-3&4*

Construction of Reactor Auxiliary Building (RAB)-3 raft is completed. Construction of Reactor Building (RB)-3 raft is nearing completion. Construction of Reactor Building (RB)-4 raft is in progress (40% completed). Construction of Temporary dyke is in progress. Manufacturing and delivery of various equipment and components are in progress. The physical progress of the unit-3 and Unit-4 are about 16% and 14% respectively as on end December 2017.

### **Sanctioned Projects**

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

Administrative approval and Govt. financial sanction, Ministry of Environment, Forest and Climate Change (MoEFCC) clearance for plant site, siting

consent from Atomic Energy Regulatory Board (AERB) and consent to establish from Haryana State Pollution Control Board (HSPCB) exist. Land for the project has been acquired. Main Plant Engineering Consultancy contract is awarded and works are in progress. Main Plant Civil Works Package-1 (Excavation) work order was issued and obtained Excavation consent from Atomic Energy Regulatory Board (AERB) and Ground Break is expected shortly. Purchase Orders were placed for Reactor headers and Primary Coolant Pumps (PCPs) in January 2018. Placement of Purchase Orders for procurement of other long delivery equipment/components viz. End Shields, Calandria, Steam Generators etc. are in advanced stage.

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

Administrative approval and Financial Sanction has been accorded by Government of India in June-2017. All statutory clearances including 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. General Framework Agreement (GFA) for setting up of KKNPP Units-5&6 signed between JSC Atomstroyexport (ASE) and Nuclear Power Corporation of India Limited in June 2017. Three major contracts viz. Contract for First Priority Design Work, Contract for development of the Working Documentation, Contract for Delivery of Equipment with Long manufacturing Cycle & First Priority Equipment were signed with JSC ASE, in July-2017. Application and requisite documents for excavation clearance from AERB are under preparation.

### **Ten 700 MW PHWRs in Fleet Mode**

Administrative Approval and Financial Sanction from GOI have been received in June 2017 for construction of ten indigenous 700 MW Pressurized Heavy Water Reactors (PHWRs) in Fleet Mode. Procurement activities for Lattice Tubes and Plates for End Shields (4 Units), Pressurizer & Bleed Condenser (BCD) and Steam Generator (SG) Forgings (6 Units) are in progress.

Various pre-project/ preparatory activities like land acquisition, Rehabilitation & Resettlement, environmental studies, site studies, regulatory submissions, public outreach, etc. are in various stages of progress for commencement of construction of these units, at Chutka in Madhya Pradesh, Kaiga-5&6 in Karnataka and Mahi Banswara in Rajasthan.

## New Project / Sites

Various pre-project activities like land acquisition, Rehabilitation & Resettlement, environmental studies, site studies, regulatory submissions, public outreach, Techno-commercial discussions with foreign vendors etc. are in various stages of progress for new LWR sites, having “In Principle” approval from the Govt. of India, namely Jaitapur in Maharashtra, Kovvada in Andhra Pradesh and Mithi Virdi in Gujarat. Land is available at Jaitapur and land acquisition is in advance stage at Kovvada. Land is to be acquired as per new RFCTLARR Act, 2013 for Mithi Virdi. At Haripur, land acquisition is contingent to initiative by State Government. Alternate site is also under consideration by the Government of India.

## Quality Assurance

Quality Assurance/Surveillance (in India and overseas) activities have been carried out expeditiously for projects and stations. Pre-service/In-service Inspection of Projects/Stations has been completed successfully. Corporate QA audits of projects i.e. KKNPP-3&4, KAPP-3&4 and RAPP-7&8 have been completed in a planned way. Corporate Peer reviews of operating stations have been conducted based on WANO guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO.

## Research Reactors

Research reactor Dhruva continued to operate with high level of safety with availability factor of around 74% and capacity factor of around 60%. Reactor was operated at the rated power of 100 MW(th) to support the researchers and isotope production. Operation of heavy water upgrading plant in BARC was continued for improvement of Isotopic Purity (IP) of the downgraded heavy water of research reactors. Civil construction of

the Nuclear Research Facility-N, lining of reactor pool, erection of reactor core structure, erection of all process equipment and 90 % of process piping were completed.

## 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 (HWB) has been producing heavy water in a cost effective manner enabling the department to provide nuclear power at an affordable cost to common man. With steady and efficient operation of the production units over the years, it is self-sufficient in meeting the present domestic demand of heavy water for the operating as well as the future PHWRs and AHWRs as per the envisioned nuclear power programme of DAE.

HWB has established itself as the largest global producer and a trusted supplier of heavy water. Non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology have in recent times opened up tremendous scope for India becoming a leader in supply of D-labeled compounds, NMR solvents, APIs and drug entities. Responding to the huge demand of these presently imported D-labeled compounds in India, HWB has initiated collaborative programme with leading Indian pharmaceutical companies.

Performance of the Board during the period was excellent with respect to production, specific energy

consumption and 'on stream' factor. With sustained operation and lowest ever specific energy consumption, the largest plant at Manuguru has recorded highest percentage recovery. HWP, Kota carried out Major Turn Around during the report period. HWP, Hazira has also completed Annual Turn Around as planned. The targeted production is expected to be achieved by all the HWPs as per annual action plan. At Tuticorin, activities are in full swing on three fronts viz. re-startup of Heavy water production, setting up of industrial scale Solvent Production Plant (SPP) and industrial scale Solvent Extraction Plant (SXP).

### Diversification Activities

HWB, after fulfilling the primary mandate of producing heavy water for the nuclear programme, embarked upon diversification activities, utilizing its expertise in designing & operation of complex isotopic separation processes to develop, demonstrate and deploy technology for production of in-core and out of core material inputs for Indian Nuclear Power Program. Progress made during the period in some of the key areas is as follows.

### Solvent Technology

The Board continued to meet DAE's complete requirement of organo-phosphorus solvents through its industrial facilities at Baroda and Talcher. Efforts for capacity building for synthesis of novel organo-phosphorus solvents like TiAP, DHOA, D2EHPA-II, TAPO & TOPO at Tuticorin have yielded encouraging results. Synthesis of some special solvents viz. DGA, Calixarene etc. is also in hand, based on collaborative efforts with DAE units.

### Boron Enrichment

To support the second stage of NPP, HWB set up enriched Boron enrichment and Boron carbide pellet



**Boron Plant induction furnace at HWP, Manuguru**

production facilities at Talcher and HWP, Manuguru. HWB successfully delivered the entire quantity of enriched Boron for the first core of PFBR. India has thus found a place in the handful of countries possessing such capability. Trial production of nuclear grade Boron Carbide pellets of higher IP required for IGCAR is at hand. Second train of pellet manufacturing facility is being put up at Manuguru to meet the targets of BHAVINI and IGCAR.

### Sodium Metal

HWB is geared up for indigenous production of sodium as coolant for PFBR. 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 2kA has been designed and is being operated continuously for last one year to collect the data and fine tune the operating parameters. Scaled up design has been completed for 24 kA proto type cell and procurement is in hand for the same, which will be operated prior to setting up of the 600 MT per annum plant at HWP, Baroda.

### Mineral Exploration and Mining

Atomic Minerals Directorate for Exploration and Research (AMD) continued the accelerated pace of exploration activities during 2017-18 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 ( $U_3O_8$ ) reserve of over 25,689 tonnes in the areas of Andhra Pradesh.

Significant uranium anomalies were located in Assam, Jharkhand, Andhra Pradesh, Telangana and Madhya Pradesh. About 2,06,090m reconnaissance, 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 Haryana, Karnataka, Andhra Pradesh, Jharkhand, Meghalaya,





**Radioactive quartzite at Kappatralla,  
Kurnool district, Andhra Pradesh**

Rajasthan, Chhattisgarh and Madhya Pradesh. New Potential/significant blocks have been identified at Uttar Pradesh, Himachal Pradesh, Jharkhand, Andhra Pradesh and Telangana.

Geochemical surveys (4,346 sq km) have been carried out in different parts of the country for delineating targets for detailed investigations. Ground geophysical surveys (Regional: 524 sq km and Detailed: 458 sq km) have delineated potential blocks associated with conductive zones in Rajasthan; high chargeability zones in Jharkhand & Karnataka and low magnetic zones in Assam & Gujarat. Airborne survey and remote sensing surveys over 58,241.65 line km have been carried out in parts of Rajasthan; Chhattisgarh; Madhya Pradesh; Andhra Pradesh & Telangana. AMD successfully carried out heliborne gravity survey for the first time in India.

Rare Metal and Rare Earth (RMRE) investigations resulted in location of significant concentrations of RMRE along Chhattisgarh and Odisha.

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; Andhra Pradesh and Odisha. The THM resources in Chinavanka - Pallisaradhi coast, Srikakulam district, Andhra Pradesh are estimated to be approximately 1.41 million tonne. The country's total heavy mineral resources are 1,173Mt which includes 12.47Mt of monazite.

Uranium Corporation of India Ltd. (UCIL) is engaged in uranium ore mining and processing since 1967. The performance of all major units of the company remained quite satisfactory. The Tummalapalle Uranium Project at Andhra Pradesh has been capitalized with effect from January 2017 and incorporated in the balance sheet of FY 2016-17. Re-Dissolution System (RDS) facility in the processing plant has been successfully completed and implemented.

Exploratory mining activities by UCIL on behalf of AMD at Rohil Uranium Project located at Sikar district of Rajasthan is in progress. Agreement has been finalized with AMD for decline and shaft construction. 3D ore-body model report and pre-feasibility report has been prepared. Terms of Reference (ToR) application for Rohil Uranium Project has been made and is under process by MoEFCC.

Pre project activities have been taken up at Gogi Uranium Project located at Yadgir district of Karnataka. Finalization of pre-feasibility report and ToR application is in progress. Land acquisition has been completed (government land) except tailings pond area.

Towards meeting the urgent need of nuclear fuel for the new upcoming reactors envisaged by DAE, UCIL has planned for augmentation of uranium production through expansion of existing facilities and setting up of new units in Jharkhand.

UCIL has also initiated activities to expand existing mine & plant and setup new mines & plants around Tummalapalle area in Andhra Pradesh.

A novel leaching process has been developed at BARC to obtain pure yellow cake from Crude Sodium Diuranate (CSDU) of phosphoric acid processing plant. Process development studies on bench-scale have been carried out for the recovery of U values from a blended split-core bore-hole U ore sample from Singridungri-Banadungri (SBD) area of Singhbhum Shear Zone.

The Indian Rare Earths Ltd. (IREL) has developed formulation for Yttrium stabilized zirconia & lanthanum zirconate to develop Thermal Barrier Coating materials for Aero-engine parts and sent it for trial to Hindustan Aeronautics Limited (HAL). The material

developed was reported to withstand tests equivalent to 1000 hours of flying.

Joint Venture Agreement (JVA) has been signed between IREL and Industrial Development Corporation of Odisha Limited (IDCOL) for mining the beach sand reserves in the state of Odisha. Company formation is under progress.

Corporate Research Centre and R&D laboratories in all the operating units of the Company accredited in accordance with the standard ISO/IEC 17025:2005 by NABL.

Investment decision for setting up of Samarium-Cobalt based Permanent Magnet Plant at Achutapuram, Vizag has been received. Activities for obtaining environment clearance prior to initiating site activities are in progress.

Setting up of Rare Earth Theme Park which interalia includes setting up of pilot plants in the value chain of Rare Earths based on home grown technologies, entrepreneur cum skill development center and state of the art R&D laboratories has been initiated. Funds have been sanctioned for the project and IREL is in dialogue with various State Governments for allotment of land.

A flow sheet for efficient process for high recovery of pure Hafnium (Hf) as oxide from the Zirconium Scrub Raffinate (ZSR) stream of zirconium oxide plant was developed at BARC. In demonstration at bench-scale about 300g of  $\text{HfO}_2$  with 95% purity was recovered.

## Fuel Fabrication

Nuclear Fuel Complex (NFC) manufactures and supplies fuel bundles for Pressurised Heavy Water Reactors (PHWRs) and Boiling Water Reactors (BWRs) of NPCIL. Highest ever production of PHWR fuel bundles was achieved from Uranium dioxide ( $\text{UO}_2$ ) powder to pellet route during the period.

Process route has been established with radial forging & single pilgering and produced 210 nos. of coolant tubes meeting stringent specifications for the purpose of En Masse Coolant Channel Replacement in 220 MWe PHWRs.

NFC-Kota project is under execution at Rawatbhata, Rajasthan. The project office is established and basic infrastructural activities of site grading, roads, drains, gates, watch towers, water reservoir and ware houses have been completed. Construction power supply is energised and the main activity of construction of Plant and Non plant buildings is in progress.

## BACKEND FUEL CYCLE

### Fuel Reprocessing and Waste Management

Refurbishment and up-gradation of various process systems, utility systems as well as instrument & control systems was taken up at Plutonium Plant, Trombay to continue operation in safe and efficient manner. Towards the implementation of the concept of “wealth from waste” caesium (Cs) was separated and immobilized in vitreous matrix to Cs- glass pencils and handed over to BRIT for its application in blood irradiators. The Minor Actinide Product Conversion Demonstration System (MAPCDS) for downstream processing of Actinide Separation Demonstration Facility (ASDF) product solution and its conversion into oxide has been setup. Induction Skull Melting (ISM) technology developed indigenously by BARC was successfully deployed for the melting and homogenization of Al-Si alloy.

## R&D OF POWER SECTOR

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

A Three-Axes custom built Measuring Machine is developed to measure diameter at various sections throughout the length of the irradiated pressure tube of the PHWR, profile of OD of the tube and quantification of surface cracks/defects etc. Shut-off Rod Drive Mechanism design is qualified through prototyping and subjecting it to life-cycle testing on full-scale mock-up test station. Linear Variable Differential Transformer (LVDT) based calandria tube sag measurement tool 'CATSAM 220' was developed, function tested in the lab at BARC and later deployed in KAPS-2 and Sag

measurement was carried out for 19 calandria tubes. The most critical step in fabrication of high efficiency phosphor bronze packing internals was completed for 14 column sections for PHWR. Installation of four indigenous Gamma Compensated boron lined Ionisation Chamber (GCIC) with Hanger Assemblies for neutron flux monitoring for reactor control and safety for Compact LWR has been completed.

## HEALTH, SAFETY & ENVIRONMENT

BARC has developed a solar powered Radon Geo-Station using indigenous Radon (Rn) Monitor (SMART RnDuo) which has the potential for early warning of earthquakes. A Back Pack Spectrometry System has been designed and developed for usage by Emergency Response Teams/First Responders to search, detect, locate and identify 'Orphan' radioactive sources. Health Physics Units (HPUs) are established at front end and back end nuclear fuel cycle facilities related to U mining and ore processing, beach sand mining and monazite processing, fuel fabrication, reprocessing and waste management to carry out radiological surveillance in-plant monitoring and personal monitoring of about 12,200 workers and monitoring of environmental discharges. Results of the surveillance programmes were in compliance with regulatory limits. Environmental Survey Laboratories (ESLs) are established at each nuclear facility as an independent agency for monitoring of environmental matrices to measure activity concentration of concerned radionuclides. Following media concerns on the high U content in drinking water of Punjab, BARC has taken a pro-active initiative to generate a national database on U in drinking water in 706 districts of India under National Uranium Project (NUP). Two prototype units of Environmental Radiation Monitor with Autonomous Vertical Profiler (ERM-AVP) for underwater radiation monitoring near coast, discharge points of nuclear facilities, ships and for detection of radiation sources lost in water etc were developed and field-tested in the Arabian Sea near Mumbai coast.

NPCIL has recorded about 473 reactor years of safe operation of reactors as on end December 2017. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety

Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by Atomic Energy Regulatory Board by following the principles of As Low as Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB. NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001: 2004 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.

The safety systems adopted and concern towards environment have helped all Heavy water Plants achieving better safety records compared to similar chemical industries in the country. All plants are certified for ISO Quality Management system, Environmental Management System and OSHA System.

## 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 other. 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

During the period, Fast Breeder Test Reactor (FBTR) continued to play an important role in testing the fuels, structural materials and special neutron detectors for FBR programme. Twenty-fifth irradiation campaign was completed with central experimental sub assembly and one Mark II sub assembly reaching their burn-up limits. Reactor was operated at 27.3 MWt generating an electrical power of 6.0 MWe. It is planned to commence the 26th irradiation campaign in January 2018 during which reactor power will be raised to 30.2 MWt generating an electrical power of 7.0 MWe. Major missions of 26th irradiation campaign include irradiation of sodium bonded metallic fuel pins and long term irradiation of structural materials.

### Prototype Fast Breeder Reactor

Prototype Fast Breeder Reactor (PFBR) is in advanced stage of commissioning. The major activities that have been completed during the year are: Integrated preheating of primary & secondary heat transport systems after ensuring leak-tightness and inertness of the systems, Integrated Leak Rate Test (ILRT) & deflection measurements of Reactor



Overall view of Prototype Fast Breeder Reactor

Containment Building (RCB), Sodium filling and commissioning of both the secondary loops etc. Presently, work is in progress for commencement of sodium filling in Main Vessel. This will be followed by isothermal testing, fuel loading and first approach towards criticality.

IGCAR continued to provide support to BHAVINI for commissioning of various systems. Support was also provided for performing detailed thermo-mechanical analyses to establish the performance of various systems being commissioned.

### FBR Fuels

To understand the fuel pin behaviour with designed linear heat rating (LHR) of FBTR, sodium bonded-metal alloy fuel pins with more fissile content containing U-Pu-Zr metal slugs were fabricated and qualified at IGCAR. BARC supplied the required mixed carbide fuel for FBTR (Fast Breeder Test Reactor) at Kalpakkam.

### Fast Reactor Fuel Reprocessing

Construction of the Fast Reactor Fuel Cycle Facility (FRFCF) and fabrication of major components for the same are gaining momentum.

### FBR Related Technologies

The R&D activities for the fast reactors and associated fuel cycle included Dissimilar Metal Weld Inspection Device for PFBR; Hydraulic performance evaluation of failed fuel localization module of PFBR; Demonstration of carbon removal from liquid sodium; Development of 450NB frozen seal butterfly valves; Commissioning and Operation of Sodium Facility for Component Testing; Studies on PFBR source pin wettability using sodium as test medium; Performance evaluation of 200 NB size Samarium Cobalt (SmCo) type PM Flow meter; Qualification of wire type leak detector layout for dished ends; Feasibility Study to detect sodium leak in nitrogen atmosphere using Sodium Aerosol Detector; Performance evaluation of Start-up Neutron Detector Handling Mechanism of PFBR; High temperature testing and qualification of Eddy Current Flow Meter (ECFM) of PFBR Primary Sodium Pump; Argon and steam injection experiments

in Sodium Water Reaction Test facility; Demonstration of Alternate Handling Scheme for BHAVINI and Investigation on heat removal capability of core catcher through natural convection.

## Future FBRs

Subsequent to the conceptual design of systems & components of future FBRs, detailed design studies and neutronics, structural and thermal hydraulics analyses were taken up towards finalizing and firming up the design. This has contributed to significant progress in the design of the future FBR. This include, finalization of the 'safety design code' to be adopted, mapping of FBR safety criteria against the international GEN-IV safety design criteria, design of 'hydraulically suspended absorber rods', equipment layout of fuel and decontamination buildings, In-vessel shielding optimization, structural analysis of grid plate, quantification of fretting wear in IHX tubes, flow induced vibration analysis of main vessel cooling baffles, comparison of dome and box-type roof slabs, development of integrated thermal hydraulic models for steam generators, design of facilities to qualify large diameter bearings and reverse flow block mechanisms.

Towards having a continued 'fast spectrum test reactor facility' and also as a replacement for FBTR, conceptual design of a 100 MWt test reactor (tentatively named as FBTR-2) with metal fuel as the driver fuel was evolved. A detailed assessment on the proposed use of the reactor such as power generation, desalination or dual use was studied. The final recommended option is power generation.

As an import substitute, a bearing measuring 4.6 m diameter was designed and developed successfully. Irradiation Capsule Fabrication Facility was established exclusively for encapsulation of fuel pins in irradiation capsule to enable irradiation in FBTR. As part of indigenous technology development for use in future Indian FBRs, a 450NB frozen seal butterfly valve was designed and manufactured successfully in collaboration with industry.

## Health, Safety & Environment

Effective radiological surveillance and health physics services were provided for the radioactive

facilities. TLD personnel monitoring services, covering about 3000 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 900 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for about 200 occupational workers were also carried out.

In-situ/in-house testing of more than 160 HEPA filters in various facilities at IGCAR and 40 HEPA filters from NFC, Hyderabad was completed. Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated. Various samples around active facilities and other samples for low level counting and determination of the radioactivity from different institutions and industries were also catered to.

Radon measurements were carried out on natural samples to quantify the environmental radioactivity levels and thereby estimating the annual effective dose due to natural background radiation.

Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Dr. Kalam Science Yatra starting from Rameswaram to Chennai was organized as part of radiation awareness programme in connection with third edition of IISF-2017. Indigenously developed Online Nuclear Emergency Response Decision Support system was demonstrated during offsite radiation emergency exercises.

## 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

Integrated Test Station (ITS) comprising of full-scale prototypes of major Control & Instrumentation (C&I) systems of Advanced Heavy Water Reactor (AHWR) has been setup at BARC for validation of AHWR C&I system architecture, system application development and integrated system testing of functional, performance and safety requirements.

### KAlpakkam MINI (KAMINI) Reactor

KAMINI reactor was in a shutdown state for replacing the existing computer based alarm annunciation operator information system, process interlock and reactor regulation system with a state-of-the-art single embedded system. The system was commissioned successfully and regular operation of the reactor was commenced, after obtaining necessary regulatory clearance. KAMINI continued to support the testing of pyro devices for ISRO and also for activation analysis and irradiation of various samples.

## 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

A prototype 650 MHz (Beta=0.92) five-cell



*First 650 MHz (Beta=0.92) five-cell SRF cavity in the country, developed at RRCAT*

superconducting radio frequency cavity has been fabricated. This is the first 5-cell, high beta, 650 MHz cavity fabricated in the country.

A semi-automatic machine for tuning of five-cell 650 MHz SRF cavities has been designed and developed to achieve the required resonating frequency and field flatness at room temperature. A five-cell 650 MHz cavity fabricated in niobium has been tuned using this machine. A computer code has been developed and benchmarked for simulating the performance limiting phenomenon of multi-pacting in SRF elliptic cavities.

A 100 kV, 20 A compact, all solid state, long pulse converter modulator and Marx modulator to drive high average power klystrons for future linacs has been developed and tested at low pulse repetition rate on dummy resistive load.

A filament arc discharge based multi-cusp H<sup>-</sup> ion source has been designed and developed for high energy proton linac to achieve the peak H<sup>-</sup> ion beam current of 12 mA at accelerating voltage -50 kV DC, with 100 amperes arc discharge current in pulsed mode.

RRCAT has designed and developed ten dipole magnets with different bending radii and field values. These magnets have been supplied to BARC for manufacturing of mass spectrometers. A microcontroller based inverted magnetron gauge controller with Switch-Mode Power Supply (SMPS) has been designed and developed indigenously.

The Pelletron-Linac facility has recorded 77% uptime delivering various ion beams through Pelletron and Linac booster as per users' requirement. A 75 MHz, 25 kW, continuous wave RF amplifier has been installed

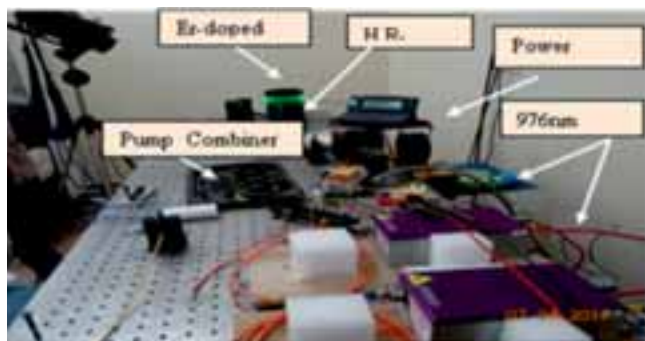
and commissioned at BARC to power the prototype room temperature heavy ion RFQ (Radio Frequency Quadrupole).

A cost effective high temperature dilatometer (Temperature range: 300-1373 K) has been developed indigenously and is being used for thermal expansion measurements of nuclear materials. A laser spectroscopy based heavy water detection system has been developed using highly sensitive off-axis integrated cavity output spectroscopic technique.

A new neutron powder diffractometer-I with a multi-detector system consisting of  $^3\text{He}$  neutron position sensitive detectors has been installed and commissioned at the beam hole TT-1015, of Dhruva reactor under National Facility for Neutron Beam Research (NFNBR). The diffractometer is available for in-house as well as external researchers for the investigation of magnetic materials over a temperature range of 2 K to 320 K.

## Laser Technology Development and Applications

Nd:YAG optical fiber coupled laser systems capable of delivering 500W average power have been developed. Beam quality of these lasers have been improved. Two such lasers were delivered to IGCAR for laser cutting of irradiated fuel subassemblies. A compact Nd:YAG laser system with single lamp ceramic reflector pump chamber has been developed for BARC and will be used for leak tight welding of radioactive iodine sources for brachytherapy treatment of eye and prostate cancer. Earlier a similar system was made for welding of radioactive iridium sources and provided to BRIT, Mumbai.



*Table-top view of Er-fiber laser*



*260W diode pumped solid state green laser under operation*

An all-fiber Er-doped CW fiber laser has been developed. The laser is capable of delivering power of 25W. The laser output is at 1600nm (line width 1.5nm) which is in eye safe region. This laser has potential applications in remote sensing, range finding, skin surgery, and free space communication. An intra-cavity frequency doubled acousto-optic Q-switched Nd:YAG laser has been developed. The laser is capable of generating 73ns pulses at 18kHz repetition rate: thus giving an average output power of 260W at 532nm. This laser has a potential for material processing of high reflectivity materials and pumping of tunable lasers such as dye laser, Ti: sapphire laser etc.

Two numbers of engineered version of Diode Pumped Solid State (DPSS) green laser systems were developed for BARC for pumping of dye laser amplifier chain. A multi pump module, diode-pumped fibre coupled high power CW Nd:YAG laser has been developed. This laser has potential applications in sheet metal cutting, welding and cladding. Several power supplies has been developed for various lasers.

The other technologies developed at RRCAT for various applications included the In-situ Laser cutting of bellow lip weld joints of KAPS-2 reactor; Underwater laser cutting of pressure tube stubs in KAPS-2 reactor; Laser cutting technology for removal of Q-15 and P-18 coolant channels from KAPS-1 reactor; Laser cutting of secondary shutdown system pipeline for replacement of double check valve at KKNPP-1 reactor; Laser cutting of triangular blocks at RAPS-3 reactor for enhancement of creep margin; Laser additive manufacturing of Deloro-50 bushes; Installation of radioactive environment compatible fiber Bragg grating based temperature sensor system at BARC, Tarapur; Laser shock peening for inter-granular corrosion suppression of sensitized 304 stainless steel and enhancing the fatigue life of hard chrome plated 15-5 PH stainless steel; Development of

a computer based cancer diagnostic system for screening of oral or cervical cancer; Development of a low cost tuberculosis screening and diagnostic device; Development of a hand-held video microscope for non-invasive imaging of micro-vasculature and blood flow etc.

## Electronics & Instrumentation

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. New Products Introduced during the year 2017-18 were Plastic Scintillator based Portal Monitoring System (PMS), Phasor Measurement Unit (PMU), RF Seeker for BrahMoS Missile, 0.45 M KU Band Airborne SATCOM Terminal, 4.6 M Ship Borne Antenna System, Linux based MPROGICON 5100 PLC system, Situation Awareness Unit (SAU), Antenna & Signal Distribution Units (ADU & SDU) for V/UHF & HF, EC-POS and Checkout System for ASTRA Missile & Launcher.



**EC-POS**

Satellite Communication (SatCom) terminal provides a stable and uninterrupted full-duplex communication link between ground control station and the airborne vehicle through a geostationary satellite. The 0.45 Satcom terminal jointly developed by ECIL-BARC was installed on DRDO's indigenous Airborne Early Warning and Control System (AEWACS) and flight trials were carried out successfully. E-fence based perimeter intrusion detection system was designed and installed at different installations.

## Cryogenics

Compact brazed aluminium plate fin heat exchanger have been developed through a local vendor for the operation of 50 lit/hr indigenous helium liquefier. A method has been conceptualized for storage and transportation of fruits and vegetables using liquid nitrogen. This system has been tested for the temperature between -50°C to 20°C.

A cloud of electrons has been successfully trapped at both the room temperature and liquid nitrogen temperature using an indigenously developed Penning trap and detection electronics system is shown in the picture. The performance of the indigenously developed detection electronics for Cryogenic Penning Ion trap operating at 4K is being studied.

## 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 operate plants for radiation sterilization of medical products and radiation processing of spices and allied products and continued to offer services to medical and agro-industry. Radiation technology based tools and techniques benefitted variety of industries and social sector.



## Agriculture

At BARC, in breeder seed programme, a total of 272 quintals breeder seeds of Trombay groundnut varieties (TAG 24, TG 37A, TG 38, TG 39, TPG 41, TLG 45 and TG 51) were produced and distributed to seed growing agencies like National Seed Corporations, State Seed Corporations, seed companies and farmers in Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Odisha and West Bengal. Trombay Chhattisgarh Dubraj Mutant-1 (TCDM-1) rice was identified for release by Indira Gandhi Krishi Vishwa Vidhyalaya (IGKV), Raipur in 2017. One rice selection, BARCKV 13 was pre-released for Konkan region in medium slender and quality grain trials of Maharashtra State Rice Coordinated Trials, 2017. 5 rice mutants of Dubraj, Jawaphool and Safri 17 jointly developed by BARC and IGKV, Raipur were entered in Chhattisgarh State rice trials and 2 mutants of Dubraj and Sarfri-17 were entered into All India Coordinated Rice Improvement Programme (AICRIP) 2017. Improvement of yellow rust resistance in Indian wheat using induced mutations was carried out. In sugarcane, two radiation induced mutants of cv. CoC671 and Co 86032 (TAKS) entered into State level yield trials. Promising 16 mutants of cv. Co 86032 were multiplied for undertaking multi-location field trials at IGKV, Raipur and BARC field facility, Vizag. A rapid and convenient gel free system for screening single locus molecular markers based on SYBR green dye melt curve was developed. A Visual colorimetric biosensor kit was developed for qualitative detection of pesticides belonging to organophosphate and organocarbamate groups. Mosquito larvicidal biopesticide formulation has been field tested in collaboration with municipal corporations of Mumbai and Chennai.

## Food Technology

A novel process has been developed for shelf life extension of litchi at BARC. A technology was developed for preparation of de-bittered Karela juice having high bioactivity. Prebiotic idli using combination of moong dal, rice and irradiated (25kGy) psyllium husk powder was prepared. A probiotic chutney (lacto chutney) was also developed to serve along with idli. A Naso-Gastric Liquid Feed formulation (NGLF) in the



*De-bittered karela juice*

form of ready-to-eat soup powder was developed for immune-compromised patients.

One 10 MeV linac for irradiation of agricultural products has been installed at the ARPF site near DABH fruit & vegetable mandi, Indore. The second linac to go here is under final testing. The accelerating structure for third 10 MeV electron linac has been fabricated.

RRCAT carried out irradiation experiments on agricultural products with the electron beam facility for several users. The irradiated samples included several varieties of rice, ground nut and tuberose bulbs. These were irradiated in a wide dose range from 20 Gy to 500 kGy using the 10 MeV electron linac.

## Nuclear Medicine and Healthcare

More than 700 Ci of I-131 products in 22563 consignments have been supplied to various hospitals in the form of capsules and solution for both, diagnostic and therapeutic purposes for thyroid disorders and treating thyroid cancer. This also includes I-131 radiolabelled mIBG for diagnosis and therapy of Neuro Endocrine Tumors (NET).



*Production facility of I-131 Lipiodol at RPhP, Vashi Complex*

New therapeutic product based on I-131 radiolabelling,  $^{131}\text{I}$ -Lipoidal injection for the treatment of Liver Cancer, was launched by BRIT in collaboration with RPhD, BARC.

26.5Ci in 256 consignments of therapeutic products, other than I-131 based radioactive products, such as  $^{153}\text{Sm}$ ,  $^{177}\text{Lu}$  and  $^{32}\text{P}$  for bone pain palliation were supplied to nuclear medicine hospitals upto December 2017.

Regular production and supply of new therapeutic radiopharmaceutical,  $^{177}\text{Lu}$ -DOTA-TATE injection for the treatment ofsstr positive neuroendocrine tumors, has been started for treating NET successfully, after its RPC clearance.

Production and supply of Kit for the preparation of therapeutic  $^{188}\text{Re}$ -HEDP injection, another alternative product for bone pain palliation, is expected by March 2018.

About 1800 consignments containing approximately 450Ci of  $^{99}\text{Mo}$  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 upto December 2017.

More than 14800 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 product,  $^{99\text{m}}\text{Tc}$ -cold kit for the preparation of  $^{99\text{m}}\text{Tc}$ -Macro Aggregated Albumin (MAA) injection, useful for lung perfusion imaging, has been started. Production and regular supply of another new product,  $^{99\text{m}}\text{Tc}$ -Ubiquidine (Tc-UBI), used for infection imaging, is also started during the reported time.

Radiopharmaceutical Committee (RPC) approval is also obtained for extension of shelf-life (expiry date) of Technetium-99m cold kits, namely, DTPA and Phytate injections, from existing one year to two years.

Production of 'Kit for the preparation of  $^{99\text{m}}\text{Tc}$ -HYNIC-TATE injection', useful for imaging

neuroendocrine tumors, started as a part of technology transfer from RPhD, BARC.

A total of 2200 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits are produced and supplied to various pathology laboratories and nuclear medicine centres throughout the country for in-vitro diagnosis of thyroid disorders.

Around 437 batches of radiopharmaceutical samples and 36  $^{99}\text{Mo}$ - $^{99\text{m}}\text{Tc}$  COLTECH Generators were routinely analysed and certified by QC during this period upto December 2017.

Validation for in-house Bacterial Endotoxin Test (BET) of TCK products (Cold kits) was successfully completed. The method is implemented in regular Quality Control tests of TCK kits. HPLC method for the analysis of  $^{99\text{m}}\text{Tc}$ -MIBI is standardized and would be put up for RPC approval. Animal use for the analysis will be stopped, once it is approved by RPC.

Batch Manufacturing Production Records (BMPR) for TCK cold kits (19 Products) were modified and improvised as per GMP guidelines.

BRIT continued the synthesis and supply of a variety of  $^{14}\text{C}$ ,  $^3\text{H}$  and  $^{35}\text{S}$ -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.

Since April 2017 and upto December 2017, more than 16000 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.

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 newly launched [F-18]-FET, which are produced in smaller scales.

So far 253 Ci of [F-18] FDG in 563 consignments have been supplied to various hospitals in Mumbai for PET imaging upto December 2017. More than 15000 patients are benefitted with PET investigations in the reported year 2017-18.

A clinical-scale (18.5 GBq)  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$  generator was developed at BARC using indigenously produced  $^{99}\text{Mo}$  by direct neutron activation route in the Dhruva reactor. Supply of  $^{125}\text{I}$  brachy therapy seeds was continued for the treatment of eye cancer.  $^{20}\text{Fe}$  X-ray sources (1.48 MBq each) were supplied by BARC to ISRO, Bangalore for use in Chandrayaan mission.

### Alternative Applications of Heavy Water

The first indigenously developed  $^{18}\text{O}$  production plant at HWP, Manuguru has reached the enrichment of  $^{18}\text{O}$  up to 39.3%. The first milestone of meeting. The final product of desired quality as  $\text{H}_2^{18}\text{O}$  will find application in nuclear medicine and bio-chemical research i.e. in PET scanning and metabolic studies.

### Cancer Diagnostics & Treatment Services

The Tata Memorial Centre (TMC) continued its mission to provide comprehensive cancer care to one and all, through the motto of excellence in its holistic services, continual education of medical and paramedical staff, and of research that is affordable and of relevance to our population. TMC launched TMC-Navya, the online second opinion services for the general population from cancer specialists. The indigenous Bhabhatron, the Telecobalt radiotherapy machine, has been given to 20 centres till now and, has been used to treat a lakh of patients. Successful bone marrow transplantation was performed on 68 patients suffering from various types of blood cancer. The clinical laboratories performed almost 45 lakh investigations. The Homi Bhabha Cancer Hospital in Sangrur district of Punjab has started functioning and more than 4000 patients have been treated. The Homi Bhabha Cancer

Hospital & Research Centre in Visakhapatnam continued to offer its services. Work to set up the Homi Bhabha Cancer Hospital & Research Centre in Mohali, Punjab and the Mahamana Pandit Madan Mohan Malviya Cancer Centre in Varanasi progressed.

### Industrial Applications of Radioisotopes & Radiation

At BRIT, nineteen teletherapy sources (CTS) of  $^{60}\text{Co}$  containing activity in the range of 154 and 232 RMM were supplied to different cancer hospitals in India and abroad upto December 2017.

Co-60 with activities of 808 Ci in eleven pencils and 83,711 Ci in 128 pencils were loaded in one unit of Blood Irradiator (based on Co-60 BI 2000) and six units of Gamma Chamber 5000 respectively. Cs-137 is planned to be loaded in Blood Irradiator 2000, the availability of which is being awaited from WMD, BARC. Also, loading of Co-60 source in two units of Gamma Chamber 5000 is planned upto March 2018.

Sixty six Irradiator sources of industrial grade in eight consignments with total activity of 11, 01, 002 Ci (1101 kCi) were supplied to nearly eight radiation processing plants within the country and abroad. Another 650 kCi of activity is planned to be sent to four processing plants within India upto March 2018.

Co-60 teletherapy source of 180 RMM was exported to Kenyatta National Hospital, Kenya. One Co-60 Irradiator source of 125 RMM was exported to Sri Lanka Atomic Energy Board for source replenishment in Multipurpose Gamma Irradiator at Biyagama.

A total of 595 consignments (with total activity of 26,845 Ci) of  $^{192}\text{Ir}$  & twelve numbers of  $^{60}\text{Co}$  Radiography sources containing 662 Ci of activity were supplied to NDT users. Another 200 sources of  $^{192}\text{Ir}$  with 9500 Ci activity and two numbers of  $^{60}\text{Co}$  sources with 100 Ci activity is expected to be supplied upto March 2018.

Thirteen consignments of Co-60 Custom Made Reference (CMR) sources with total activity of 739 mCi were supplied and another 4 sources with 250 mCi is planned to be supplied upto March 2018 to its users.



Integrated Facility for Radiation Technology (IFRT) continued the fabrication & loading of radioactivity (sealed sources) in Gamma Chambers and Blood Irradiators which are supplied from Vashi Complex

At BARC, Radiotracer technique has been successfully applied for the first time in India to accurately measure the flow rate of water in two large diameter pipelines (dia: 3.6 meter) carrying sea water for cooling into a condenser of thermal power plant.

## Radiation Processing

About 3872 Cubic meters of medical supplies have been sterilized using gamma radiation processing at ISOMED, BRIT upto December 2017. About 3654 MT of spices and allied products were processed during the reported time period. It is expected to process nearly 5000 MT of various products upto March 2018. Surveillance Audits for ISO – 22000:2005 (Food Safety Management Systems) and ISO 9001:2008 were carried out by certifying agency and found the Radiation Processing Plant at Vashi, in full compliance with Standard's requirement. Dose rate certification was provided to two blood irradiators and three gamma chambers which were supplied to various cancer hospitals and research universities respectively. Production & supply of 1.5 Lakhs Ceric-Cerous Sulphate Dosimeters were done for various gamma irradiators in the country and abroad for the measurement of absorbed dose. NABL accreditation was renewed for the Calibration Dosimetry Laboratory till 2019. BRIT signed two MoU's for setting up Gamma Radiation Processing Plants for disinfection, shelf-life extension of food products and sterilization applications of healthcare products. One with M/s Jamnadas Industries, Dahod, Gujarat, to set up Gamma Radiation Processing Plant at Indore, Madhya Pradesh and the other MoU was signed with M/s. Andhra Pradesh Med Tech Zone Ltd., Vishakhapatnam, Andhra Pradesh.

## Radiation Technology based Equipment & Services

Forty three Radiography Cameras, ROLI-2 model, were supplied to various NDT users within India and services were provided for 658 numbers of BRIT

and imported radiography cameras. Five Blood Irradiators – 2000 (BI-2000) units with Cs-137 source were supplied to hospitals in India in the reported time period. Four Gamma Chamber – 5000 units have been supplied to various Universities/Institutions for research purposes upto December 2017.

Portable Extra-Cellular Acidity Analyser (ECAA) has been developed at BARC to differentiate cancer cells from normal cells in cancer diagnosis. An improved 4D dynamic phantom system was designed and developed which contains a plastic body having provision for accepting inserts (targets of different dimensions and targets with dosimetry detectors), a motor drive system and a graphical user interface based operating software. A unified phantom containing various test objects for performing comprehensive imaging QA tests on Computed Tomography (CT) scanners was designed and developed

## Water Purification, Water Desalination & Isotope Hydrology

BARC provided technical assistance in the installation and commissioning of two units of 500 m<sup>3</sup>/h Water Treatment Plant (WTP) at Holy Shiv Ganga Pond, Deogarh, Jharkhand. A safe, simple and low cost solution for remediation by removal of fluoride to make water potable using rare earth material as adsorbent has been developed. Hybrid Biofilm-Granular Sludge (HBGS) technology was developed for treating industrial waste waters generated in DAE units.

## BASIC & APPLIED RESEARCH

Basic and applied researches relevant to DAE's programme are carried out in the research centres of the department and the autonomous research institutes are supported by the grant-in-aid. 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, in Mathematics, evidence was established of a Homotopy and Commutativity Principle

for special linear, symplectic and orthogonal automorphisms. The techniques of Euler Class groups were used to prove that certain unimodular rows of length three over a class of rings are completable. Under Interdisciplinary Mathematics, study is being carried out on how dumbbells, placed inside a tilted hollow cylindrical drum that rotates slowly around its axis, climb uphill by forming dynamically stable pairs, seemingly against the pull of gravity.

At IMSc, a new comprehension of certain distinguished bases for representations of the Lie algebras of traceless matrices and their current algebras were obtained. A new class of smooth manifolds were studied.

## Physics

The work related to the assembly of the MACE telescope is at an advanced stage at Hanle. The Imaging camera of MACE telescope has been installed on the telescope at Hanle site with electronics for 188 channels.

One of the most significant work in basic research, which made high impact this year is the extraction of shear viscosity from the  $\tau$ -decay of the isovector giant dipole resonance for the first time, employing the LAMBDA spectrometer using the alpha beams from the K-130 cyclotron. This work has resulted into a publication in Physics Review Letters. A major experimental campaign of Indian National Gamma Array (INGA) has started at VECC with light ion beams using the setup of state of art Clover HPGe detectors and Low Energy Photon Spectrometers (LEPS) along with the Digital Signal Processing (DSP). The VENTURE (VECC array for nuclear fast Timing and angUlar corRElation studies) array of fast timing CeBr3 detectors has also been used for measurements of lifetimes of nuclear excited states in pico second range.

In Nuclear and Atomic Physics at TIFR, innovative use of intense 5 fs duration laser pulses has enabled demonstration of ultrafast intramolecular proton migration and bond-selective dissociation of small molecules for the first time. In Condensed Matter Physics and Materials Sciences an important research has found evidence for bulk superconductivity in pure

bismuth single crystals at ambient pressure. This discovery also makes Bi as the superconductor with the lowest carrier density thus, breaking the record held by doped SrTiO<sub>3</sub> for nearly 50 years. In Theoretical Physics under Condensed Matter and Statistical Physics a novel superconductor driven by resonant tunnelling was predicted in the Ionic Hubbard model.

IOP remained focused in the vibrant research program in the fields of theoretical and experimental condensed matter physics, theoretical high energy physics and string theory, theoretical nuclear physics, ultra-relativistic heavy-ion collisions and cosmology, quantum information and experimental high energy nuclear physics. The important research areas in the field of nanoscience, nanotechnology, and surface and interface studies continued. The 3MV Pelletron accelerator facility catered to around 80 research groups from various Institutes, IITs, IISERs and Universities across the nation.

The Institute of Mathematical Sciences (IMSc) have addressed the possibility of New Physics (NP) beyond the Standard Model of particle physics in rare decays of beauty quarks to strange Quarks and pairs of leptons.

## Synchrotrons and their Applications

The synchrotron radiation sources, Indus-1 and Indus-2, are a national facility, and are being operated in round-the-clock mode since Feb. 2010. Indus-1 is



*A view of the indigenously developed RF cavity installed with the Indus-2 ring straight chamber*



operated at 450 MeV energy, 100 mA current, and Indus-2 is operated at 2.5 GeV energy and current up to 200 mA. The Indus facility underwent a major upgrade in 2017. This entailed installation and commissioning of the first indigenously developed RF cavity in Indus-2, replacement of the microtron with an improved version, and upgradation of transport line from the microtron to the booster synchrotron. During 2017, the Indus machines have operated for 325 days. The beam availability to users was more than 6500 hours for Indus-1 and more than 5000 hours for Indus-2.

The first 505.8 MHz. bell shaped copper RF cavity, designed and developed indigenously, was installed and commissioned in Indus-2. With this indigenous RF cavity deployed along with the existing four other RF cavities, more than 200 mA beam current at 2.5 GeV beam energy was achieved in Indus-2.



**New 20 MeV injector microtron for Indus**

The aging 20 MeV/ 30 mA injector microtron of the Indus accelerators has been replaced with a new upgraded version. The new microtron has improved mechanical design and additional diagnostic features for better performance. In addition to the microtron, the Transport Line-1 (TL-1) which takes the microtron beam to the booster synchrotron, was also upgraded by installing new vacuum chambers, vacuum gauges, upgraded beam position monitors, and additional beam slit monitors.

Several types of specialized power converters and power supplies, with improved performance, were developed, installed, and commissioned in various sub-systems of Indus-1 and Indus-2. A betatron tune feedback system is used in Indus-2 to ensure electron beam stability and to maintain the betatron tune constant within specified band, during machine operation. An enhanced version of the betatron tune feedback system has been developed and successfully deployed in Indus-2.

A Raman Optical Fibre Distributed Temperature Sensor (ROFDTS) has been developed and deployed for detection of hot spot in one of the dipole magnet vacuum chambers (DP-2) of Indus-2.

Some additional control systems have been developed and deployed in the Indus synchrotron radiation source facility. Various web based software packages have been developed or upgraded. These are e-Logbook; f-Logbook and Indus-Online.

During 2017, upgraded versions of several subsystems of the Indus SRS facility have been developed and tested. These will be deployed in near future. These include Upgrade of pulsed injection kicker magnets of Indus; Modification in Indus-2 dipole magnet; Upgradation of beam diagnostic system of Indus-2; Development of non-evaporable getter coated aluminium chamber for Indus-2 and Design and Development of a 505.8 MHz RF circulator.

Indus-1 and Indus-2 are national facilities with 10 beamlines in Indus-2 and 6 in Indus-1 available to users. More than 700 user experiments were carried out in the calendar year 2017 leading to 120 research publications in peer reviewed international journals. RRCAT, in collaboration with Indian Space Research Organization and Indian Institute of Astrophysics, has developed multilayers of Tungsten / Boron Carbide (W/B<sub>4</sub>C) for multilayer reflective mirrors to be used in X-ray telescopes for astronomical applications. Several users have utilized the Indus beamlines to study various materials of potential technological interest. The protein crystallography beamline has been used for determination of the crystal structure of several proteins. Some of the Indus beamlines have been upgraded to carry out more challenging and novel experiments by the users.

An in-situ Extended X-ray Absorption Fine Structure Spectroscopy (EXAFS) setup has been designed and installed to probe heterogeneous catalysis reactions on-line at Indus-2 SRS at RRCAT, Indore.

## Fusion and Other Plasma Technologies

A Plasma jet developed (patent filed in India) by IPR has been used for skin treatment trials in IPGMER-

SSKM Hospital, Kolkata. The patients were cured in 2-3 sittings without any additional medicines/oointments. Infection did not recur even after one year and there were no observable side effects.

Following his deep interest in IPR's technologies during the Parliament House exhibition, Shri Giriraj Singh, Hon'ble Minister of State (I/C) for Micro, Small and Medium Enterprises visited IPR. A live demonstration before the Hon'ble Minister showed that plasma treatment for 15 minutes allows the use of natural dyes like indigo on Khadi, which is of great interest to Khadi & Village Industries Commission (KVIC). He expressed interest in deploying such systems in training centres run by KVIC. He also expressed a desire to install IPR's Plasma Nitriding systems in all Central Tool Rooms operated by his ministry. IPR has sent offers in both areas.



**Shri Giriraj Singh, Honourable Minister of State observing the plasma nitriding system**

Plasma Nitriding system along with documentation describing optimized process parameters and Standard Operating Procedures, has been delivered to ISRO Inertial Systems Unit, Thiruvananthapuram.

Plasma Thrusters are routinely used for attitude control & station-keeping of satellites. ISRO has so far imported these thrusters. IPR has developed good understanding of helicon-wave driven plasmas through basic experiments over the past several years. Leveraging this expertise, IPR has started in-house development of this critical system. An important step is the in-house development of three-dimensional software which has just been completed. This is providing new insight into the dynamics of such Thrusters, especially oscillations in Thrust. This insight

will help in design/optimization of in-house experimental systems.

An IPR-supplied Regulated High Voltage Power Supply (RHVPS) for the LEHIPA experiment at BARC has been re-commissioned for a new phase of experiments with LEHIPA. All sub-systems of RHVPS (i.e., power modules, transformers and controller) have been successfully tested and commissioned by a team of scientists and engineers from IPR. A long (approx. 15 days) round-the-clock campaign has been successfully concluded.

A 200m long Nb<sub>3</sub>Sn based multi-filamentary superconducting wire has been fabricated by BARC.

## Chemistry

A sensitive technique for the detection of Fibril or plaque formation of the native proteins both in-vitro and in-vivo for diagnosis and therapy of amyloidosis was developed at BARC.

A simple and rapid visual colorimetric method based on using a complexing agent followed by pre concentration using a surfactant that results in the formation of coloured complex instantaneously was developed for the detection of U in ground water.

A silver nanoparticle based optical test strip has been developed by synthesizing silver nanoparticles in Nafion-117 membrane for quantitative assay of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) in aqueous solution.

BARC has developed synthetic diamond based H<sub>2</sub>S (range 0.5-20 ppm) sensor and tin oxide thin film based SO<sub>2</sub> (range 1-100 ppm) sensor operating at room temperature to monitor these gases in petroleum refineries and other industrial establishments.

In collaboration with India Government Mint (IGM) and CSIR-NPL, New Delhi, Certified Reference Standard of 9999 fineness (99.99% purity) gold was prepared [Bharatiya Nirdeshak Dravya (BND 4201.1)] as reference standard for Analysis of gold content in gold bullion, carat gold and gold artifacts, analytical procedures of cupellation by fire assay method and reference standard of gold for calibration of instruments.

At SINP, the detailed conformational dynamics of the melted region in double-stranded DNA has been studied using a combination of ensemble and single-molecule FRET techniques that has been developed in house.

## Biology

At BARC, a radiation dose response calibration curve for exposure to  $^{60}\text{Co}$ - gamma rays has been generated for biological dosimetry of suspected individuals exposed to radiation. The established method will be used for cumulative exposure scenario to estimate biological dose.

In Biological Sciences at TIFR, an important study was done on Malarial parasites. The only vaccine against malaria on trial by Smith Kline, (RTS,S), uses the antigen Circumsporozoite protein (CSP). In TIFR, a study has shown that CSP provides the malaria cell flexibility and pliability, possibly for a lubricative capacity required for its long and penetrating journey through tissue layers during early infection. At National Centre for Biological Sciences, Bangalore a study from Ecology and Evolution group revealed how deep valleys in the Western Ghats Mountains influence the species and biodiversity there, resulting in the new and unique species of birds. A new study showed how a single instance of severe stress can lead to delayed and long-term psychological trauma. Under Wildlife Biology and Conservation program on-the-ground conservation action across almost 25 Indian states, involved developing anti-malaria prevention measures for forest anti-poaching staff.

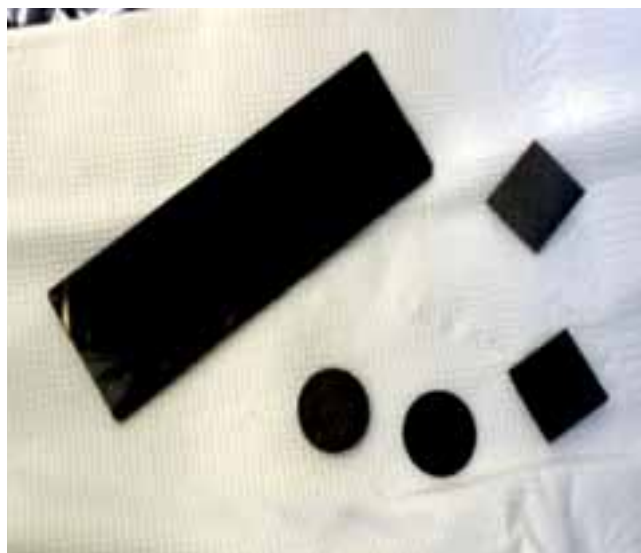
At IMSc, a new study on application of active matter ideas to the problem of collective phototaxis has been initiated and it is hoped to stimulate research along similar lines into other problems involving the physics of collective bacterial motion.

## Materials Science

High pure gadolinium nitrate hexa-hydrate ( $\text{Gd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ) meeting the stringent specifications for burnable poison application in KAPP 3 & 4 has been prepared from indigenous resources following the hydrometallurgical processing routes. BARC has developed light weight ballistic resistant jackets

(Bhabha Kavach), which are 20% lighter with respect to the existing ones. Bhabha Kavach uses carbon nanotubes (CNTs) and boron carbide which have been developed in house. Well dispersed nano-sized alpha-silicon carbide powder for developing SiC based structural component for the nuclear reactor has been synthesized by reaction conversion method.

The various activities undertaken at RRCAT on material science includes Demonstration of vortex-glass transformation within the surface superconducting state of the  $\beta$ -phase  $\text{Mo}_{1-x}\text{Re}_x$  alloys; Demonstration of magneto electric coupling in nanocomposites; Development of a magneto-photoluminescence and magneto-surface photovoltage setup for quasi-simultaneous measurements; Femtosecond laser induced photoluminescence enhancement of quantum dots; Growth and spectroscopic studies on nanomaterials; Theory and computational activities; Demonstration of high speed resistive switching in Au/NiO/Pt devices for fast and low power non-volatile data storage applications; Development of plasmonic gold nanoparticles based sensing technique for mercury detection ( $< 100$  ppb) in aqueous solution; Development of InAsP/InP multiple quantum well based IR detectors; Rare earth doped strontium barium niobate single crystals for pyro-electricity based laser energy meter application; Pt-Ti doped carbon aerogel catalyst for hydrogen isotope exchange; Transparent ceramic for X-ray imaging and Titanium thin film coating on ceramic sample.



*Titanium coated substrates*



VECC has characterized the Zirconium-based alloys, which are widely used in nuclear industry as cladding materials for BWRs and PWRs, by Grazing Incidence X-Ray Diffraction Technique after irradiation with 306 KeV  $\text{Ar}^{9+}$  ions from the ECR ion source. The evolution of the microstructure of the pure Nb metal was also carried out using 5 MeV protons from K-130 cyclotron.

At IGCAR, an advanced dual beam irradiation set up was developed to facilitate simultaneous helium ion injection from an indigenously built 400 kV accelerator and heavy ion irradiation from the 1.7 MV tandetron accelerator to closely simulate reactor conditions. Micro and Nano-crystalline Diamond films with improved crystallinity and well-defined color centres were developed. A prototype SQUID based time domain electromagnetic system for geophysical application has been developed and tested for the detection of conducting objects in the neighbourhood by recording the decay profiles. A transient eddy current non-destructive examination system for the detection of defects in multi-layered structures was developed.

## Cancer Research

At Advanced Centre for treatment, Research and Education (ACTREC) in Navi Mumbai, the Clinical Research Centre (CRC) remained focused on clinical and translational cancer research and on cancer treatment, and its Clinical Research Institute (CRI) performed basic and applied research on cancer. The hospital provided innovative better and cheaper treatment options for cancer patients.

## INTERNATIONAL RESEARCH COLLABORATIONS

On 16 January 2017, India has become an Associate Member State of CERN. The initial signing ceremony was conducted on November 21, 2016 between the Atomic Energy Commission Chairman, Dr. Sekhar Basu and the Director-General of CERN, Dr. Fabiola Gianotti.

RRCAT has successfully developed and installed a 20 kW pulsed solid state amplifier at CERN for energizing sub-harmonic, bunching system of the

Compact Linear Collider (CLIC) drive beam injector. The amplifier provides a pulse width of 140.3  $\mu\text{s}$ , repetition rate of 50 Hz, and 3 dB bandwidth of 58 MHz, with centre frequency 499.75 MHz.

The Photon Multiplicity Detector (PMD), developed at VECC is successfully taking data in the ALICE experiment, after a major repair of electronic modules, readout system. During the current year, VECC has made large size GEM chambers and RPCs for CBM experiments at FAIR facility at Germany. VECC has demonstrated, for the first time, the feasibility of using GEM chambers for X-ray imaging for medical purpose. In addition, VECC in collaboration with BARC and BEL has designed, developed and fabricated a 20Xr thick sampling type silicon-tungsten calorimeter prototype and tested at CERN-SPS. A new signature of first-order phase transition in intermediate-energy heavy-ion collisions could be observed from theoretical calculation using canonical model for nuclear multi-fragmentation.

The contributions of TIFR, under LIGO-Virgo collaboration, include tests of Einstein's theory using near-simultaneous observations of gravitational waves and gamma rays. It hopes to work on the development of a Bayesian framework to identify strong lensed gravitational wave signals from merging binary black holes and the development of a consistency test of general relativity using higher order multiples of gravitational radiation from merging black holes.

The Institute of Physics (IOP) remained actively involved in International Collaborations with CERN (Switzerland), BNL (USA), ANL (USA), GSI (Germany), and other laboratories around the world.

## ITER-Project

There has been visible progress of site construction and manufacturing activities. Physical progress of the ITER project is now at 48% for the components and systems necessary for First Plasma in 2025. From the beginning of the project in 2007, a total 14 (out of 15) Procurement Arrangements (PA) have been signed. Eleven major contracts for the manufacturing of ITER components have been signed till date. Good progress has been made at



**Base Section Tier-1 setup completed and cleared for welding**

manufacturing sites and some components are already delivered to IO or to other DA sites.

## RESEARCH EDUCATION LINKAGES

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

The synchrotron radiation sources, Indus-1 and Indus-2, are being operated in round-the-clock mode as a national facility. Several users have utilized the Indus beamlines to study various materials of potential technological interest. A number of research scholars from various academic institutions utilized the Dhruva reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

## HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

### Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a deemed to be University aided by DAE continued to nurture academic programmes of eleven premier institutions of the DAE under a single umbrella making it a vast research and faculty resource for students within DAE. It continued to serve as a catalyst to accelerate the pace of basic research and facilitated its translation into

technology development and applications through academic programmes viz. Postgraduate degrees/diplomas and Ph.D. degrees in Engineering Sciences, Physical Sciences, Chemical Sciences, Mathematical Sciences, Life Sciences, Health Sciences and Applied Systems Analysis.

### Training

While the academic programme of the 60th batch of BARC was continuing, screening examination for 9 engineering and 5 science disciplines for the 61st batch was organized at 65 venues in 45 cities. This year one candidate was selected for the first time in Nuclear Engineering discipline, which was introduced last year. A total of 164 candidates were selected for OCES/DGFS-2017. At BARC, a total of 126 Trainee Scientific Officers (TSOs) and 7 fellows of OCDF 2016 scheme, after successful completion of the training, were placed in various units of DAE. In order to promote DAE activities and thereby attract best talent to our fold, visits to as many colleges and universities as possible during January 6 to February 4, 2018 have been planned under the outreach programme.

Thirty three Trainee Scientific Officers of the eleventh batch of BARC Training School at IGCAR have completed their training in five disciplines and were placed in various units of DAE. Twenty three Research Scholars were inducted, to pursue their doctoral programmes in the frontier areas of engineering and basic sciences.

BARC Training School AMD Campus, Hyderabad continued its activity in the eighth year by imparting induction training to Geology and Geophysics Trainee Scientific Officers (TSO's).

Human resources development activities at RRCAT continued to contribute in a significant way towards development of quality scientific and technical manpower in the country. Trainee Scientific Officers (TSOs) were imparted one year training in physics, electrical and electronics disciplines, which also served as one year course work towards the successful completion of M.Tech. and Ph.D. degrees of HBNI, Mumbai.

NPCIL, continued to achieve the organizational goal through its HR initiatives directed towards attracting, motivating and retaining the trained manpower. These initiatives included developing strategic and incremental packages from time to time for effective Human Resource Management to meet the aspirations of the employees. Optimization of manpower continued to be an important strategy towards best utilization of human resource. Accordingly, staffing has been done strictly in accordance with the optimized manpower models for Projects, Stations and Headquarters, including multiunit Sites. Harmonious Employee Relations were maintained across NPCIL.

The Administrative Training Institute (ATI) continued to offer wide range of programmes starting from induction to post retirement & periodic in-service programmes and subject specific workshops ensuring depth and range.

## SPONSORED RESEARCH

### Promotion of Extra-mural Research in Nuclear Science

Board of Research in Nuclear Science (BRNS), as an advisory body of DAE continued the funding of research projects and provided financial assistance to organize symposia/ conferences/ workshops on topics of relevance to the programmes of DAE. BRNS also awarded projects to young scientists to initiate them in a career of research and Dr. K. S. Krishnan Research Associateship to identify and encourage highly talented young scientists and technologists. Graduate Level students for doing M.Tech. at the IITs were inducted through the DAE Graduate Fellowship Scheme (DGFS). The Raja Ramanna Fellowship of BRNS utilized the expertise of the retired eminent scientists for various ongoing programmes of the Department. To avail the honourable services of Scientists and Technologists who have distinguished themselves at national and international levels, the Homi Bhabha Chair has been instituted. During the calendar year, 112 new research projects were sanctioned. Fifteen new students were inducted under DGFS-Ph.D programme, Financial support to the tune of ₹ 278 Lakh was extended to DAE

as well as Non-DAE academic and scientific organizations for conducting 156 seminars on various topics of relevance to DAE. Out of these, 23 symposia were solely organized by the DAE fraternity and they were fully funded. Under the Raja Ramanna Fellowship scheme, grant for 64 scientists was disbursed, besides two Homi Bhabha Chairs.

### Promotion of Mathematics

NBHM has been in charge of the Mathematics Olympiad activity for talented young students at higher secondary (the plus two) level. In the EGMO 2017 (European Girls' Mathematics Olympiad held in Zurich, Switzerland during April 6-12, 2017, one member of the team won a bronze medal and another an Honourable mention for a perfect solution. In the APMO 2017 (Asian Pacific Mathematics Olympiad), the top 10 students from IMOTC participated and won 3 silver medals, 4 bronze medals and 4 honourable mentions. The IMOTC 2017 was held over 3 weeks from April 20th to May 18th in HBCSE, at the end of which a team of six students were selected to represent India in IMO 2017 in Brazil. The pre-departure camp for the six selected students was held from July 6-14, 2017 in HBCSE. The team secured 3 bronze and 3 honorable mentions. NBHM continued to conduct Madhava Mathematical Competition for the undergraduate students. NBHM gave grants to various Mathematical centers engaged in activities of promoting higher mathematics. The Board provided scholarships and fellowships to the students to pursue studies at masters and Ph.D. levels. The Board offered post-doctoral fellowship positions to the young Mathematicians after their PhD degrees through the selection process. The Board also provided grants for promotion of activities in pure and applied mathematics, under several schemes. NBHM has been providing grants to mathematics libraries around the country on regular basis.

## 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.

Establishment of Mahatma Pt. Madan Mohan Malaviya Cancer Centre in BHU Campus in Varanasi, Uttar Pradesh has been approved. The Department has taken over Dr. Bhubaneswar Borooah Cancer Institute (BBCI), Guwahati under the administrative control of Tata Memorial Centre (TMC), Mumbai. The Centre for Cancer Epidemiology has been set up with a dedicated facility in Advanced Centre for Treatment, Research & Education in Cancer at Kharghar. The Homi Bhabha Cancer Hospital in Sangrur District, Punjab has become functional.

### 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 2017-18 for such partial financial assistance is to the tune of ₹ 20.98 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. For this purpose, an Apex Committee was formed under the Chairpersonship of Director, TMC. The initiatives taken to achieve the above stated objectives will lead to further gains in the DAE's outreach in the cancer care programme.

### Olympiad Programme

The Olympiad teams representing India in the international Olympiads continued their run of successful performance. India was the 3rd ranking country in the International Junior Science Olympiad, 5th in the International Physics Olympiad and 5th in the International Olympiad on Astronomy and Astrophysics.

## INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

At VECC, a new High Performance Computing System with Theoretical Peak Performance of 90 TFLOPS have been commissioned and deployed to users.



**Inauguration of High Performance Computing System by Chairman, AEC and Secretary, DAE**

As part of e-governance initiatives of IGCAR, automation and integration of the activities in the areas of Administration, Accounts, Stores and Purchase with a software named as "Automated Workflow Management System (ATOMS)" was implemented in IGCAR. DAE Budget Automation System (DAEBAS) was developed, tested and implemented by IGCAR for automation of budgeting process of DAE.

Various workflow based software applications have been developed and deployed on RRCAT Infonet (RRCAT information portal). The data centre has been upgraded to accommodate 200 kVA of server load, distributed in 32 number of racks, with each rack of 42U size, capable of bearing 1200 Kgs of physical server loads. A new electronic messaging/ mailing setup with enhanced user email data storage has been commissioned for in-house usage. A web based monitoring system has been designed, developed and commissioned to visualize the state of electric fence surrounding the RRCAT campus.

As part of mobile-governance, a few employee-centric mobile phone based software applications viz IBA (Integrated Business Administration), TIME (Task and calendar management) and ONETEAM (Messaging solutions) were developed by NPCIL and are being widely used by employees.

## TECHNOLOGY TRANSFER

DAE has developed and transferred the spin-off technologies generated out of the core programmes of the Research and Development organizations to industries for commercial exploitation. A number of technologies have been transferred to various industries.

BARC has facilitated the transfer of several spin off technologies developed to the private domain for further commercial proliferation. During the year, 23 Technologies were transferred to 41 parties, DTDDF (DAE Technology Display and Dissemination Facility) centres was inaugurated, 11 Technologies advertised on BARC, 7 ATP (Akruthi Tech Pack) were established.

The transfer of technologies developed at the department have been made available for commercial production through Technology Transfer Cell, VECC/DAE. Four important technology transfer took place at VECC they are RFID based embedded Issue/Return System for Library Management; RFID based Hand Held Reader for Attendance Recording; Digital Nano-ammeter and Digital Pico-ammeter.

A MoU was signed between IPR and SAC for collaboration in technology development. An MoU was signed between IPR and the Health Dept., Govt. of Gujarat, to facilitate development of a) Artificial Intelligence (Deep Learning) software for health applications, (b) Plasma Pyrolysis plant for biomedical waste disposal in hospitals. Artificial Intelligence (AI) software has been developed in IPR for automated detection of Pulmonary Tuberculosis footprints in chest X-rays.

IPR has developed a thermal plasma-based nano-powder production system. This is a single-step process, designed and fabricated indigenously. There is a single integrated system to produce as well as collect the nanomaterials. A special feature is the large production rate and low operational cost. The capital cost is less than a fifth of a comparable imported system. Furthermore, this is a single technology/process to produce varied nanomaterials. A patent application has been filed in May 2017. The technology has been transferred on non-exclusive basis to an Ahmedabad



*Nano-titania production system installed at Institute for Plasma Research, Gandhinagar*

based company, M/s Vishal Engineers & Galvanizers Pvt. Ltd. (VEGPL). VEGPL plans to use this technology for production of zinc oxide nanoparticles and market them.

## COLLABORATIVE PROGRAMMES

BARC in collaboration with IIT Bombay has developed Parallel Model Checker (ParMC) Software for Hardware Description Language (HDL) designs that makes use of parallel computing systems in order to improve the scalability of model checking algorithms.

## SOCIETAL INITIATIVES

In Technology development for Industrial & Societal applications, IPR has initiated collaborative studies in several application areas of plasma techniques. A plasma nitriding process will be developed to treat special steels of NPCIL to obtain three different specific case depths of hardened layers. FCIPT in collaboration with IIT-G will work on development of indigenous technology to develop CZTS absorber based solar cells using industry friendly magnetron sputtering and RTP (Rapid Thermal Processing) Sulphurization process. FCIPT will develop and supply 'a Plasma jet along with the necessary power-supply' to IIT-Kanpur. In a project sanctioned to Nirma University by BRNS, FCIPT in collaboration with Nirma University will explore non-equilibrium atmospheric pressure plasma for effective hand sterilization. In a research project sanctioned to IIT\_G, FCIPT will carry out synthesis and study of stable isotope nanoparticles.



A project has been sanctioned by M/s ABREF Chennai, in which feasibility studies on the interaction of thermal plasma with fly ash have been initiated in order to investigate the possible production of SiAlON. A new plasma torch and feeder mechanism to introduce the fine powder has been designed, installed and experiments are underway. A Dielectric Barrier Discharge (DBD) plasma system for food processing applications has been developed for Anand Agricultural University, Anand, Gujarat. In an on-going project, sanctioned by DST, bio-compatible coatings are being developed in collaboration with CGCRI-Kolkata.

## 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 2017-18, four DAE-IPR cell meetings were held. DAE filed seventeen new patent applications which includes; one application under PCT (Patent Co-operation Treaty), ten in India, three in USA, two in Europe and one in Japan. During this period, eight of the previously filed patents have been granted to the Department. These includes; seven in India and one in Europe. During the same period, 3 patents were licensed to 4 companies in India.

## PUBLIC SECTOR UNDERTAKINGS

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 expected profit for the year 2017-18 is about ₹ 2400 Cr. The profit (Total Comprehensive Income) for previous FY 2016-17 was ₹ 2491 Cr. NPCIL bonds continued to be rated as AAA (Highest Safety) by CRISIL and CARE.

### URANIUM CORPORATION OF INDIA LTD

The performance of all major units of the company during the year 2016-17 remained quite satisfactory. The total income of the Company during the year 2016-17 was ₹ 1272.71 Crore as against ₹ 1025.53 Crore in the previous year. The Company has registered a Profit Before Tax of ₹ 209.84 Crore in the year 2016-17 as against ₹ 154.53 Crore in the previous year. Performance of the Company in terms of MoU signed with DAE is expected to be "Very Good" for the year 2016-17.

### INDIAN RARE EARTHS LTD

During the period upto December 2017, the Sales Turnover achieved is ₹ 414.69 crore against ₹ 330.85 crore of the corresponding period of previous year. The projected sales turnover for 2017-18 is ₹ 514.64 crore against ₹ 412.02 crore of the Sales Turnover achieved in the year 2016-17.

### ELECTRONICS CORPORATION OF INDIA LTD

Against the MoU target of ₹1675 Crore each for production and Net Sales, the Company achieved a production of ₹ 818 Crore and a net sale of ₹ 689 Crore upto December 2017.

## 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. India participated in the IAEA's International Conference on Nuclear Power in 30 October - 1st November 2017 in Abu Dhabi. India became an Associate Member of CERN on January 16, 2017. As part of India's continued engagement in civil nuclear cooperation with major partners, an Agreement between the Government of Republic of India and the Government of the People's Republic of Bangladesh on cooperation in the Peaceful Uses of Nuclear Energy was signed on 08.04.2017. The Agreement between the Government of the Republic of India and the Government of Japan for Cooperation in the Peaceful Uses of Nuclear Energy was signed on November 11, 2016 during the visit of Prime Minister to Japan and came into force on 20.07.2017. To bolster international cooperation, a Joint Working Group meeting was held with USA on 21-22 August, 2017 and a Joint Working Committee meeting was held on 2-3 November, 2017 with Canada. India gifted Bhabhatron II and Imagin Simulator to Kyrgyzstan. The source has reached Bishkek in December 2017. The Kyrgyz team has undergone training in India and the machine would be made operational soon.

Global Centre for Nuclear Energy Partnership (GCNEP), established at Bahadurgarh, Haryana is the sixth R&D unit under Department of Atomic Energy (DAE). Phase-I construction of the Centre has been completed and on-campus operation has started from April 2017. In the first phase of the project, School Building – 1 and Guest House Block A, has been constructed. During the year, various International and National on-campus programs were conducted at GCNEP.

NPCIL is a member of international organizations such as World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and participating actively in various programmes of these organizations to enhance the safety and reliability of its nuclear power plants. NPCIL participated in various meetings, workshops, seminars organized by IAEA. NPCIL continued to provide information for IAEA PRIS database.

## SCIENCE RESEARCH COUNCIL

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

## BARC-SAFETY COUNCIL

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

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

## CRISIS MANAGEMENT

The Crisis Management Group (CMG), 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. CMG continued to provide its expertise in the field of nuclear / radiological emergency management at various National and International level. During the year 2017, 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.

## 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 CVOs discharges these responsibilities. The vigilance functions were continued at DAE headquarters. "Vigilance Awareness Week 2017" was observed in DAE during October 30th to November 04th, 2017 on the theme of "My Vision-Corruption Free India". At NPCIL, a number of initiatives were taken and innovative methods were adopted in spreading vigilance awareness and imparting knowledge to employees. Vigilance Seminars, Interactive Sessions at various sites and headquarters were organized.

## SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resources of BARC was continuously upgraded and was equipped with the state-of art facilities and technology infrastructure including 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 to provide seamless access to information to BARC scientists and engineers in their day to day R&D activities and also extends its facilities to other DAE institutions. The Scientific Information Resource Centre of DAE continued to provide the library & information services. The publication & printing of various DAE publications such as reports, periodicals, brochures, booklets etc. were also continued.

## PUBLIC AWARENESS

The Department of Atomic Energy (DAE) organized and participated in several events throughout the year to ease groundless unnecessary panic and addressed apprehensions harboured against Nuclear Energy. Across the nation there exists a void of any real understanding, on the part of general population, of anything related to nuclear energy and technologies developed for better quality of life. To keep the public abreast with the latest developments and contributions of atomic energy towards societal welfare, DAE also

participated in and organized events comprising exhibitions, seminars, workshops, essay and quiz contests in different parts of the country which were well received by the targeted audience.

DAE initiated a massive awareness programme about atomic energy through Workshops for Journalists. 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. The workshop was held in collaboration with the National Union of Journalists (NUJ) from March 02-06, 2017 at Mumbai. This DAE-Journalist Workshop, was the first in a series, which facilitated a forum for brainstorming and exchange of views regarding the Department's activities.



*Group Discussion of Journalists with Scientists*



*The Journalists at TAPS 3 & 4*

During the year DAE participated in various exhibitions and events they are an exhibition on "Science and Technology Innovations" at Parliament Annex Building, New Delhi during July 28 to August 12, 2017; Participation in the Government Achievements & Science Expo 2017 at Pragati Maidan, New Delhi during July 14-16, 2017; Participation in the Indian national Exhibition cum fair 2017 during August 17-20, 2017 at Gaira, Kolkatta; Abhiyantrik 2017: a Technical festival held during October 06-07, 2017 at K.J. Somaiya College of Engineering, Somaiya Vidyavihar Campus, Mumbai; The Indian International Science Festival held





**Smt. Sumitra Mahajan, Speaker, Lok Sabha  
at the DAE pavilion**

during 13-16th October 2017 at Science City, Chennai; Gujarat Scientific Literacy Festival – A Science & Technology Workshop cum exposition on Multidimensional Technology & Innovation for empowerment of Weaker Section at Valsad during October 26-28, 2017; Two day Workshop organized by Graphic Era Hill University, Uttarakhand during November 02-03, 2017; Unmesh-Gyan Vigyaan Vichar Sangathan organized Parmanu Urja Jan Jagrati Abhiyaan at Jabalpur during November 15-17, 2017; Conference and exhibition at Nehru Centre, Worli, Mumbai during November 9-10, 2017. A session on Radiation Processing of Food was organized for the first time; Participated in National Metallurgist Day – Annual Technical Meeting (NMD-ATM) - 2017 held at Goa during November 11-14, 2017; Two days seminar organised by National Association for Application of Radioisotopes & Radiation in Industry (NAARRI) on “Application of Radioisotopes and Radiation Technology in “Industries, Agriculture & Healthcare” at GKV University, Bengaluru during November 29-30, 2017; 13th Jatiya Sanhai Utsav-0-Bharat Mela 2017 organized by Bangiya Seva Samity during December 14-18, 2017; ‘Science Academies’ Refresher Course at IWSA Complex, Vashi during December 18-20, 2017 organized by Indian Women Scientists Association (IWSA); Participated in Sundarban Kristi Mela O Loko Sanskriti Utsav organized by Kultali Milan Tirtha Society during December 20-29, 2017 and organized Bhabha Day on November 15, 2017 at DAE Headquarters, Mumbai.

The 29th All India Essay Contest on Nuclear Science and Technology was held in October 2017. A total of 358 essays were received out of which the

authors of 36 were selected for making an oral presentation at Mumbai. The selected participants visited various DAE facilities like BARC, RMC, ACTREC, BRIT and TAPS 3 & 4. Prizes, in cash were awarded on Founder's Day. The essays were received in Hindi, English, Tamil and Marathi languages.

NPCIL has been carrying out public outreach activities in structured manner through a multipronged approach. Several innovative public awareness programmes have also been conceived and implemented across the nation for different sections of the society. Use of exhibitions, regular interaction with the public living nearby nuclear power plants and projects, visits of members of public to nuclear power plants and introducing innovative awareness campaigns on nuclear power for various target groups are some of them. Similarly, NPCIL is also organizing seminars, scientific meets, distribution of Public Awareness publications, screening animated films in vernacular languages, interaction with press and media, e-public awareness campaigns etc. to scale up outreach activities.

NPCIL has also been partnering with several expert agencies to enhance public awareness. NPCIL has set up permanent nuclear galleries at Science Centers in Mumbai, New Delhi and Chennai. In the smaller cities miniature galleries are also planned in large numbers to promote 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.

## SOCIAL WELFARE

### Corporate Social Responsibility

From the inception of nuclear power programme in the country, the units of NPCIL have been implementing social welfare activities for the benefit of local population living within sixteen (16) Km radius from plant site. With enactment of the Companies Act 2013, NPCIL has started structured programme as per the provisions under the Act. Under CSR programme, NPCIL is taking up the activities in the identified thrust areas of education, healthcare, infrastructure

development, skill development, sustainable development and Swachh Bharat Mission.

### Swachha Bharat Mission

The Department of Atomic Energy and its constituent units continued its activities for the “Swachha Bharat Mission”. On 02nd October 2017 a cleaning campaign was conducted by GSO at Anupuram Township. The Swachhata Pledge was taken, followed by cleaning up of the area. At IGCAR, old records were weeded out and handed over to Stores for disposal and cleaning of dump yards was also taken up. Swachh Bharat activities have been carried out at Headquarters and seven Regional Centers of AMD. AEES took lot of initiative and participated in the Swachhata campaign.

Medal by Indian Society of Applied Geochemists (ISAG). ECIL won many awards such as SCOPE Award for Excellent & Outstanding Contribution to the Public Sector management Institutional Category III (Other Profit Making PSEs) 2014-15 on 11th April 2017; Significant Contributions to Digital Initiatives - Swayam Prabha Program on 10th July 17; SCOPE Commendation for the Best Corporate Communication Campaign for the year 2017 on 7th December 2017 etc.

### EMPLOYEE'S WELFARE

BARC is providing health care facilities to entire Mumbai based CHSS beneficiaries through its 390 bedded hospital, 13 zonal dispensaries, 3 occupational health centres and 24 hr casualty facility. All the units are computerized with unique Hospital Information system.

### 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. AMD officers were conferred with National Geoscience Award by Ministry of Mines; Homi Bhabha Science & Technology Award-2016 & Group Achievement Award-2016 by DAE; Life Time Achievement Award & Dr. G.R. Udas – Dr. K.K. Dwivedy



# CHAPTER NUCLEAR POWER PROGRAMME STAGE-I



*Site view - Kakrapar Atomic Power Project KAPP-3&4*



*Site View - Rajasthan Atomic Power Project RAPP-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 (including RAPS-1, which is under long shutdown) with an installed capacity of 6780 MW. Second unit of Kudankulam Nuclear Power Project (KKNPP-2) commenced commercial operation from 11:00 hrs of March 31, 2017. With this, 1000 MW of nuclear power capacity was added to Southern Grid. 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) are under construction. In addition, First Pour of Concrete (FPC) for Reactor foundation slab of Kudankulam Nuclear Power Project Unit-3 (KKNPP-3, 1000MW LWR) was done on June 29, 2017, signifying the actual start of construction of the project. Administrative Approval and Financial Sanction from GOI exists for Gorakhpur Haryana Anu Vidyut Pariyojana Unit-1&2 (GHAVP-1&2, 2x700 MW PHWRs). Administrative Approval and Financial Sanction from GOI was received for construction of Ten indigenous 700 MW Pressurized Heavy Water Reactors (PHWRs) in Fleet Mode and for Kudankulam Nuclear Power Project Unit-5&6 (2x1000 MW LWRs) in June 2017. Various pre-project/ preparatory activities, towards commencement of construction of these projects, are in progress. NPCIL in all its endeavor 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

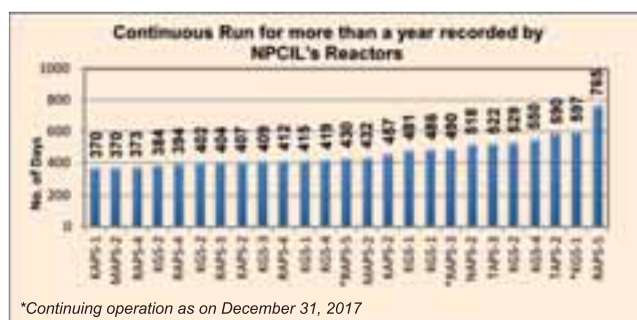
During the Calendar Year 2017, NPCIL registered generation of 37180 Million Units (in addition,

there was an infirm power generation of 1427 MUs from KKNPP-2 during 2017). In the previous calendar year 2016, the generation was 37881 MUs (in addition, there was an infirm power generation of 900 MUs from KKNPP-2 during 2016).

During the Financial Year 2017-18, NPCIL has registered a power generation of 27744 MUs till December 31, 2017. The expected generation for the Financial Year 2017-18 is about 38600 MUs. Actual generation during the last year 2016-17 was 37674 MUs (in addition, there was an infirm power generation of 2327 MUs from KKNPP-2 during 2016-17)

The overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 67% and 70% respectively till December 31, 2017.

During the Financial Year 2017-18, four reactors i.e. KGS-1, KGS-4, RAPS-3 and RAPS-5 achieved continuous run for more than a year. As on December 31, 2017, KGS-1, RAPS-3 and RAPS-5 registered 597 days, 490 days and 430 days of continuous run respectively and are still continuing running. KGS-4 registered 550 days till 25.11.2017 after which it was shut down for carrying out planned BSD activities. So far, the continuous run of more than a year has been achieved 25 times by various reactors operated by NPCIL.



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 under IAEA safeguards. KAPS-3&4 (700MWe), which are under advanced stage of commissioning also have been placed 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 under DAE safeguards.

KAPS Unit-1&2 were under shutdown since March 2016 and July 2015 respectively for coolant channel health assessment. Subsequently, these units have been taken in project mode from August 2016 for En-masse Coolant Channel Replacement (EMCCR) & En-masse Feeder Replacement (EMFR). In Unit-2, after cutting and removal of feeders and coolant channels, new Coolant Channels installation has commenced. In Unit-1, core was defueled and feeder cutting is completed. Various works including procurement & supply of various components are in progress. KAPS-2 is expected to start electricity production by December 2018 and KAPS-1 thereafter.

## Projects under Construction

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

The construction activities of Kakrapar Atomic Power Project-3&4, India's first pair of indigenously designed Pressurized Heavy Water Reactors of 700 MW unit size, are presently in advance stage and the project has entered the commissioning phase. Various equipment/ systems of Electrical and Common Services are commissioned.

In Unit-3, all main plant civil construction works are completed except Outer Containment (OC) dome concreting. Inner containment dome concreting was completed in July 2017 and presently pre-stressing of inner containment of Reactor Building (RB) is in progress. Both Natural Draught Cooling Towers (NDCTs) civil structure was completed up to full height i.e. 166 M EI and its internal civil works are presently in progress.



Site view - Kakrapar Atomic Power Project KAPP-3&4



Feeder installation in KAPP-3

Critical path activity of reactor header and boiler interconnection piping work was successfully completed in July 2017. Presently, on critical path, Feeders erection job is in progress and top half feeders in both FM vaults have been erected, bottom half feeders erection is in progress and is expected to be completed by March 2018. In parallel, pneumatic and hydro test of various circuits has started in main Primary Heat Transport (PHT) System related piping. In Reactor front, after completion of Calandria and coolant channels installation, presently reactivity devices erection work is nearing completion. All three Condensers erection and tubes installation work is completed. The HP and LP turbine erection works are in progress. The remaining systems in Turbine Building are also nearing completion with nearly 85% piping work completed.

Charging of Start-Up Transformer (SUT) and both buses of 400 kV switchyard was completed. Subsequently all buses of 6.6 kV Class-IV & Class-III and 415V Class-II switchgear/MCC along with associated transformers were charged. Main Control Room is established and functional. Various common service systems viz. firewater system, chilled water system, service water system and compressed air system have been erected and commissioned as per project requirement. Induced Draught Cooling Tower (IDCT) has been commissioned successfully along with service water system and is presently in service. With chilled water system commissioned, all Control Building (CB) &



Service Auxiliary Buildings (SABs) ventilation system is commissioned and now being operated with Chilled Water. In Common Service piping system, nearly 80% circuits have been hydro-tested and are ready for service. Simulator Building construction has been completed and all panels received, erected and pre-commissioned. Commissioning of Simulator is in progress and expected to be completed by February 2018.

In Unit-4, construction of all structures in Reactor Building are completed except Inner Containment (IC) and Outer Containment (OC) dome concreting. In November 2017, IC dome liner structure was lifted and erected, and with this, preparation towards IC dome concreting has started. Inside Reactor building, all major equipment viz. Reactor Headers, Steam generators, Passive Decay Heat Removal System (PDHRS) tanks, Pressurizer, ECCS accumulators etc. have been erected. Calandria Tube rolling work was successfully completed in August 2017 and coolant channel installation commenced.

Many equipment/ components for both units are being progressively delivered to site.

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

The construction activities of Rajasthan Atomic Power Project (RAPP) Unit-7&8, India's second pair of indigenously designed Pressurized Heavy Water Reactors of 700 MWe unit size, are presently in progress.



Site View: Rajasthan Atomic Power Project RAPP-7&8



RAPP-7 IC Dome Liner Assembly

In Unit-7, concreting of ring beam, which is a part of Inner Containment dome is completed and fabrication & ground assembly of dome supporting structure is completed. Construction of steam generator vaults is completed. In Control Building, 111 M El is released for C&I works. In Turbine Building-7, construction up to 127 M El slab is completed and work for columns above 127M El is in progress. A major milestone of 'Installation of Coolant tubes' has been completed. Subsequently installation of Feeders is in progress. Major equipment like PDHRS tanks, Pressurizer and 1st Steam Generator have been lowered in RB-7. Fabrication and erection of nuclear piping is in progress.

In Unit-8, welding of End shields & Calandria has been completed. Erection of Fuelling Machine (FM) columns & Bridge is completed. Work for 8th tier of Inner Containment (IC) wall is in progress. Concreting of 115 M El slab is completed, further works are in progress. In Turbine Building-8, construction of TG deck is completed.

Civil construction of Plant Water Pump House, DM Water Plant, Chlorination Plant, Safety Related Pump House, Safety Related Electrical House and Fire Water Pump House is nearing completion. Construction of four Natural Draft Cooling Towers (NDCT) and four Induced Draft Cooling Towers (IDCT) is in progress. Common service equipment and piping erection is in advanced stage.

Hydro testing of CCW Inlet lines of Unit-8 is completed. Erection of Electrical cable trays & equipment like panels, switchgears etc. in Control

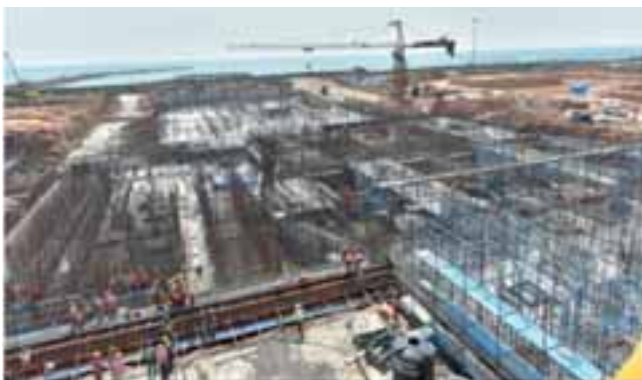
Building, RAB-7 and TBEB-7&8 is nearing completion. Erection of 2 DG sets in SAB-7B & related piping work is completed. 400KV Switchyard, Line reactors for Sujalpur-I, Sujalpur-II and Jaipur lines have been charged and synchronized.

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

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

Work Order was issued for the “Main Plant Civil Works” and First Pour of Concrete (FPC) for Reactor foundation slab for KKNPP-3 was carried out on June 29, 2017. Construction of Reactor Building, Reactor auxiliary building, Emergency power supply building, Turbine building etc. are in progress. Work Order was issued for “Construction of Hydro technical structures & temporary dyke” and construction of temporary dyke is in progress.

Development of Working Documentation (WD) is in progress. Manufacturing of some of the Long Manufacturing Cycle Equipment (LMCE) and first priority equipment located below 0 M EI are completed. Manufacturing of other LMCE like Reactor Pressure



**Site view of Kudankulam Nuclear Power Project KKNPP-3**



**Site view of Kudankulam Nuclear Power Project KKNPP-4**

Vessels, Steam Generators, Turbines, Polar Cranes etc. is in progress.

Logistics contract was awarded in July 2017 for transportation of equipment from Russian / Third Country's Port to Kudankulam Site and three ship loads of various equipment/ components were delivered at Tuticorin port / Kudankulam site. One more ship is expected to depart from Russian port in the last quarter of the financial year 2017-18. Progressive delivery of First priority mechanical equipment/ component (Indian Scope) like SS tanks & PAB pipeline is in progress.

Two contracts were signed with JSC ASE, during the year; (a) Delivery of Equipment and materials (Phase-2) from RF and (b) Deputation of Contractor's (Russian) specialist to site. Notice inviting tender (NIT) published for Main Plant Electrical package, Diesel Generator package and Sea water system package.

### **Sanctioned Projects**

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

Administrative approval and Govt. financial sanction, Ministry of Environment, Forest and Climate Change (MoEFCC) clearance for plant site, siting consent from Atomic Energy Regulatory Board (AERB) and consent to establish from Haryana State Pollution Control Board (HSPCB) exist. Land for the project has been acquired. Excavation clearance from AERB was obtained and Main Plant Civil Works Package-1





**Inauguration of Engineering Extension Wing by Shri N. Nagaich, Director (HR) at GHAVP**

(Excavation including ground improvement) work order was issued in January 2018. Ground break is expected shortly. Various pre-requisites for excavation like commissioning of construction 11KV/415V power supply and civil works of construction water tank and dewatering tank have been already completed. Work for water treatment plant for construction water, domestic water and fire water supply is in progress and is expected to be completed by March 2018. Work for 33 KV construction Power Supply Network is in progress. Procurement action for long delivery equipment/components such as End Shields, Calandria and Steam Generators is in advanced stage. Purchase orders were placed for Reactor Headers and Primary Coolant Pumps in January 2018. Consultancy work for Residential Complex has been awarded. Engineering consultancy contract was awarded and work is in progress.

### **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) and Republic of India in December-2008 for construction of two more units in second phase i.e. KKNPP Units-5&6, Administrative approval and Financial Sanction were obtained from Government of India in June-2017. General Framework Agreement (GFA) for setting up of KKNPP Units-5&6 was 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. Application and requisite documents for excavation clearance from AERB are under preparation.

Three major contracts signed with JSC ASE, in July-2017 are (a) Contract for First Priority Design Work; (b) Contract for development of the Working Documentation and (c) Contract for Delivery of Equipment with long manufacturing cycle & First Priority Equipment. Discussions with JSC ASE are in progress for the finalization of the remaining contracts.

Geotechnical Investigation Report is submitted for development of Floor response spectra (FRS). Contract was awarded for the remaining Geo-Technical Investigation in October 2017.

### **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 MWe Pressurized Heavy Water Reactors (PHWRs) in Fleet Mode. Procurement processes for Lattice Tubes and Plates for End Shields (4 Units), Pressurizer & Bleed Condenser (BCD) and Steam Generator (SG) Forgings (6 Units) are in progress.

Various pre-project/preparatory activities like land acquisition, Rehabilitation & Resettlement, environmental studies, site studies, regulatory submissions, public outreach, etc. are in various stages of progress for commencement of construction of GHAVP- 3&4 units in Haryana, at Chutka in Madhya Pradesh, Kaiga-5&6 in Karnataka and Mahi Banswara in Rajasthan.

### **New LWR Sites**

Various pre-project activities like land acquisition, Rehabilitation & Resettlement, environmental studies, site studies, regulatory submissions, public outreach, Techno-commercial discussions with foreign vendors etc. are in various

stages of progress for new LWR sites, having “In Principle” approval from the Govt. of India, namely Jaitapur in Maharashtra, Kovvada in Andhra Pradesh and Mithi Virdi in Gujarat. Land is available at Jaitapur and land acquisition is in an advanced stage at Kovvada. Land is to be acquired as per new RFCTLARR Act, 2013 for Mithi Virdi. At Haripur, land acquisition is contingent upon initiative by State Government. Alternate site is also under consideration by GOI.

## Quality Assurance

NPCIL, in all its endeavours, is committed towards upgradation and continuous improvements in Quality Management, Quality Assurance, Quality Surveillance, Pre-service Inspection/In-service Inspection, Software Quality Assurance 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 of Projects/Stations has been completed successfully. Corporate QA audits of projects i.e. KKNPP-3&4, KAPP-3&4 and RAPP-7&8 have been completed in a planned way. Corporate Peer reviews of operating stations have been conducted based on WANO guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO. Various Directorates of NPCIL namely Quality Assurance, Engineering, Electrical & Instrumentation, Technology Development, Procurement, Reactor Safety & Analysis, Health, Safety & Environment and Human Resources (Knowledge Management Functions) are ISO:9001 certified. Surveillance/Re-certification audits of these Directorates by the certifying body have been successfully completed.

## 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.

Performance of the Board during the period was excellent w.r.t. production, specific energy consumption and 'on stream' factor. With sustained operation and lowest ever specific energy consumption, the largest plant at Manuguru has recorded highest percentage recovery. HWP, Kota carried out Major Turn Around during the report period. HWP, Hazira has also completed Annual Turn Around as planned. The targeted production is expected to be achieved by all the HWP's as per annual action plan. At Tuticorin, activities are in full swing on three fronts viz. re-startup of Heavy water production, setting up of industrial scale Solvent Production Plant (SPP) and industrial scale Solvent Extraction Plant (SXP).

### Heavy Water Plant, Manuguru

The performance of Heavy Water Plant (HWP), Manuguru during the year 2017-18 was excellent achieving 115 % of target production and highest ever Recovery of 19.09%. One of the major activities was replacement of structured packing with sieve trays in SSB2 of XU-I followed by film formation.

HWP, Manuguru has completed 25 years of operation and Extended MTA is planned from January 2018 for a period of 90 days including common systems shutdown of 30 days. In addition to the routine jobs, some major recommendations of IPSD and SARCOP will be taken up.

Waste heat powered Hot Water Vapour Absorption based refrigeration machines (2\*1000 TR) are under commissioning, which will further improve the capacity factor. For improving security set up, Periphery Intrusion Detection System (PIDS) and CC TV for HWP, Manuguru Plant Site & Colony have been tendered.

To mitigate the environmental issue connected to fly ash generated from captive power plant, action was initiated to increase the capacity of Ash Pond-2. Vibro-Stone Columns have been installed to increase the load bearing capacity and reducing liquefaction under seismic stress. Action now has been initiated to increase Ash Pond bund height. Pond ash disposal was taken up for the first time and 25,000 MT was disposed. Major breakthrough was achieved by disposal of Bottom ash to M/s Singareni Collieries for underground mine stowing and Fly ash disposal to bricks manufacturing units.

During the period, few safety related modifications like double containment of liquid  $H_2S$  piping within first isolations of  $H_2S$  bullets and alkali spray provision for  $H_2S$  bullets, were carried out.

At Captive Power Plant (CPP), power is being exported to TSTRANSCO as per the agreement with PTC. Auxiliary Steam Turbine (TG-4) continued to recover throttling energy losses in HP steam loop by generating 25-30 MU every year. The 12 MWp Solar Photo Voltaic Power Plant continues to operate satisfactorily.

Elemental Boron Plant for production of Elemental Boron is being operated on sustained basis. Trial operations for meeting the requirement of boron carbide pellets were successfully carried out.



**Boron Plant induction furnace at HWP, Manuguru**



**Boron Plant hot press internals, HWP, Manuguru**



**HWVAR machines installed at HWP, Manuguru**

## Heavy Water Plant, Kota

The plant is under 'Major Turn Around' from August 2017 and is scheduled to restart in February 2018. Safety provisions were strengthened by providing double jacketing of drain line and liquid dump line of  $H_2S$  storage tanks within first isolation as per recommendation of AERB to mitigate the Design Basis Accident and other credible accident scenario. Alkali Spray System has been provided to effectively mitigate minor liquid leakage. Nitrogen injection as diluent has been provided in LP flare for its use under non-availability of flare of HP flare stack.

In addition to the routine MTA maintenance activities, critical activity related to replacement of bottom crown in second stage hot tower 2HT, replacement of two drain tanks were carried out. Towards compliance of design adequacy requirement (seismic requalification), strengthening of Emergency shelter (Multipurpose Hall) and entrance porch was also done.





**Alkali Spray system for H<sub>2</sub>S tank at HWP, Kota**



**Double Jacketing of drain line and liquid dump line of H<sub>2</sub>S storage tanks at HWP, Kota**

Sodium Sulphate Crystallizer plant installed last year continued to be in operation and produced 114 MT of Na<sub>2</sub>SO<sub>4</sub> crystals of marketable quality from the effluent Sodium sulphate solution.

### Heavy Water Plant, Hazira

The performance of HWP, Hazira was excellent achieving 106.5 % of target production. The plant completed the Major Turn Around in April – May, 2017. Having completed more than 26 years of operation, chemical cleaning, equipment overhauling / replacements were taken up. Improvements were made to increase plant processing rate and energy efficiency by re-tubing of cooling water exchanger, replacement of amide to amide heat exchanger and BFW to amide heat exchanger.

### Heavy Water Plant, Thal

The performance of HWP, Thal remained exemplary achieving targeted production, specific energy and capacity utilization despite external disturbances from fertilizer plant and MSEB. The



**New Instrument air compressor installed at HWP, Thal**

physical & fiscal progress of most of the capital schemes for modifications and improvements in plant remain satisfactory. Few equipment were replaced as part of system upgradation.

Solution annealing of 168 service aged cracker tubes was accomplished affecting large capital saving. 'Annual Turn Around' 2017 was safely executed with compliance to statutory requirements resulting in enhancement of operational efficiency, overcoming load limitations and improving safety.

### Heavy Water Plant, Baroda

Tri-butyl Phosphate (TBP) plant, Potassium Metal plant & Sodium test cell are in continuous operation meeting the production targets. 96.98MT of TBP and 10MT of potassium metal was produced during the report period as targeted. Plant continued the production of high pressure D<sub>2</sub> gas mixture.

D-labeled NMR solvents were manufactured as a part of developmental activities on alternate application of heavy water. Chloroform-d, DMSO-d<sub>6</sub>, Acetone-d<sub>6</sub> & Acetonitrile-d<sub>3</sub>, Benzene-d<sub>6</sub> and D<sub>2</sub>SO<sub>4</sub> are being synthesized using conventional/innovative processes. Inorganic products like KOD, NaOD, DCl, and D<sub>2</sub>SO<sub>4</sub> are also produced. The purity and deuterium



**Sodium Distillation Unit at HWP, Baroda**



content @ 99.8% of the Organic Deuterated solvents produced meets international standards and are well accepted by the users.

Operation of 2 kA test cell for developing the Sodium production technology continued to collect required data needed for scale up of the cell to be employed at industrial facility for production of 600 MTPA Nuclear grade sodium, for which the financial sanction has been received.

### Heavy Water Plant, Tuticorin

Subsequent to resumption of stable operation of M/s SPIC and assurance on availability of synthesis and natural gas to the HWP at Tuticorin, re-startup activities have been initiated. Work has started on setting up of two new facilities, Industrial scale Solvent Production Plant (SPP) and Industrial scale Solvent Extraction Plant (SXP).

### Heavy Water Plant, Talcher

At HWP, Talcher, the production facilities for D2EHPA and TBP operated continuously to meet the target production. The plant produced 40.02MT of TBP and 20.67MT of D2EHPA, meeting the target for the financial year.

At the R&D pilot plant facility, 255kg of TAPO was successfully synthesized. Three batches of TAPO equivalent to 205kg was also synthesized.

During the period, Boron Enrichment Facility was in operation with 100% capacity factor for enriching  $^{10}\text{B}$  in  $\text{BF}_3$  complex. Required quantity of enriched  $\text{KBF}_4$  ( $^{10}\text{B} \sim 92\%$ ) has been dispatched to HWP Manuguru. Three kg of  $\text{BF}_3\text{-CaF}_2$  complex was dispatched to ECIL, Hyderabad. Purification and  $\text{BF}_3$  gas generation Plant has been set up. Gas generated will be bottled for transportation and supply.

## 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 a 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 2016-17 (November 2016 to October 2017), the 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 earth resources. The coastal stretches of the country have been explored for augmentation of economic heavy mineral 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

### Ground radiometric surveys

Reconnaissance (6,842sq km) and detailed (324.35sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

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

**Shillong Basin, Hojai district, Assam:** Quartzite at Buriganga.

**Motur Formation, Satpura Gondwana basin, Betul district, Madhya Pradesh:** Sandstone at Khapa-Jhapri.

**CGGC, Singrauli district, Madhya Pradesh:** Breccia / cataclasite near Jhapar.

**Gulcheru Formation, Cuddapah Supergroup, Kurnool district, Andhra Pradesh:** Quartzite at Kappatralla.

**Basement crystallines, Wanaparthy district, Telangana:** Leucogranite at Mastipuram - Dharampuram- Mullamala sector.

**Basement crystallines, Mahabubnagar and Nalgonda districts, Telangana:** Granite at Viraboyanapalli-Dindi-Singaram-Hajipur.



*Radioactive quartzite at Kappatralla, Kurnool district, Andhra Pradesh*



*Radioactive outcrop of leucogranite at Mastipuram, Wanaparthy district, Telangana*

## Geochemical Surveys

Geochemical surveys (4,346sq km) have indicated up to 13,100ppb U along Rayavaram-Pincha-Reddivaripalle tract, Kadapa district, Andhra Pradesh and up to 112ppb U near Barmer and Dhorimanna, Barmer district, Rajasthan.

## Ground Geophysical surveys

Ground geophysical surveys have been carried out in parts of Singhbhum Shear Zone, Jharkhand; North Delhi Fold Belt, Aravalli Fold Belt and Jaisalmer Basin, Rajasthan; Hanspani Shear Zone, Assam; Ambadongar Carbonatite Complex and Saurashtra Basin, Gujarat; Bhima Basin, Karnataka and Satpura Gondwana Basin, Madhya Pradesh. The geophysical surveys delineated potential blocks associated with conductive zones in Umra, Udaipur district, Rajasthan; high chargeability zones in Sankadih-Galudih, Kharswan-Burughutu, Saraikela-Kharswan district, Jharkhand & Tirth-Tintini, Yadgir district, Karnataka and low magnetic zones in Hanspani, Karbi Anglong district, Assam & Ambadongar, Chhota Udepur district, Gujarat.

## Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 58,241.65 line km in parts of Aravalli Fold Belt & North Delhi Fold Belt, Rajasthan; Chhattisgarh Basin, Chhattisgarh; Satpura Gondwana Basin, Madhya Pradesh and Cuddapah Basin, Andhra Pradesh & Telangana. In addition, AMD successfully conducted



*Gravimeter (GT-1A) installed on helicopter platform before survey*



heliborne gravity surveys over 2,815 line km in parts of Alwar basin, Rajasthan for the first time.

Processing of heliborne geophysical data of Aravalli Fold Belt, Rajasthan has identified prominent NNW-SSE trending formational conductors which are inferred as carbonaceous phyllite belonging to Debari Group (Aravalli Supergroup). Data processing has indicated sixteen potential target zones for ground validation in parts of Alwar Basin, North Delhi Fold Belt, Rajasthan. Preliminary target zones, 12 in Chhattisgarh basin and 7 in Satpura Gondwana basin, were delineated for detailed studies.

### Exploration by Drilling

A total of 2,03,687.60m (Departmental: 88,079.85m and Contract: 1,15,607.75m) drilling (reconnoitry, 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:

**Tummalapalle sector, Kadapa district, Andhra Pradesh:** Vempalle dolostone at Motunutalapalle, Kanampalle, Gidankivaripalle & Tummalapalle block-I.

**Rohil and its extensions, Sikar & Jhunjhunu districts, Rajasthan:** Albitite zones in NDFB along Rohil west, Narsinghpuri, Gumansingh ki Dhani, Barkhada, Karoi and Jahaz.

**Wahkut and Kulang, South West Khasi Hills district, Meghalaya:** Lower Mahadek sandstone at Wahkut and Kulang blocks (Nongjri Plateau).



*In-house training programme on 'Safety Aspects at Work Place' conducted at drill site in Kanchankayi, Yadgir district, Karnataka*

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

**Suldhah-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.

**Singhbhum Shear Zone, East Singhbhum and Seraikela-Kharswan districts, Jharkhand:** Associated with quartz-chlorite-sericite schist at Jaduguda (North), Turamdih (East), Singridungri-Banadungri, Rajdah, Bangurdih and Mahalimurup. Associated with altered peridotite in Kudada (Turamdih East extension).

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



*Radioactive sandstone-conglomerate at Polian, Una district, Himachal Pradesh*



*Mastipuram area showing secondary uranium minerals (yellow colour) in granite*

In addition to the above, potential/significant blocks have also been identified for sub-surface exploration at Naktu, Sonbhadra district, Uttar Pradesh; Rajpura, Una district, Himachal Pradesh; Kappatralla, Kurnool district, Andhra Pradesh and Mastipuram, Wanaparthy district, Telangana.

## Rare metal and rare earths investigations

Reconnaissance (1,020 sq km) and detailed (4 sq km) surveys have been carried out for identification and evaluation of Rare Metal and Rare Earth resources in Chhattisgarh, Odisha, Rajasthan and Karnataka.

Additional resource of 1,106 kg of columbite-tantalite was estimated in pegmatites at Jangapara, Jharsuguda district, Odisha and at Jogiyani, Balrampur district, Chhattisgarh.

Recovery of columbite-tantalite, beryl as by-product and polymetallic xenotime bearing concentrate was achieved at Pandikimal and Jangapara unit, Jharsuguda district, Odisha; Allapatna-Marlagalla sector, Mandya district, Karnataka; Buchara area, Jaipur district, Rajasthan and at Siri River, Jashpur district, Chhattisgarh.



**Excavation for recovery of columbite-tantalite mineral from pegmatites and associated gravel zones at Jangapara, Jharsuguda district, Odisha**



**Columbite-tantalite mineral recovery site at Marlagalla, Mandya district, Karnataka**



**Columbite-tantalite minerals in pegmatite at Marlagalla, Mandya district, Karnataka**

A total of 2,402.50 m drilling has been carried out for RMRE in Dantala and Phulan areas of Siwana Ring Complex, Barmer district, Rajasthan. Continuity of REE mineralisation associated with microgranite dykes have been established over 1.2 km strike length in Phulan area.

## Beach Sand and Offshore Investigations

Survey (Reconnaissance: 366.32 sq km and detailed: 12.31 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 1,815 boreholes with a cumulative depth of 9,205.60 m and 6,374 samples have been generated.

The following potential heavy mineral zones have been delineated:

Melekidaram-Seraikulam, Ramanathapuram district, Tamil Nadu with upto 10% Total Heavy Mineral (THM) concentration.

Thurpupalem – Vainateyam Godavari confluence, East Godavari district, Andhra Pradesh with upto 28% THM concentration.

Chinavanka – Pallisaradhi and Bhavanapadu – Jogammapeta, Srikakulam district, Andhra Pradesh with upto 44.49% and upto 26.39% THM concentrations respectively.





**Beach sand drilling operations and sampling process in the coastal dunes of Sirikulam-Ervadi tract, Srikakulam district, Andhra Pradesh**

Sana Arjapalli – Agastinuagaon, Ganjam district, Odisha with upto 67.66% THM concentration.

## Resources

The country's total heavy mineral resource was updated to 1,173 mt which includes 648 mt ilmenite, 34 mt rutile, 12 mt monazite, 36mt zircon, 187 mt garnet and 255 mt sillimanite.

## Mining & Mineral Processing

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

Uranium Corporation of India Ltd. (UCIL) is engaged in uranium ore mining and processing since 1967. The performance of all major units of the company during the year 2016-17 remained quite satisfactory. The Tummalapalle Uranium Project at Andhra Pradesh has been capitalized with effect from January 2017 and incorporated in the balance sheet of FY 2016-17. Re-

Dissolution System (RDS) facility in the processing plant has been successfully completed and implemented.

Exploratory mining activities by UCIL on behalf of AMD at Rohil Uranium Project located at Sikar district of Rajasthan are in progress. Agreement has been finalized with AMD for decline and shaft construction. 3D ore-body model report and pre-feasibility report has been prepared. Terms of Reference (ToR) application for Rohil Uranium Project has been made and is under process by MoEFCC.

Pre project activities have been taken up at Gogi Uranium Project located at Yadgir district of Karnataka. Finalization of pre-feasibility report and ToR application is in progress. Land acquisition has been completed (government land) except tailings pond area.

Towards meeting the urgent need of nuclear fuel for the new upcoming reactors envisaged by DAE, UCIL has planned for augmentation of uranium production through expansion of existing facilities and setting up of new units in Jharkhand. Projects that have been taken on priority includes Augmentation of production of Narwapahar, Turamdih and Banduhurang; Setting up of a new mine and processing plant at Banadungri; Setting up of a new processing plant at Banduhurang and Setting up of a new mine at Garadih. ToR applications to MoEFCC for the projects have been made.

UCIL has also initiated activities to expand existing mine & plant and setup new mines & plants around Tummalapalle area in Andhra Pradesh; these include Tummalapalle Mine and Plant Expansion; Tummalapalle Deeper Mine and Plant Uranium Project; Kannampalle Mine and Plant Uranium Project and Kannampalle Deeper Mine and Plant Uranium Project.

A novel leaching process has been developed to obtain pure yellow cake from Crude Sodium Diuranate (CSDU) (27%  $U_3O_8$ , 10% Fe, Si, Ca, Mn, Mg, rare earths, organic matter etc.) of phosphoric acid processing plant. Various process variables such as concentration of lixiviant, solid to liquid ratio, digestion time and temperature have been optimized. The main advantage of the process is its ability to selectively solubilise U, from all the impurities including iron, silica, rare earths and others. U is later re-precipitated as

yellow cake either as Sodium Diuranate (SDU) or uranyl peroxide under controlled pH.

As part of the pre-feasibility studies on the recovery of the U values from Rohil-Ghateswar multi-metal U-Cu-Mo deposit (Rajasthan), bench-scale investigations were carried out for physical-chemical-mineralogical characterization followed by hydrometallurgical studies. By following sulfuric acid leaching process, the overall recovery of U from the Rohil ore sample was about 80% and the yellow cake product analyzed 74%  $U_3O_8$ . Cu and Mo are important by-products of the ore which can be recovered to about 75% in the pre-concentration stage. Based on the data generated from various experiments, a process flow-sheet is recommended and mass balance sheet generated.

Process development studies on bench-scale have been carried out for the recovery of U values from a blended split-core bore-hole U ore sample from Singridungri-Banadungri (SBD) area of Singhbhum Shear Zone. Siliceous minerals form the major gangue comprising quartz, albite, biotite, chlorite, muscovite and epidote. Fluorapatite, magnetite, pyrite, traces of chalcopyrite and sphalerite in minor quantities are also observed. The  $U_3O_8$  assay of the composite ore is about 0.03% present as mineral uraninite. The Rare Earth Elements (REE) (including Sc and Y) content of the feed is about 0.1%, with Ce being the predominant amongst them. Chemical analysis of the ore showed:  $SiO_2$  55%; total Fe of 10%,  $Al_2O_3$  13.5%,  $P_2O_5$  1.4%. Cu, Ni and Mo contents are about 0.0135%, 0.02% and 0.002% respectively. The entire processing scheme is carried out in acid medium (sulfuric) due to negligible content of acid consuming gangue. By following the same process philosophy presently implemented at Jaduguda and Turamdih uranium mills, the overall recovery of U works out to be about 87%.

Rheology studies were undertaken on the Tummalapalle U ore to develop the characteristic curves of ground ore slurry under various process conditions viz. particle size, solid content, temperature and influence of dissolved leachants. The flow-curves satisfied the power law and Herschel-Bulkley models in the entire range of shear rate (10 to 1200  $S^{-1}$ ). Work on applying these flow-patterns in predicting and control of unit operations is in progress.

The Indian Rare Earths Ltd. (IREL) has developed formulation for Yttrium stabilized zirconia & lanthanum zirconate to develop Thermal Barrier Coating materials for Aero-engine parts and sent it for trial to Hindustan Aeronautics Limited (HAL). The materials developed are reported to withstand tests equivalent to 1000 hours of flying.

Joint Venture Agreement (JVA) has been signed between IREL and Industrial Development Corporation of Odisha Limited (IDCOL) for mining the beach sand reserves in the state of Odisha. Company formation is under progress.

Corporate Research Centre and R&D laboratories in all the operating units of the Company accredited in accordance with the standard ISO/IEC 17025:2005 by NABL.

Investment decision for setting up of Samarium-Cobalt based Permanent Magnet Plant at Achutapuram, Vizag has been received. Activities for obtaining environment clearance prior to initiating site activities is in progress.

Setting up of Rare Earth Theme Park which interalia includes setting up of pilot plants in the value chain of Rare Earths based on home grown technologies, entrepreneur cum skill development center and state of the art R&D laboratories has been initiated. Funds have been sanctioned for the project and IREL is in dialogue with various State Governments for allotment of land.

A flow sheet for efficient process for high recovery of pure Hafnium (Hf) as oxide from the Zirconium Scrub Raffinate (ZSR) stream of zirconium oxide plant was developed at BARC. In demonstration at bench-scale about 300g of  $HfO_2$  with 95% purity was recovered.

To strengthen the resource base of Heavy Rare Earth Elements (HREE), investigations were taken-up on mapping of REE in various secondary resources including fly ash and developing process flow sheet for the recovery of HREE. Mapping of REE in the fly ash generated from coal-fired selected thermal power plants across the country was conducted in the last two years and promising locations short-listed for resource recovery.

Neyveli, a location in southern India showed significant concentration of REE, including that of HREE. The total rare earths (TREE) content in the sample is about 0.216% with lighter REE (LREE) content of 0.145%; medium REE (MREE) of 0.0235% and heavy REE (HREE) of 0.0472%, amongst which Y alone is 0.03%. The sequential chemical extraction studies indicated that about 55% of the TREEs are ion-exchangeable type followed by about 30% TREEs which are Fe-bound. A hydrometallurgical process flow sheet was developed for the recovery of HREE & Y from the fly ash in sulfuric acid medium. The REE + Y values from the leach solution were selectively extracted using DEHPA (di-ethyl hexyl phosphoric acid) into two exclusive products – LREE & HREEY. The stripped phases were neutralized and the dissolved REE were precipitated as oxalates and subsequently calcined. The process flow sheet yielded end products with an overall TREE recovery in the range of 55 – 58%. There was quantitative recovery of REEs during the solvent extraction and precipitation stages.

A two cycle solvent extraction process based on organic extractant PC88A and Aliquat336 has been developed for the recovery of high purity (>99.9%)  $Y_2O_3$  from xenotime mineral. Yttrium from heavy rare earths was separated in the first cycle with PC88A from chloride medium, while its purity >99.9% with recovery >99% was achieved in the second cycle employing Aliquat336 from thiocyanate medium. The technical know-how has been shared with Indian Rare Earths Limited for large scale production.

A novel process employing Hollow Fibre Membrane (HFM) Module has been developed under optimized hydrodynamic conditions to recover critical rare earth elements neodymium and dysprosium from discarded computer Hard Disk Drive (HDD) magnets. The feasibility of the developed process of recycling of waste HDD has been established in kilogram scale.

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

Production of 73 BWR fuel assemblies was achieved during the year till December, 2017 and target of 95 assemblies would be completed during the financial year 2017-18.

The PHWR fuel assemblies are manufactured in two separate streams. The imported uranium ore concentrate is processed in Uranium Oxide Plant (UOP) and Ceramic Fuel Fabrication Plant (CFFP) while the indigenous raw material from UCIL is processed in Natural Uranium Oxide Fabrication Plant- Oxide (NUOFP-O), Natural Uranium Oxide Fabrication Plant-Pelletizing (NUOFP-P) and Natural Uranium Fuel Assembly Plant (NUFAP).

## The Uranium Oxide Plant

The Uranium Oxide Plant (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

### Modification in slurry extraction



In order to match the increased dissolution capacity, the slurry unit was modified to handle 'U' feed having concentration of 475 gUpl and higher flow of 425 lph. These modifications have resulted in increase in solvent extraction capacity from 100 kg/hr to 200 kg/hr.

#### Enhancement of Uranium Stripping Capacity

The capacity of the re-extraction cycle has been increased to 4.6 MT/day from cumulative capacity of 1.8 MT/day through introduction of innovative mechanical coalescer units, introduction of temperature controlled stripping and increasing the hydrostatic head at LS and UNPS exit point in Mixer Settlers (MS-I and MSII).



**Enhancement of Uranium Stripping Capacity**

#### Modification in batch precipitation

The capacity of the batch precipitation process has been improved from 2.3 MT/day to 4.5 MT/day by increasing the Uranium Concentration. Precipitation of this high concentration UNPS with higher vapour ammonia flow rate is first of its kind. This has helped in the production of more active AU powder and reducing the median particle size by 2-3  $\mu\text{m}$ .

#### Turbo dryer modification

All the 76 heating elements in the turbo dryer have been replaced with new elements. In addition to this, 12 nos. of new heating elements have been added which has increased the heating capacity. The thermal insulation of the dryer surface has helped in an increase of 10°C by reducing the heat losses.

#### Discharge Pit Trolley Movement System

A new automatic Discharge Pit Trolley Movement System (DPTMS) was developed and implemented at Calcination, Reduction and Stabilization operations for easy and accurate handling and fool proof fixing. This has greatly reduced the operator fatigue and improved the working conditions.

#### **Ceramic Fuel Fabrication Plant – Pelletizing (CFFP – P)**

CFFP (P) is involved in the production of natural  $\text{UO}_2$  sintered pellets from the nuclear grade  $\text{UO}_2$  powder received from UOP through conventional powder metallurgy route.

#### Development of co-mill technique for single stage granulation of $\text{UO}_2$ powder

A new concept of once through granulation technique has been developed by introducing novel Co-Mill technique for production of granules without recycling of fines. The pre-compaction process parameters like compaction pressure, rotor speed and sieve hole diameter were optimized for achieving consistent granule quality and subsequent overall pellet quality.

#### Development of Automatic $\text{UO}_2$ Pellet Unloading System for Moly Charge Carrier

Presently,  $\text{UO}_2$  pellets after sintering are manually discharged from the molybdenum charge carrier boats into SS trays for subsequent operations



**Development of Automatic  $\text{UO}_2$  Pellet Unloading System for Moly Charge Carrier**



and quality inspections. Manual discharging process leads to increased risk of radiation exposure and operator fatigue. Hence, an Automatic Pellet Unloading System (APUS) was developed at CFFP (P) to reduce manual intervention.

### **Ceramic Fuel Fabrication Plant –Assembly (CFFP –A)**

The following improvements in equipment have been successfully completed.

#### Automation of End Cap Welding Machines

All the existing end cap welding machines have been converted into fully automated mode of operation and put into production. Additional safety guards including additional light curtains have been provided around all the machines for ensuring operator safety.

#### Introduction of Oil Skimmer in Double Head Turning Machines

In order to ensure the cleanliness of the recirculating coolant oil, oil skimmer has been introduced on the existing double head turning machines. This has helped in increased machine cleanliness and also improved the PHWR fuel element cleanliness during subsequent degreasing process.



**Introduction of Oil Skimmer in Double Head Turning Machines**

#### Commissioning of Special Purpose Resistance Welding Machine

A welding unit having capability to carry out resistance welding on special and new materials has been developed for studying the effect of welding parameters on quality. Final trials are currently in progress for commissioning the advanced data acquisition system.



**Commissioning of Special Purpose Resistance Welding Machine**

#### Online weight measurement system

Online element measurement has been introduced on double head turning machines. The system weighs each individual element and checks the weight against specified values and stops if the weight is out of range.



**Online weight measurement system**

#### Introduced additional mechanisms on Integrated Spacer Pad and Bearing Pad Units (ISBUs)

Suitable modifications have been done on all ISBUs by providing additional mechanism to prevent any possibility of component mixing at the feeding magazines. This has considerably reduced the dependency on the operator for visually identifying such undesirable mixing.

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

#### **Developmental Works at NUOFP**

#### Modified UNR Treatment for Reduction in generation of Uranyl Nitrate Raffinate Cake (UNRC)

UNR (Uranyl Nitrate Raffinate) generated in solvent extraction contains about 0.5 gpl of 'U' which was being precipitated with vapour ammonia till pH 8.0

followed by filtering in a rotary drum filter with dicamol as filter-aid. A modified UNR treatment has been developed wherein precipitation is carried up to pH 7.0. The precipitated UNR slurry is allowed to settle for about 24 hrs to separate solids at the bottom and clear solution at the top of the tank. The filtration of solids and clear solution is carried out separately. During the filtration of solids, the filter-aid (dicamol) along with UNRC is cut resulting in generation of UNRC. During the filtration of clear solution the cake is not cut and practically yields no UNRC. This has resulted in reduction of UNRC generation from 700 kg to 400 kg/MT of  $UO_2$  produced.

#### Installation and Commissioning of Filtration System for ADU sludge

The treated Ammonium Nitrate sludge contains ADU particulate matter and ferric chloride. The generation rate is about 1000lts per day. This sludge due to the uranium content is completely recycled by dissolution. A new filtration system involving a nutsch filter has been installed and commissioned for the filtration of ammonium nitrate to separate the clear ammonium nitrate and sludge containing ADU particulate matter and ferric chloride. The clear ammonium nitrate solution is disposed by sale whereas the cake from the top of the filter is recycled to dissolution. This has helped in greatly improving the quality of the ammonium nitrate effluent.



*Installation and Commissioning of Filtration System for ADU sludge*

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

The plant has achieved production of about 275.876 MT of finished  $UO_2$  pellets during this period.

#### **Developmental works at NUOFP**

#### Installation and commissioning of Hydrogen Gas Manifold

A new leak proof hydrogen gas bank system with automatic changeover facility was successfully commissioned for supplying  $H_2$  gas to all the sintering furnaces during emergency.

#### Automatic pellet stacking machine

An automatic vision based industrial scale pellet stacking machine has been erected and commissioned.

#### Sintering Furnace (SF) 5 Hearth brick lining re-design and walking beam replacement

The insulation and hearth bricks of few high heat zones of SF5 were found damaged and the reasons for damage were investigated. Consequently, the design of the brick linings in those zones has been modified to avoid such damages. Further, the damaged walking beam of SF-5 has been replaced with a newly fabricated walking beam. All the gas lines, water lines and sensor mountings have been integrated and the furnace has been put back into regular production activities. The replacement of the walking beam has improved the operational safety of the furnace.

#### Modification in Vibratory Bowl feeder

A bowl feeder is used for feeding sintered pellets in to centreless grinding machine. During feeding, vibration of pellet generates fine dust. Over a period of time, dust is getting accumulated into vibratory track and obstructing pellet feeding. This causes pellet jamming which in turn leads to more chipping and airborne activity. A dust collection system is introduced in the bowl. Multiple (8 mm) holes are drilled in to lower bowl track. Outlet of these holes are connected to a scrubber. This modification has minimized pellet chipping and airborne activity.

#### Modification and Refurbishment of Ammonia Crackers

The control system of Ammonia Cracker 1 is modified to eliminate frequent maintenance and false alarm generation through introduction of Duplex thermocouples. In Ammonia Cracker 2, the bricks and retorts have been removed safely and have been replaced with SS 316 bars to avoid bending under load

and high temperature. The nickel catalyst in the retorts has been replaced with fresh nickel catalyst. The refurbishment will help in increased flow capacity and availability of the ammonia cracker.

### Natural Uranium Fuel Assembly Plant (NUFAP)

NUFAP carries out all tube processing operations like machining, graphite coating & baking and appendage welding for production of entire PHWR fuel bundles of 19 element and 37 element type in addition to final assembly of fuel bundles.

### Equipment Development & Automation (ED&A)

Major works that were carried out with respect to equipment development & automation are mentioned as under:

#### Advanced pick & place system for final compaction press

A new pick & place system was developed using precision CC- Link based, linear actuators driven by servo motors for precise movements in horizontal and vertical directions. A positional Accuracy of  $\pm 20\mu\text{m}$  can be achieved with this control system. This system was mounted on three numbers of final compaction presses and they are working satisfactorily. This pick & place system improved machine availability time for production, enhanced productivity and reduced operator exposure to radio activity during handling of pellets on conveyor units etc.



**Advanced pick & place system for final compaction press**

#### Modification of ADU Bunkers

The SS bunkers are used for collection and handling of ADU powder from Turbo dryer unit to Calcination furnace. These bunkers are modified to



**Modification of ADU Bunkers**

enhance the volumetric capacity of the S.S. bunker by 30 to 35%. This modification has reduced the frequency of handling of the bunker, manpower requirement for production. Total 14 nos. of such bunkers are modified, tested and kept in regular production use.

#### Automatic Granule Transfer System

Automatic  $\text{UO}_2$  Granule Transfer system was designed, developed, fabricated, assembled and commissioned at CFFP (P) for transferring  $\text{UO}_2$  granules from container to the hopper mounted on the Rotary press for production of green pellets at CFFP (P). This system has features for gripping the container, tilting, raising and swivelling the container to locate onto hopper of the press at a height of 3.5 meters from ground.



**Automatic Granule Transfer System**

#### Provision of Additional Digital Vacuum switches and Pressure Switches

The digital vacuum switches are used to detect the reverse orientation of appendages and for proper placement of appendages on the PHWR tubes. The





**Digital Vacuum switches and Pressure Switches**

spacer pad welding machines (of both 19 element type 2 No's and 37 element type 3 No's) at NUFAP are having vacuum switches with single output are replaced with Vacuum switches having two outputs. Mechanical type pressure switches are replaced with Digital pressure switches for display of the pressure. The provision of these switches will ensure the proper orientation and placement of the appendage on the tube before welding.

#### Automatic Shear Strength Testing Machine

Automatic Shear strength testing machine is used to measure the shear strength of the welds after welding of appendages on PHWR fuel tubes. This machine measures the strength of both Spacer pad and Bearing pads welded on the appendages. The fork, display unit mounting, control panel and Design of the load washer assembly with shear tool are modified. The modification in the load washer assembly has improved the sensitivity of the machine and is working satisfactorily at NUFAP.



**Automatic Shear Strength Testing Machine**

#### Five Linear Movement guides based track systems for Uranium Oxide Powder plant

Uranium Oxide Plant (UOP) is having five underground trenches for Discharge Bunker movement, one each below the Rotary Furnace's discharge head. Earlier "UOP" was handling manually the discharge bunkers on castor wheeled trolleys. ED&A has developed, fabricated, installed Linear Movement (LM) Guides based track systems for movement of discharge bunkers on the LM tracks. This development has made discharge bunker movement alignment very easy. Only one operator is required to pull or push the bunker trolley against two earlier.

#### Five Motorized Discharge Bunker Trolley Movement Systems for Uranium Oxide Powder plant

To further automate the manual pulling / pushing of Discharge bunker trolleys, ED&A has developed & fabricated five Discharge Bunker Trolley movement Systems.

#### "ADU" Wet Cake Feeding System for NUOFP(O)

ED&A has developed and in-house fabricated, scroll unit in S.S. materials to feed the wet cake in to the Calcination Furnace at controlled rate for carrying-out various process developmental studies. The equipment is performing satisfactorily with required throughput rate.

#### Two Specially designed Bunker Lifting Tackle units in S.S. materials for Uranium Oxide Powder plant

ED&A has specially designed and fabricated two Lifting Tackle units in S.S. materials. Each is having a pay load capacity of 1.5 MT. These lifting tackle units will be used to lift and handle dried "ADU" powder bunkers to charge it in to the Calcination Furnace. ED&A has specially designed the lifting tackle units to avoid this wire rope cutting problem and to reduce the bunker handling time which leads to improvement in productivity.

#### Incorporation of Weld Checkers on all Appendage Welding Machines

For ensuring the quality of welding on appendage welding machines, an additional feature has





**Weld checker System**

been incorporated in the form of Weld checker System. This system monitors the amount of current during welding and alerts the operator if the welding current is out of a pre-defined range. All ISBUs and SPWs at CFFP (A) & NUFAP were provided with these systems to ensure the quality of Appendage Welding operation.

#### Development of Drop test Mechanism for fuel shipment Box

Designed and developed a pneumatically actuated four bar mechanism for lifting and dropping of fuel shipment box along with the fuel bundles from 1.2 meters distance from ground to the bottom most corner



**Development of Drop test Mechanism for fuel shipment Box**

of the container, when the container is lifted from the diagonally opposite corner. The detailed drawings were developed, components were fabricated in-house and assembled the complete mechanism. The trials were conducted and the drop test was successfully completed for the first time in NFC along with fuel assemblies weighing around 350 kg.

### **Enriched Fuel Fabrication Plant (EFPF)**

Produced 73 nos. of BWR assemblies from April 2017 to December 2017 with average top plug welding recovery of around 98% as against 65 no's produced in same period of previous year. Carried out de-canning of around 9,250 nos. of rejected PHWR fuel elements and recovered more than 7.3 MT of  $\text{UO}_2$  pellets for inspection and subsequent loading into fresh fuel tubes.

### **Metallic Fuels**

Nuclear grade U metal has been produced and supplied. 6.5 Kgs of Natural U –Metal powder & 200 grams Th metal powder has been supplied to various divisions for the purpose of R&D. Two Tons of natural U has been recovered from legacy waste to minimize the active waste disposal. A new stretchable type ( $\text{UF}_4 + \text{Mg}$ ) charge powder feeding system has been installed to reduce the airborne radioactivity. Augmented nitrogen plant from 10  $\text{Mt}^3/\text{hr}$  to 50  $\text{Mt}^3/\text{hr}$  has been procured to meet the present requirement of U-processing plant. A new analytical laboratory has been established for various R&D works. 120  $\text{M}^3$  of radioactive solid waste has been disposed under BARC Swatchta Abhiyan (BARC Cleaning Drive).

Design basis report for Uranium Metal Production Facility (UMPF) at Vizag has been approved by Task Force. Architectural Plant layout was finalized for preparation of structural design.

### **Structural Materials & Components**

#### **Zirconium activities**

##### **Zirconium Oxide Plant (ZOP)**

The Plant has produced 5 kgs. of high purity Hafnium oxide ( $\text{HfO}_2 > 95\%$ ) and supplied to BARC, Mumbai. Plant has reprocessed contaminated

zirconium oxide material collected from exhaust pipe lines, aiming at recovery of valuable zirconium values. Plant has completed the erection and commissioning of a high capacity pulveriser unit. Introduction of this new unit enhanced the capacity of grinding zirconium oxide to 500 kg/hr, doubling the productivity with same man power. Revamping of SCADA is taken up in Zirconium Oxide Plant for modernising the operation & control of Dissolution, Solvent Extraction, Precipitation, etc.

### Zirconium Sponge Plant (ZSP)

Plant has successfully installed and commissioned additional positive displacement type briquetting system to enhance the capacity of feed preparation for chlorination. Replacement of all MS vacuum piping of all vacuum distillation units with SS316L for withstanding HCl corrosion and solenoid operated air-admittance valve to avoid any accidental air ingress. Plant has successfully processed higher titanium  $ZrO_2$  feed material by optimizing parameter in chlorination and reduction operations. Over 50MT reactor grade Zr sponge has been produced with this material. Introduced Second retainer plate in vacuum distillation unit to minimise Zr sponge loss by run down. Introduced non-metallic corrosion resistant line heater end connections in reduction units to improve life, ease of fixing and improving safety. Provided perforation on coking crucibles & forced air cooling of coking retort to reduce retort cooling time in furnace and increase furnace utilization in the bottleneck coking operation. Introduced safety interlock based on current load in vacuum distillation units to isolate the distillation chamber in case of vacuum system failure due to snapping of vacuum pump belts.

### Online Chlorine & HCl gas analysers for ZSP

Continuous Emission Monitoring System (CEMS) based on state-of-the-art technology has been provided, with Online Chlorine gas analyser to detect chlorine gas concentration in the stack discharges of ZSP and Online HCl gas analyser for continuous monitoring of the incinerator stack discharge. The analysers work on a unique technique called Differential Optical Absorption Spectroscopy, Chlorine in the Ultra Violet range (UV-DOAS) and HCl analyser in the infrared range using FTIR Infra-Red Spectrometry and are



*Online Chlorine gas Analyser*



*Gas Monitoring System*



*Fast loop, emitter and receiver*

therefore not subjected to cross interference. The units have been commissioned and put into operation.

### 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.

Major activities that were taken place include the development of process route for new design of Garter Spring assemblies and supply of 734 nos. out of 1300 nos. of Garter Springs for KAPS-2 and remaining are being sent soon; In-spite of a 2 month unexpected shut down of the extrusion press, EPP, ably supported by the Machine Shop and BPS, completed record number of extrusions in April-December 17, 8489 nos: exceeding the number of extrusions for the same period last year by planning suitably to reduce frequency of container change, working on holidays etc. ; BPS completed much more than its targeted production of Bars making a record production; Nearly 210 Pressure Tubes have been produced for the KAPS -2, 220 MWe reactor meeting much more stringent quality standards compared to earlier supplies and remaining 110 are planned to be dispatched soon; Manufacturing of 12 Nos. of Cobalt Absorber Assemblies for 220 MWe PHWR; Manufacturing and supply of Electron Beam welded Zr-4 / Hf absorber blades (12 nos.) for up-graded APSARA research reactor, BARC; Completed manufacturing of one reactor charge i.e. 6 nos. of Liquid Poison Injection assemblies for RAPP-7 (700 MWe PHWR), OFT and IFT assemblies (4 nos. each, total 8 nos.) for 220 MWe PHWR (KAPS-1 & 2), and Electron Beam Welding of 3 nos. of Nozzle less Booster (NLB) Head for DRDL, Hyderabad.



*Electron Beam Welding of Nozzle less Booster (NLB) Head for DRDL, Hyderabad*

Major repairs were taken up on the extrusion press and using a welding and quality check process specifically developed for the purpose, the Maintenance team along with QA accomplished the specialized works successfully in the shortest possible time. The press has been performing excellently since then.

Various process improvements that were carried out include the change from lathe operations to Automatic Machine Centre operation for the process of machining of PT billets for extrusion; The continuous furnace was overhauled with new heating elements, thermocouples etc.; In Fuel Tube production operations many improvements were made to increase the productivity and bring down maintenance of equipment; Revamping of vertical annealing furnace; For the first time SS 321 round to hexagonal tube of smaller across flat- of 29.5 X 0.4 mm is pilgered successfully; Visual recovery of BWR tubes is enhanced to 100% ; An in-house developed automatic mandrel inspection system is made ready and being commissioned shortly in TRTP; Development of as extruded Seamless Al- Fin Tube of size Ø17.5X3mm for Dhruva clad tube application was completed; Development of 3 advance grades ODS steel rods by extrusion for ARCI for potential applications in fusion reactor and advance ultra-super critical boilers was carried out collaboratively; Twin head Avasrala 10-20 and 6-15 HPTR pilger mills coolant lines were modified to install standby coolant pumps to improve availability of mill; Installation of Standby pumps for HPTR pilger mills to improve availability and Design, modification and manufacture of Die housing assembly of 2000Te hydraulic press to increase die insert life and ease of manufacturing.



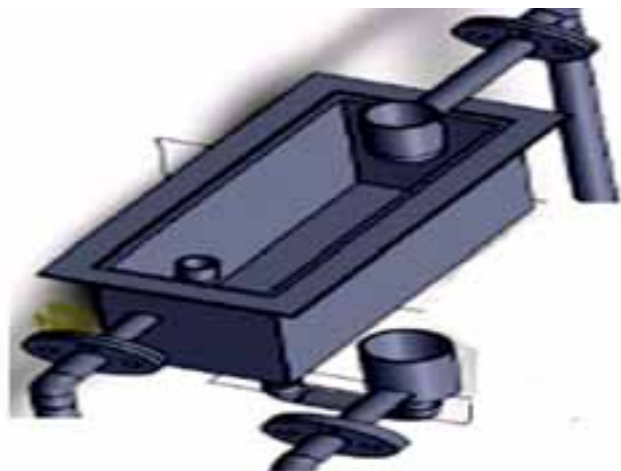
*The high pressure return rams in which specialized major welding repairs carried out on the underside*



Some of the other developmental activity include Development and commissioning of PLC based HMI control system for 50 VM pilger mill at ZFP; Development of scaled down pressure tubes for RSD, BARC and Automation of tube unloading operation in tube straightening machine.

### Special Materials

This plant produces niobium metal granules used for pressure tubes. Produced & supplied 50 kg of micron size zirconium metal powder to meet requirement of Defence & Space departments. A process has been developed for preparation of Aluminium coated Zr Metal Powder for HEMRL for applications in high energy solid propellant &. 25 kg has been prepared. 50 nos. of cold rolled NbZrC coupons (90x10x10mm) were prepared for high temperature creep tests at RSD, BARC. Design, Fabrication & Testing of new standalone single stage PP airlift mixer settler was completed.



**3D view of the standalone single stage  
PP airlift mixer settler**

### Commercial activities

Stainless Steel Tube Plant (SSTP) is specialized in manufacturing speciality tubing in advanced grades of Stainless Steels and special alloys.

During the period, SSTP has manufactured and supplied critical products which include 7947 nos. of SS-D9 grade Fuel clad tubes for Prototype Fast Breeder Reactor (PFBR), 125MT of SS304L pipes in different sizes for FRFCF project, 1.7MT of Ti-Half alloy tube to VSSC & LPSC of ISRO, PT 7M tubes to BHEL etc.

### Projects related to SSTP

Fabrication of 50-8 pilger mill is in progress under the project "Renovation & Augmentation of SSTP". Project proposal for augmenting the SSTP facility to meet the requirement of FBR 1&2 is under preparation.

### Projects

#### Green field Projects of NFC

##### NFC-Kota

NFC-Kota, 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 Kakrapar 3&4. Site grading work involving approx. 5.25 lakh cub mtr of rock excavation by blasting, around 21 Km of road and drain construction and about 3 Km of compound wall construction is completed. Construction of raw water reservoir, 12nos. watch tower, 4nos. of warehouses, project site office, entry gates are completed. Construction power of 750 kVA is energised. Construction of plant and non plant buildings is in progress. Foundation works completed for all the non plant buildings and slabs are being cast for a few of them. An overall progress of 16.65% was achieved in the project till December, 2017.

##### Other sanctioned projects of NFC

Augmentation of MSDS-2, Replacement of LT switch gears and redistribution of loads is in progress.

#### Augmentation of Amenities and Infrastructure at NFC (AAIS)

The objective of the project is to augment the existing amenities and infrastructural facilities at NFC, Hyderabad and Zirconium Complex, Pazhayakayal. The financial sanction for the same was obtained. Tenders are floated for setting up Sewage Treatment Facility in the Plant and Colony premises of NFC.

#### Advanced Melting & Machining Facility

Advanced Melting & Machining Facility under Project is for indigenous development of Electron Beam



Gun of 150 kW capacity, EB melting furnace of 300kW capacity and various components as an import substitute to facilitate melting of zirconium, niobium, hafnium, molybdenum and its alloys. This will enable direct utilization of scrap and off-grade materials for melting, refining and consolidation into ingots of Zr, Nb, Ti, Hf, Mo etc. Electron Beam melting furnace was designed jointly by NFC and BARC. After initiation testing at vendors works, the furnace is reassembled / erected at NFC and is under commissioning. Clearance from AERB for commissioning was obtained in December 2017.

### 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). Zirconium Complex was commissioned in November 2009 and regular production activities for both zirconium oxide and zirconium sponge continued since then. 216 MT of nuclear pure zirconium oxide and 198.691 MT of zirconium sponge were produced during the year till December, 2017.

Atomic Energy Central School was inaugurated on 20th March 2017. Classes (upto 3rd standard) are functional in current academic year in temporary campus. Competitions and festival celebrations are conducted in Township actively by ZC staff and CISF personnel.

### 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. One stream has been commissioned and is in operation. Commissioning activities for the second stream are in progress.

### Magnesium Recycling Technology Development & Demonstration Facility

During the production of zirconium sponge by the well-known Kroll Process of magnesio-thermic reduction of zirconium tetrachloride, anhydrous magnesium chloride is generated as a by-product. This magnesium chloride can be converted to magnesium metal and chlorine by fused-salt electrolysis for captive

recycle, thereby contributing to the reduction in the cost of production of zirconium. By-product chlorine from the Cells can be recycled after purification. The multi-polar cell technology has been extensively studied and experimented at Defense Metallurgical Research Laboratory (DMRL) In order to perfect the technology and make it suitable for commercial adaptation, it is proposed to set-up a Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF) at Zirconium Complex, Pazhayakayal, Tuticorin. The project is being implemented jointly by NFC, HWB, and DMRL as a collaborative effort pooling resources and technological strengths of all the organizations under a Memorandum of Understanding (MoU). Civil construction of plant buildings are in advanced stage. Detailed specification & drawings of process items have been made for most of the equipments and are at various stages of tendering.

### Technology Demonstration Unit for 1.5 Ton Zirconium Sponge Batch

The production of nuclear grade Zirconium Sponge from Hafnium free Zirconium Oxide is a batch process. At present, equipments are designed for a batch size of 750 Kg of Nuclear Grade Zr Sponge. A Technology Demonstration Unit (TDU) with bigger capacity reduction & vacuum distillation units of 1500 kg batch size was set up by utilizing the space and infrastructure at Sponge Production Facility. The unit is scaled up from 750kg batch size. Reduction and Vacuum Distillation units have been commissioned and trial runs completed in 1MT, 1.25MT and 1.5MT stages in reduction unit.

### Projects related to Melting Facilities

Civil foundation works for erection of Vacuum Arc Remelting furnace are in progress. Major equipment procurement is in progress and civil works for Zirconium reprocessing facility are being taken up.

## BACK END FUEL CYCLE

### Fuel Reprocessing

Computational Fluid Dynamics (CFD) based model to predict hydrodynamics and mass transfer in Pulsed Sieve Plate Column (PSPC) was validated with

large-scale data. Detailed sensitivity analysis was carried out to understand dependence of hold up, Sauter mean drop diameter and axial dispersion coefficient in continuous and dispersed phases on geometric and operating parameters for aqueous dispersed and aqueous continuous mode of operation of PSPCs. CFD model for estimating continuous phase axial dispersion in Pulsed Disc and Doughnut Column (PDDC) was developed and validated with in-house experimental data for different operating conditions and internals of the column.

About 50g of synthesised di-tertiary butyl dicyclohexano-18-crown-6 (DTBDCH<sub>18</sub>C<sub>6</sub>) ether, a highly strontium (Sr) selective ligand, was evaluated for recovery of Sr from simulated high level waste (HLW) with high selectivity with respect to Am and Pu.

Direct thermal denitration of uranyl nitrate to uranium oxide powder was demonstrated in 150 NB fluidized bed reactor.



**Product UO<sub>3</sub> discharged from the reactor to the product collection vessel**

Continuous smooth operation was observed with demonstration of online regeneration of off-gas filter candles and solid withdrawal from the reactor. The fine UO<sub>3</sub> powder obtained from filter housing during operation of bench-scale plant was reduced to UO<sub>2</sub> (O/U 2.06 – 2.09) for pelletisation.

For input accountability of Pu, eighteen dissolver solutions of irradiated fuel were analyzed by Isotope Dilution - TIMS. Concentration of Pu determined after chemical separation of fission products and bulk of U.



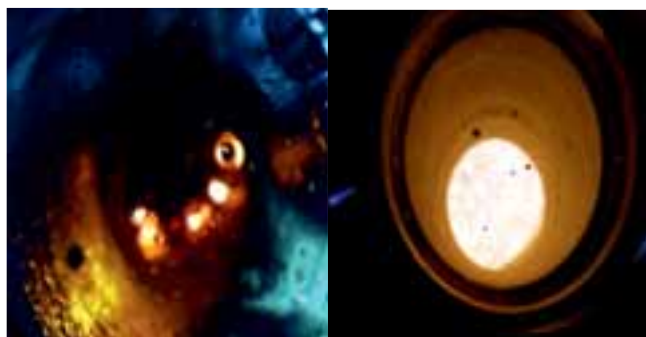
**Dissolution Set up housed in Fume hood**

Studies on the development of a process flow-sheet for the reprocessing of spent fuel from HFRR using TBP at laboratory scale was completed. Natural uranium silicide fuel plates were used to optimize the dissolution parameters. Dissolved solution after filtration was used as feed after adding other elements including Pu from their respective nitrate solutions so as to get a more realistic feed solution of reference burn up of 80000 MWD/te at 3M HNO<sub>3</sub>.

Results from extraction studies showed quantitative recovery (>99.5%) of U and Pu in four and seven stages respectively. Extraction of other elements present in the feed was found to be insignificant. Organic phase from extraction experiments was subjected to partitioning using a mixture of Hydroxyl Amine Nitrate (HAN) and HNO<sub>3</sub>. U losses in the aqueous phase were prevented by incorporating a TBP wash step during partitioning. Further purification of Pu and U can be achieved to the desired level using conventional method. Low-level effluent generated from TRIX operation at NRB, Tarapur contains high concentration of <sup>99</sup>Tc activity and an effective process for Tc sequestration was developed.

Induction Skull Melting (ISM) technology developed indigenously by BARC was successfully deployed to demonstrate melting and homogenization of boron-containing Zr-Ni motheralloy produced by NFC. Boron containing stainless steel was also produced using the ISM Facility.

Cs volatilisation studies were conducted in Cold Crucible Induction Melter to compare the Cs volatility losses at high temperature in cold crucible melter with



**With Cold Cap      Without Cold Cap**  
Cold cap conditions at different time of operation

existing metallic as well as Joule melter. Nearly 50 hours long melting operation with continuous liquid feeding (using simulated waste with a composition of ROP Tank-6 HLW) was carried out to quantify the Cs volatilization per canister produced using the cold crucible induction melter. Off-gases from the melter were sampled at different intervals of time to quantify the Cs volatilisation in the cold crucible. The Cs volatility losses were found to be lesser in stable cold cap condition and similar in absence of cold cap as comparing with operating experience of existing metallic melter.

## Waste Management

Refurbishment and up-gradation of various process systems, utility systems as well as instrument & control systems was taken up at Plutonium Plant, Trombay to continue operation in safe and efficient manner. Two process evaporators and a Thermosiphon evaporator were replaced. Root-cause analysis of failed equipments was carried out and found to be mainly due to corrosive environment. Aged manual steam valves (~500 Nos.) from operating gallery were dismantled and replaced with new air actuated valves to facilitate remote operation of steam valves for ejector transfer mode resulting in reduction of personnel radiation exposure, along with associated vacuum breaker valves. Up-gradation of I&C systems for Plutonium Plant with PLC & SCADA system was completed and will facilitate safe and secured remote process operations of Plutonium Plant. The system also provides several features like ease in operation, safety interlocks, user friendly, self-diagnostic tools, report generation etc. All the three aged muffle furnaces were thoroughly decontaminated and dismantled. New furnaces with modified design were installed, tested and commissioned. Associated electrical and

instrumentation systems for these furnaces are provided outside the Glove box for ease of maintenance.

Fresh HLW generated during reprocessing of spent fuel having high amount short lived radionuclides after its decay was subjected to pre-concentration prior to partitioning.



**Treatment scheme for fresh HLW**



**Solvent Extraction System, WIP Trombay**

Advanced Servo Manipulator (ASM) was installed to replace the existing servo manipulator. New process pots were installed remotely along with accessories to the melters.

At Effluent Treatment Plant, the low level radioactive liquid waste was safely managed by employing Chemical Treatment and Ion Exchange processes. The low level effluents were disposed after monitoring. Fuel components from Dhruva reactor and protective wears from various plants and laboratories in Trombay were decontaminated and recycled back for reuse.



**Effluent Treatment Plant, Trombay****Decontamination Centre, Trombay****Compaction of wastes      Waste disposal in RCT**

Towards the implementation of the concept of “wealth from waste” Cs was separated and immobilized in vitreous matrix to Cs- glass pencils which have been handed over to BRIT for application in blood irradiators. 52 nos. of caesium pencils having 2 Ci/gm specific activity has been produced and WIP Trombay has achieved a milestone of production of 100 numbers of Cs pencils.

In-house developed two stage Supported Liquid Membrane based  $^{90}\text{Sr}$ - $^{90}\text{Y}$  generator system was used to generate carrier-free  $^{90}\text{Y}$  from  $^{90}\text{Sr}$  recovered from PUREX-HLLW. Using the generator system, six lots of 160mCi each (40 Ci/L) of carrier-free  $^{90}\text{Y}$  in acetic acid medium were separated and supplied to RMC, Parel for Radiopharmaceutical applications. Contamination of  $^{90}\text{Sr}$  in all the lots was found to be within the permissible limits.

**Minor Actinide Product Conversion  
Demonstration Facility, at ASDF, Tarapur**

The Minor Actinide Product Conversion Demonstration System (MAPCDS) for downstream processing of ASDF product solution and its conversion into oxide has been setup. The facility comprises of chromatographic separation of Eu from alpha product stream, precipitation of alpha product as oxalates and its calcination to oxide. Initial cold commissioning trials using rare earths as markers have yielded satisfactory results both with regard to Eu separation and precipitation into oxalate followed by conversion into oxide form.

Setting up of Demonstration facility based on R&D in laboratory for decontamination of alpha bearing cellulosic waste- Area 64, WIP has been completed. The facility has been cold commissioned and safety clearances for hot commissioning is in progress.

**Demonstration facility for decontamination  
of A bearing cellulosic waste**

Under the programme for the development of technology for production of Radiation Shielding Window (RSW) glass using refractory crucible in collaboration with CGCRI, Kokata, experimental studies were carried out at CGCRI using 10L refractory crucible to optimize the process parameters. Performance of the stirrer was initially evaluated using model liquid at room temperature and subsequently in molten glass at 1100°C.





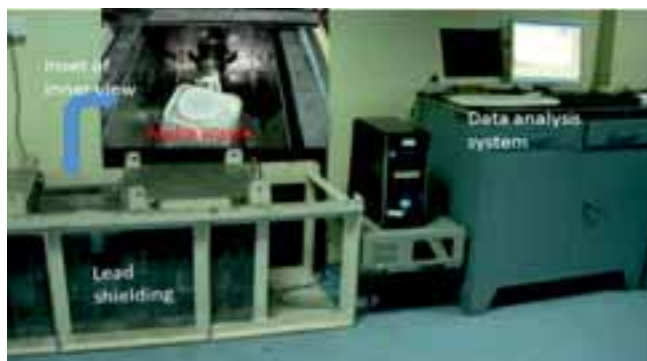
**Stirrer designed and fabricated at CGCRI**



**60L Refractory Pot and Trial tilt cast operation**

Ternary sodium borosilicate glasses were prepared with alumina and zinc oxide added to the glass. It is confirmed that ZnO addition can greatly improve chemical durability with no apparent detrimental effects on radiation stability. Results of the study are useful in preparation of high alpha bearing glasses for immobilization of alpha rich streams that are generated from ASDF facility.

Alpha assaying has been developed and a detector assembly with lead shielding facility has been installed at WIP, Trombay. The assaying system has



**Alpha assaying system**

been calibrated down to 1 mg  $^{239}\text{Pu}$  in 5 L package containing assorted waste. The system is to be used for certification of waste as non-alpha category after electrochemical treatment of cellulosic waste.

Silver impregnated synthetic zeolite of mordenite type has been prepared and tested for the removal of iodine from simulated off-gas streams. Iodine is trapped in the Ag loaded mordenite by the formation of AgI in the pores of the mordenite through a solid-vapour reaction. In the presence of NO<sub>x</sub> and water vapour, formation of large aggregates of AgI crystals on the surface of the mordenite observed indicating efficacy of the sorbent for in-situ immobilization of radioiodine from off-gas streams of reprocessing plants.

The Alpha Waste Transit Storage Facility (AWTSF) II was setup and commissioned to augment the storage capacity of AWTSF-I. Alpha Solid Waste Treatment Facility (ASWTF), has been sanctioned. Architectural layout drawing has been received and is presently being reviewed for process, mechanical handling, ventilation and radiological criteria. The Preliminary Safety Analysis Report for this facility has been initiated for necessary safety clearances.



**Alpha Waste Transit Storage Facility (AWTSF) II**



**RCC trench between AWTF and WIP-Pump House**

High level radioactive liquid waste transfer trench (60m long) elevated 3m above ground, having 15 nos. of Stainless Steel lines with pipe-in-pipe configuration in SS lined RCC/MS shielded was constructed for the to & fro waste transfer between Additional Waste Tank Farm and PP resulting in considerable savings financially as well as in terms of land resources.

Building layout & civil design of Alpha Waste Transit Storage Facility (AWTSF) of BARC, Vizag has been finalized. Low Level Waste (Liquid & Solid) Management Facility (LLWMF) building layout including sectional elevation has been prepared. Near Surface disposal Facility (NSDF) Site location has been finalized and further detailing has been initiated. The Project information report comprises of AWTSF, LLWMF, NSDF and Discharge line to sea has been prepared including process, mechanical/material handling and ventilation, radiological, electrical and instrumentation detailing.

## Safety Performance of Reactors

NPCIL is performing the safety analysis including deterministic and probabilistic safety assessment of nuclear power plants for design, siting, 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.

During the FY 2017-18, following major activities were completed:

**Determination of Safe Grade Level for Proposed Kovvada Site:** The safe grade elevation of the proposed coastal nuclear power plant site, Kovvada (Andhra Pradesh), has been established to avoid flooding of the site considering tsunami as well as storm surge. All safety related buildings are to be located above this safe grade elevation of the site. The assessment has been carried out using internationally accepted Computational Fluid Dynamics (CFD) based approach adopted currently for realistic assessment.

**Development of a plant specific real-time analysis tool for Risk Monitor:** Plant specific real-time analysis tool for Risk Monitor based on the Probabilistic

Safety Assessment (PSA) model of the plant was implemented for Narora Atomic Power Station (NAPS). This will help the plant operators and management to maintain enhanced safety of the plant.

**To demonstrate capability of handling accident safely in multiple units:** An integrated mock exercise of simulated extended Station Blackout (SBO) in both units simultaneously was carried out at all PHWR stations as a part of building confidence in line with defence in depth philosophy, with an objective to verify and validate accident management guidelines and provisions.



*Arranging water from alternate source*



*Arranging power from alternate source*

**Development of general purpose Computer program for Fire Hazard Analysis (FHA) of Nuclear Power Plants (NPPs):** In view of importance of fire as a common cause initiator, a general purpose in-house computer code for fire hazard analysis of NPPs and solution techniques have been developed by incorporating established correlations for various fire scenarios. The computer code is validated against



experimental data available in open literature and used for revision of fire hazard analysis of MAPS-1&2 as a case study. With this code, a user friendly tool is made available for fire protection engineers at sites for fire analysis using both containment and influence approach.

**Up gradation of Annulus Gas Monitoring System (AGMS) guidelines of Indian Pressurized Heavy Water Reactors (IPHWRs):** All aspects of AGMS have been reviewed extensively and guidelines for operation of AGMS of IPHWRs have been upgraded taking cognizance of various operational aspects for enhanced safety.

Containment response during Loss of Coolant Accident (LOCA) initiated severe accident with consideration of Severe Accident Guidelines (SAGs) in IPHWRs, was analyzed. The analyses demonstrate the adequacy of above mentioned additional means in maintaining containment integrity in case of postulated failure of all diverse design routes

Thermal-hydraulic analysis was carried out for deployment of Fuelling Machine Remote Operated Internal Diameter Measurement (FRIDM) Tool.

Level-1 Probabilistic Safety Assessment (PSA) for TAPS-1&2 (BWR) for Shutdown State, was carried out. The results of the Shutdown PSA indicate that a fairly high level of defence-in-depth exists in TAPS-1&2 design during Shutdown mode of operation.

## HEALTH, SAFETY AND ENVIRONMENT

A glowing metal wire based nanoparticle aerosol generator has been developed to study the specific aerosol behaviour such as charge fraction of aerosols, implications towards evolution models and calibration of aerosol instruments. Nichrome and tungsten metal wires of different chemical compositions have been used for generation of aerosols. It was observed that the generator can produce a stable particle concentration of the order of  $10^7$  per  $\text{cm}^3$  with geometric mean size of 15 nm and geometric standard deviation of 1.4. TEM analysis revealed that the observed primary aerosol sizes were as low as 3 nm.



*Hot wire Aerosol Generator (HWG)*

National Occupational Dose Registry System (NODRS) of BARC, with a database of 6,73,109 radiation workers, maintains and updates occupational dose data of all monitored radiation workers in the country. The networked NODRS system has been expanded further to HPUs at RAPS 7&8, KAPS 3&4 as well as to WIP & P3A at BARCF, Kalpakkam. NODRS is now operational at 59 monitoring labs (TLD labs/HPUs) at 7 NPPs and 10 other DAE units. The system facilitates online allotment of personal numbers to new radiation workers, online updation of dose data, linking of dose records, and online availability of dose history of existing radiation workers. Recently introduced Global fingerprint comparison software is being extensively used for indentifying radiation workers with previous dose history as well as for tracking the movement of radiation workers within DAE units.

BARC has developed a solar powered Radon Geo-Station using indigenous Radon (Rn) Monitor (SMART RnDuo) which has the potential for early warning of earthquakes. The Rn gas detection based Geo-station is used for the detection of Rn anomaly peak at a geologically favourable location. This peak



*In-house developed Radon Geo-Station*



can occur a few days to a few hours prior to the earthquake event, depending on the distance, magnitude, depth of earthquake.

About 15 stations have been set up in the north and north-eastern regions and correlations have been drawn between the observed Rn peaks and the occurrence of earthquake. The results, based on compilation of about 150 earthquake events (of magnitude  $>3$ ) which could be correlated to prior Rn peaks are very encouraging. It is opined that having a dense network of stations will improve the predictability w.r.t. location, time and magnitude of earthquake.

A Back Pack Spectrometry System has been designed and developed for usage by Emergency Response Teams/First Responders to search, detect, locate and identify 'Orphan' radioactive sources. The system has been specifically designed and developed for carrying out radiation monitoring of suspected places without drawing attention of the public.



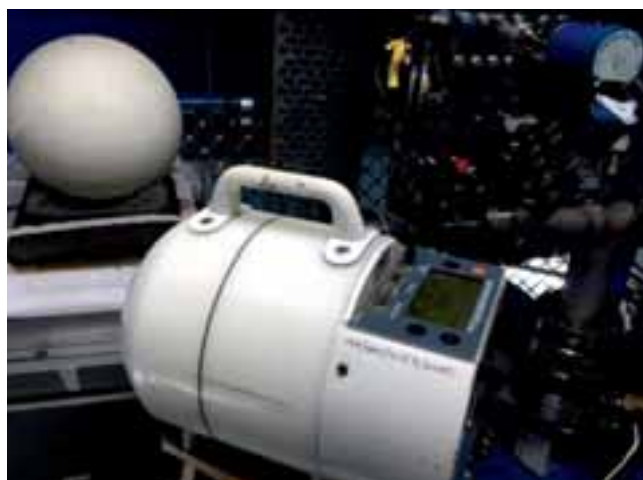
*Usage of BPSS in search of Orphan Source*



*Spectrum obtained using BPSS in presence of Cs-137 & Co-60 source*

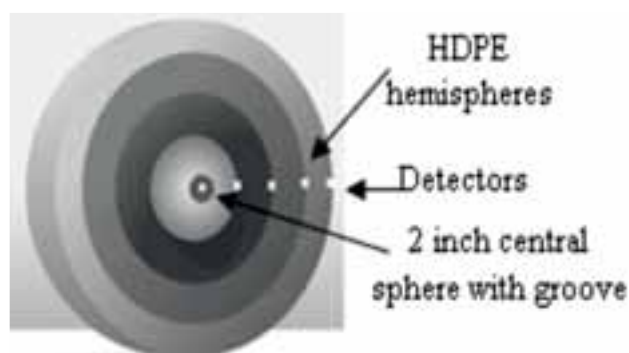
The system consists of a Field Programmable Gate Array (FPGA) based spectrometer developed in-house and a 3"×3" NaI(Tl) Detector. Online data is transferred to a Tablet over Bluetooth and an Android Application has been developed for spectrum analysis and display.

A series of experiments have been carried out at BARC-TIFR Pelletron facility to generate thick target dose and induced activity in structural material during the operation of proton accelerators. The experiments will provide inputs for planning radiation protection practices, insight of interaction mechanisms at different structural and commonly used target materials in accelerator environment. It will serve as an important input for shielding requirements and safety practices to be adopted during and after operations. Induced activity studies will be helpful for getting precise knowledge regarding radiological consequences during accidental cases and minimization of the radioactive wastes during de-commissioning stages.

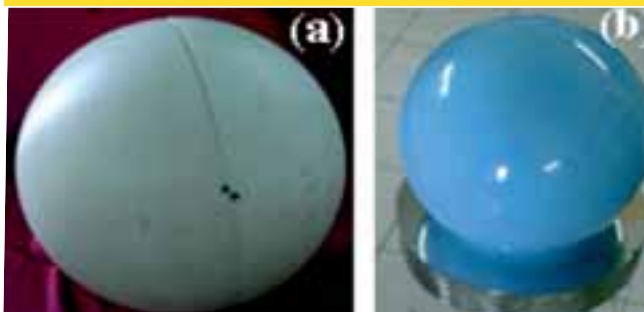


*Experimental Set up for irradiation studies*

A Single Sphere Neutron Spectrometer (SSNS) has been designed and fabricated. SSNS has the advantage of measuring neutron spectrum in just a single exposure which has been a challenge in accelerator radiation environment where space and time for exposure are limited. Use of an external Pb shell was found to enhance its energy response to GeV orders via  $(n, xn)$  reactions. The system has been calibrated with standard neutron source ( $^{241}\text{Am-Be}$ ) and real field measurements have been carried out at TIFR-BARC Pelletron Accelerator Facility for validation purpose.



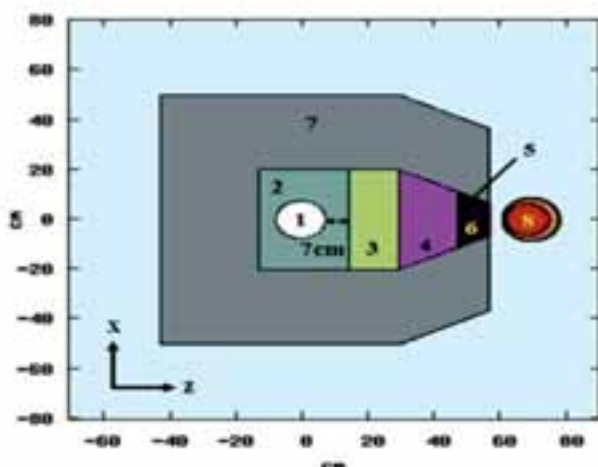
**Schematic diagram of SSNS (cross-sectional view)**



**(a) Single Sphere Neutron Spectrometer  
(b) SSNS with Pb shell for higher energy neutrons**

A Beam Shaping Assembly (BSA) for compact D-T neutron generator has been designed using the FLUKA Monte Carlo simulation to determine best composition of materials for producing epithermal neutrons. This can be useful in Boron Neutron Capture Therapy (BNCT) treatment of deeply seated tumor in the brain.

Designed BSA would provide an appropriate beam intensity and quality as per IAEA recommendations at lower source strength. Dosimetric



**Cross sectional view of BSA with head phantom  
1) Neutron tube, 2) W, 3) D<sub>2</sub>O moderator, 4) TiF<sub>3</sub>,  
5) Cd, 6) Bi, 7) Pb, 8) Snyder head phantom**

evaluation with Snyder head phantom was found to be satisfactory for treatment of deeply seated tumor with a treatment time of 115 minutes. It can be installed in hospital premises for BNCT treatment with a better social acceptance.

Health Physics Units (HPUs) are established at front end and back end nuclear fuel cycle facilities related to U mining and ore processing, beach sand mining and monazite processing, fuel fabrication, reprocessing and waste management to carry out radiological surveillance, in-plant monitoring and personal monitoring of about 12,200 workers and monitoring of environmental discharges which include measurement of gamma radiation, neutron, radon, thoron and their daughter products, surface contamination, long lived alpha air activity and off-gas releases. Results of the surveillance programmes were in compliance with regulatory limits.

Environmental Survey Laboratories (ESLs) are established at each nuclear facility as an independent agency for monitoring of environmental matrices to measure activity concentration of concerned radionuclides. ESLs participate in regular public awareness programmes for greater acceptability of nuclear energy and also act as Emergency Response Centres. Environmental matrices such as soil, sediment, air particulate matter, water, milk, food items, sea food and grass are collected upto 10 km and 30 km radius around front end facilities and NPP sites and radiochemically processed and analyzed as per BARC standard protocols for concerned radionuclides using various radiometric techniques. The results clearly indicated that the dose to the member of public at fence post is only a small fraction of regulatory limit of 1000  $\mu\text{Sv/y}$  and negligible compared to the dose received by the public from natural sources (2400  $\mu\text{Sv/y}$ ). The radiation dose received by the members of public is less than 3% of the limit prescribed by AERB.

Following media concerns on the high U content in drinking water of Punjab, BARC has taken a pro-active initiative to generate a national database on U in drinking water in 706 districts of India under National Uranium Project (NUP). This database is being generated through collaborative project with local universities / institutions. Each project covers an area of



*Dual detector based Pu-in-air monitor*

about 20,000 sq. km comprising of a few districts of a state. The study area is divided to an optimized grid size of 6 x 6 km for screening purpose and one representative sample is collected from each grid near the population centre. Uranium, sixteen associated water quality parameters, environmental gamma radiation levels along with location coordinates are measured as per standard protocols. Strict quality assurance and quality control program is implemented to ascertain data quality. Study in 16 states is partially completed covering 322 districts out of 706 districts. The total number of drinking water samples (n) collected and analysed are 10415. The U concentration is found to vary from < 0.2 – 4918 ppb with median value of 0.96 ppb. It was observed that 99.2% of samples were below the AERB prescribed limit of 60 ppb for drinking water on the basis of radiological toxicity and 97.6% of samples were lower than the WHO guideline value of 30 ppb on the basis of chemical toxicity. About 0.8% samples were observed to be more than 60 ppb.

Pu-in-air monitors based on two different techniques have been designed and developed as import substitutes for on-line monitoring and evaluation of air borne activity due to Pu in presence of background and extensively field tested. Minimum Detectable Activity (MDA) is Less than 0.25 DAC h (derived air concentration–hour) of Pu.

Owing to good heavy metal sorption characteristics of Hydroxyapatite (HAP) and Activated Charcoal (AC), a composite material using HAP and AC has been synthesized. Characterization of the composite material was done by FT-IR and P-XRD. A series of sorption studies like Kinetics of U sorption, efficiency of sorption of U with varying U concentration in water and varying sample volume to sorbent weight



*ERM-AVP*

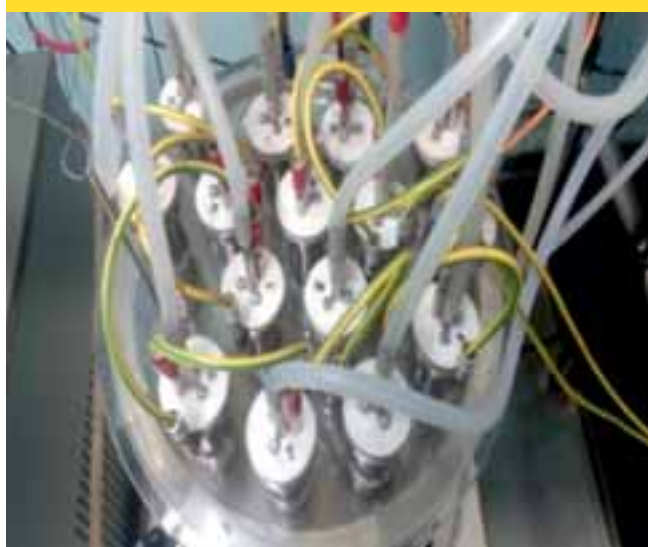
ratio were performed. Majority of the spiked U (91%) was removed within 5 minutes and steady state equilibrium achieved after 1h. The efficiency of HAP for removal of U(VI) from water decreases with increase in dissolved organic matter, whereas dissolved organic matter has no influence on sorption efficiency of HAP-AC. The study reveals HAP-AC composite is a promising candidate material for treatment of U contaminated water especially as it is also a biomaterial and will not add any extra stress to the environment.

Two prototype units of Environmental Radiation Monitor with Autonomous Vertical Profiler (ERM-AVP) for underwater radiation monitoring near coast, discharge points of nuclear facilities, ships and for detection of radiation sources lost in water etc were developed and field-tested in the Arabian Sea near Mumbai coast. The system is battery operated and communicate data via RF. It descends underwater (to a maximum depth of 200 m) from water surface using a single DC thruster, stabilizes at multiple pre-set depths and measures and stores the radiation levels. It is positively buoyant and hence slowly ascends to the water surface after completing its pre-programmed mission without any requirement of power and transmit data to a local PC through RF. The system has energy compensated GM tubes as the gamma radiation detectors. The system development has enhanced the underwater radiation monitoring capabilities of DAE.





**Electrolytic enrichment cells**



**Electrolytic cells in cooling tank**

Tritium ( $^3\text{H}$ ) contamination of the environment, expressed in terms of tritium units (TU) (1 TU = 1 atom of  $^3\text{H}$  per 1018 atoms of  $^1\text{H}$  i.e.  $0.12 \text{ Bq kg}^{-1}$  of water), may be used as a tracer in hydrological investigations or in groundwater dating.  $^3\text{H}$  concentration in water samples is so low (5–10 TU) that it cannot be detected even by most sensitive liquid scintillation spectrometers. A system for electrolytic enrichment of  $^3\text{H}$  in water samples was developed consisting of electrolytic cells (20 nos, each of 200mL capacity). Electrolysis is carried out at lower temperature in order to maximize isotope discrimination and by passing a current from cathode to anode through the water sample containing electrolyte. At the end of electrolysis,  $^3\text{H}$  gets concentrated by factor of 15 and the detection limits improves from 12 TU to  $\sim 1$  TU.  $^3\text{H}$  concentration in Antarctica ice core, hot spring and drinking water samples was estimated using this technique and was found to be in the range of 3–8 TU.

Whole Body Monitoring Console (WBMC) was developed for harmonization in maintenance and reporting of monitoring data in WBM Laboratories throughout the country. WBMC software controls spectrum acquisition, performs calculations for body activity content, estimates intake and internal dose and maintains synchronized monitoring related database generated using various systems available in a given WBM laboratory. The software can be used for identification of the monitored subject (worker) using employee number, finger prints as well as photograph. The parameters used for activity, intake and dose computations are accessible to a user for update and remote access to database and report generation of the monitored worker is possible with appropriate authorization.



**WBMC System**



**ICRP Male Voxel Phantom**

A Monte Carlo scheme was developed for neutron activation of an individual using ICRP male voxel phantom in FLUKA code. Amount of  $^{24}\text{Na}$  produced in human body by neutron irradiation in standard geometries such as isotropic (ISO), Anterior-Posterior (AP), Posterior-Anterior (PA), Left Lateral (LLAT) and Right Lateral (RLAT) was estimated for various neutron energies (range 0.1 keV to 20 MeV). WBM system comprising of 4"x3" NaI(Tl) detector was calibrated for measurement of  $^{24}\text{Na}$  activity in human body. The method developed will be more sensitive than the blood-analysis method in prompt estimation of internal dose due to neutron absorption.

In the human body, lungs and liver are in very close proximity and therefore,  $^{241}\text{Am}$  activity estimation present in one organ interferes with that of other organ's content during measurement resulting in an over-estimation of activity. A methodology was developed to estimate the Cross Talk (CT) between lungs and liver for  $^{241}\text{Am}$  using realistic thorax phantom i.e. Lawrence Livermore National Laboratory (LLNL) phantom and phoswich detector system. CT contribution was observed to vary with chest overlay thickness and for a reference Indian worker overestimation could be  $\sim 10\%$  for liver (for  $^{241}\text{Am}$  activity present in lungs) and  $100\%$  for lung activity (for  $^{241}\text{Am}$  activity present in liver). The results were also validated using voxel phantom and Monte Carlo simulations in FLUKA code. This methodology is helpful in realistic estimation of organ activity and internal dose received by the workers.

$^{90}\text{Sr}$  was separated from 20 mL urine using Sr-spec resin. Sr eluted from resin was mixed with scintillation cocktail in a glass scintillation vial and counted in a 300 SL – Triple to Double Coincidence Ratio (TDCR) Liquid Scintillation Counter. Radiochemical recovery is 92% and total time required for single sample analysis is  $< 2\text{h}$ . Minimum Detectable Activity (MDA) is  $8\text{ mBq mL}^{-1}$  which is well below the required generic emergency action level of  $19\text{ Bq}$  for 20 mL urine.

National audit programs of  $^{131}\text{I}$  activity measurements are conducted biannually to establish traceability to national standards and to check the measurement capabilities at nuclear medicine centres. The activity of the radiopharmaceutical is measured with

radionuclide calibrators before administering it to patients. Quality audit programmes help to ensure the safe and effective use of the radiopharmaceutical to the patient. Result of audit of participating nuclear medicine centres showed that 76 % of participants have deviation less than  $\pm 5\%$ , 15 % participants were within deviation  $\pm 5\%$  to  $\pm 10\%$  and only 9% have deviation greater than  $\pm 10\%$  as shown in pie chart. Activity measured by 91% of the participants complies within the acceptable limits of  $\pm 10\%$ .

Two 'Innova' model vehicles of Toyota make have been modified to serve as Mobile Radiological Assessment Laboratory (MRAL) and Mobile Environmental Assessment Laboratory (MEAL) has been analysed. The vehicles house Radiation monitoring instruments / software / systems for display and all radiation safety gadgets / decontamination kits / personnel protective gears and battery power source for supply. MRAL and MEAL can be air lifted to the affected site for radiation survey and assessment in case of radiological emergency in public domain. They are being regularly used for site survey around facilities of BARC, Trombay and outskirts of Mumbai. It is planned to use them for radiation survey of Emergency Planning Zones (EPZ) around NPP sites.



An attempt has been made to employ an atmospheric circulation model that predicts meteorological parameters at the regional and global scales, and a transport model that utilizes these meteorological parameters for the radioactive aerosol dispersion. Non-hydrostatic Icosahedral Atmospheric Model (NICAM) coupled with Spectral Radiation-Transport Model for Aerosol Species (SPRINTARS) is used for simulating effects of conventional aerosols on atmospheric pollution and climate system. Global simulation is carried out for a horizontal resolution of  $110$

km to model the dispersion of radioactive aerosol ( $^{35}\text{S}$ ,  $^{131}\text{I}$  and  $^{137}\text{Cs}$ ) releases from the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident. The results obtained were compared with the available literature data. The comparisons were better for locations faraway ( $> 150$  km) from the emission location. Continuous run of this system will help in predicting the activity concentration in forecast mode and it may be used for decision support, particularly in the case of long range transport ( $> 100$  km).

Estimation of external exposure due to atmospheric releases of photon emitting radionuclides from nuclear facilities is important during normal and emergency conditions. Gaussian Plume Model (GPM) coupled with either semi-finite cloud model or finite plume integration method is normally used to estimate this dose component for inland sites. For coastal sites, shoreline dispersion model (Shoreline Gaussian Plume Exposure Model, SGPEM) that handles local sea-land breeze circulation has been coupled with the external plume dose-computing module for estimating the Plume external photon dose. Based on this model, a fast calculation tool is developed to estimate external plume doses under normal operating and accidental conditions. This numerical program can also be used for source term estimation from field measurements, thereby assisting decision support system during emergency situations.

The safety systems adopted and concern towards environment have helped all Heavy water Plants achieving better safety records compared to similar chemical industries in the country. All plants are certified for ISO Quality Management system, Environmental Management System and OSHA System.

NPCIL has recorded about 473 reactor years of safe operation of reactors as on end December 2017. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by Atomic Energy Regulatory Board by following the principles of As Low

as Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB. NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001: 2004 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 granted extension of validity of Environmental Clearance (EC) for KAPP-3&4, and RAPP-7&8 and extension of validity of EC & CRZ clearance for JNPP. Expert Appraisal Committee (EAC), has recommended extension of validity of CRZ clearance for KKNPP-3&4 and KNPP-5&6. In respect of NPP at Mahi Banswara (4x700 MW, PHWR), validity of TOR is extended by MoEFCC, draft EIA report is finalized and application for Public Hearing is being finalized for submission to State Pollution Control Board. For Kaiga-5&6 (2x700 MW, PHWR) three seasons environmental monitoring is completed in line with approved TOR and the draft EIA report is under preparation. MoEFCC has granted Terms of Reference (TOR) for EIA/ EC / CRZ clearance for NPP at Kovvada (6x1208 MW, LWR) and for AFR for KKNPP-1&2. For NPP at Kovvada three season environmental monitoring is completed and reports are under finalization and for AFR for KKNPP-1&2 activities for preparation of EIA are in progress.

The Environment Stewardship Programme (ESP) is a voluntary initiative of NPCIL, launched with an aim to preserve the environment in and around nuclear power plant sites. Under ESP, a range of nature conservation activities including scientific studies on bio-diversity in and around all nuclear power plants are being carried out. Besides, training of local volunteers, surveys, organizing public awareness campaigns on environment, publishing of articles based on the findings of nature studies are also part of the programme.



In ESP, exclusive gardens for butterflies are being established to provide these delicate fliers a safe habitat. Three such gardens have been setup in three different sites namely, Kakrapar, Tarapur, Kaiga of NPCIL. Similar gardens are planned at the other sites, as well.

Having understood the important role that riverine turtles play in the ecosystem, NPCIL has kick-started a special initiative called “Project Turtle” to protect the endangered species of turtles in the river Ganges. This project which is being executed in association with Wildlife Institute of India (WII) - an expert conservation agency under the Ministry of Environment and Forestry, Government of India - focuses on the conservation of two species of turtle viz. Batagur dhongoka and Chitra indica. An exclusive turtle facility has been developed in the NAPS township to preserve the eggs of these turtles. Eggs are collected from the nests of turtles in the Ganges where there are more threats and are stored in the nests in the turtle center for safe hatching. Later, the hatched neonates are kept in the hatchery with proper nutrition and care. After attaining desired growth, the turtles are released in river Ganga.

NPCIL has also partnered with WII for the Clean Ganga Mission – Namami Ganga Project, NPCIL, an ambitious project of Government of India to make the Ganges clean.

During every winter, NPCIL has been organizing bird marathons at Narora and Kaiga as part of ESP to study the avian fauna in these sites. In 2016, the Kudankulam Nuclear Power Plant (KKNPP) in Tamilnadu has also began a similar event called Kudankulam Bird Count (KKBC) to create a database of birds in the region.

The KKNPP site of NPCIL has established a pair of mudflats in association with BNHS (Bombay Natural History Society) in the former's township premises to provide a safe foraging habitat for water birds and migratory birds. After the mudflats, KKNPP is preparing to develop mangroves along the shores to create micro habitat for numerous species of life. Similarly, the Kakrapar Atomic Power Station (KAPS) in Gujarat is making all its efforts to develop a botanical garden that will feature common to rare species of plants.

## RESEARCH & DEVELOPMENT

NPCIL's Directorate of Technology Development (DTD) carries out technology development activities for achieving continual enhancement of nuclear and radiation safety, reliable operation and reduction in costs of Nuclear Power Plants (NPPs).

For the financial year 2017-18, major achievements/ progress derived from the four verticals i.e. R&D Facilities, Remote Tooling, Indigenization and Construction Time Minimization are as mentioned as under:

### R&D Facilities

#### Post Fukushima Safety Enhancement measures

Significant further progress related to Passive catalytic recombiners, hard vent and Iodine scrubbing has taken place as follows:

#### Hydrogen Recombiner Test Facility (HRTF)

Performance Evaluation of first batch of indigenously developed Passive Catalytic Hydrogen Recombiner Devices manufactured by Electronics Corporation of India Limited (ECIL) for deployment at IPHWR Units successfully completed at NPCIL's dedicated test facility viz. Hydrogen Recombiner Test Facility (HRTF) at R&D Centre, Tarapur and clearance given to ECIL for bulk production.

#### Containment Filtered Venting System (CFVS)

After completion of all planned tests, experimental studies with low flow relevant to accident scenario conducted, found satisfactory. Report issued and results reviewed by Regulatory body. Full scale CFVS vessel erection is over at TAPS-3.

#### Iodine Scrubbing thru Containment Spray System

As per review and recommendation by Regulatory body, beyond quantification of the coverage,

mass flux distribution, mixing phenomena, further studies on aerosol behaviour taken up. Accordingly, facility shifted to NPCIL R&D Centre from IIT-Bombay and re-commissioned with automation and instrumentation for Caesium iodide (CsI) particulate scrubbing tests. Experiments using bubbler method, air sampling and injection of the aerosol in different configuration using tubular furnace has been carried out. Experiments using Nano particles using cold trap has been envisaged and is in progress.

### **Critical Heat Flux (CHF) Enhancement of Zircalloy-4 Calandria tube using glass peening as surface modification technique**

To improve the effectiveness of heat sink in the outer surface of Calandria tube in case of design basis accident, an experimental set up consisting of automated pool boiling system made with glass beading on outer side of Zircalloy tube specimen and experiments/ studies commenced (Nine major experiments out of a matrix of 24 are completed) to optimize the surface roughness value. Balance experiments are in progress.

### **Integrated Thermal Hydraulic Test Facility (ITTF)**

This facility comprising of NPCIL Thermal Hydraulic Test Facility (NTTF), BARC's AHWR (Advanced Heavy Water Reactor) Thermal Hydraulic Test Facility (ATTF) and AHWR Fuelling machine Test Facility (AHWR FMTF) has been progressing well.

Copper Bus ducts are installed and all Five Full Power Rectifiers along with auxiliary systems has been commissioned and performance tests with the available ATTF loads are nearing completion. Verification of performance of Rectifier operation for experiment matrix in NTTF (2 nos) is planned on availability of NTTF PCPs.

### **NPCIL Thermal-hydraulic Test Facility (NTTF)**

Commissioning of NTTF PCP with newly replaced motors is being taken up after resolving issues related to PCP sealing system, Variable Frequency Drive (VFD) and indirectly heated fuel element simulators etc.

This will permit PDHRS Full power experiment to proceed ahead with after the earlier low power experiment.

### **AHWR Thermal hydraulic Test Facility (ATTF)**

ATTF is re-commissioned with available loads at much higher power level after commissioning of Full Power Rectifiers.

### **Fuelling Machine Test Facility (FMTF) for 700 MW PHWR**

Milestone of Phase-1 Qualification Testing of two Fueling Machine (FM) heads of 700MWe (KAPP-3&4) achieved. Preparation for Phase-2 qualifications testing at high temperature and pressure with hot interconnect from NTTF is in progress.

### **Environmental Qualification (EQ) Activities**

Equipment qualification of components like Paints for use in future 700MW PHWR, NAPS 1&2 Terminal Blocks, MAPS Moderator Pump motor and Differential Pressure Transducer etc. were successfully completed. Residual life assessment of TAPS 1&2 Motor Operated Valve (MOV), Control Rod Drive (CRD) and Source Range Monitor (SRM) cables was completed. TAPS 1&2 Source Range Monitor (SRM)/ Intermediate Range Monitor (IRM) Motor modules and 700 MW air lock inflatable seal were subjected to design basis accident profiling. Further Twenty one instruments, from various operating stations, were subjected to Main Steam Line Break (MSLB) V1 profile testing. Radiation testing of Fuelling Machine Proximity Switch connectors and Accelerated thermal ageing of TAPS-3&4 Shutoff Rod Drive Mechanism (SRDM) Limit Switch, Rosemount transmitters and NAPS fuelling machine vault cooler motor were also successfully completed.

### **Primary Coolant Pump Test Facility (PCPTF)**

After completion of Detailed Project Report (DPR), civil consultancy order executed to arrive at construction ready design. Tendering activities for civil construction are in progress. Design and Specifications for Heat Exchangers and Vessels approved, cost estimation and tender documents finalization in

process. Specifications, Drawings, Data sheet of balance process equipment/ piping/ support are under preparation/ review. Control & Instrumentation (C&I) specifications for field instruments and control system are under review/ approval. PCPTF specific electrical package tendering inputs are being readied. Approval of MoU with Nuclear Recycle Board (NRB), BARC obtained for provision of Long term Reliable Electrical Power Supply (REPS) from TAPS-1&2 switchyard.

### **Environmental qualification of airlock inflatable seal for 700 MW PHWR**

Thermal ageing, radiation ageing and LOCA/MSLB testing were conducted as per specified requirement. The specified qualification criteria during the test and after the test were met satisfactorily.

### **Remote Tooling**

NPCIL's remote tooling related activities encompass Technical and coordination plus training and qualification support along with carrying out of design and execution of certain portions of remote tooling. Following salient progress/activities have taken place:

### **Coolant Channel Health related activities of NPCIL's Operating PHWR fleet**

Pressure Tube In-Service Inspection (ISI): These campaigns using BARCIS for 220/540 MW PHWRs (KAPS-1&2, TAPS-3&4) were successfully carried out along with BARC. Deployment of on-line data recording of UT/ECT BARCIS Signals made at PHWR Sites. Design inputs provided for successful Calandria Tube – Poison Injection Unit (CT-PIU) gap measurement system development at TAPS-3&4. Development of Linear Variable Displacement Transducer (LVDT) and LVDT Signal Conditioning Units (SCUs) through M/s ECIL and utilized for sag measurement of Coolant channel and Calandria tubes. Technical support provided and participation made for TAPS-4 sag measurement of identified/ selected Pressure Tubes at TAPS-4 and executed successfully by modified sag tool. Technical support, development & qualification of various tools/ tooling techniques and participation made towards various EMCCR jobs of KAPS-1&2

### **Moderator Heat Exchanger (HX) Remote Tooling**

An Integrated in-house delivery system for inspection of 220 MW moderator HX tubes designed and execution is being taken up. For remote operation of Moderator/ D<sub>2</sub>O Heat Exchangers at Nuclear Power Stations, a semi-automatic Pusher-Puller system developed. Specification and drawings completed, order under execution for D<sub>2</sub>O HXs manipulator development based on Selective Compliance Articulated Robot Arm (SCARA) principle. In-house Software programming is in advanced stage for SCARA based inspection arm.

### **SG In-Service Inspection (ISI) Manipulator system**

A Memorandum of understanding (MoU) signed with Centre for Artificial Intelligence and Robotics (CAIR), DRDO for technical support and Technology transfer for NAPS Steam Generator (SG) Inspection system.

### **Cobalt Bundle Opening Tools (COBOT) system qualification**

Design of Bundle opening tool completed and the final drawings are under review.

### **Cobalt Adjustor Rods Dismantling Tools (CARDS) System**

Design of Cobalt Adjustor Rods Dismantling Tools (CARDS) System has been completed.

### **Development of Laser Welding Head**

Order for development and qualification of Single Pass Laser Welding of Lattice Tube to Calandria Side Tube Sheet (CSTS) joint is under execution for future 700 MW PHWRs, aimed towards enhanced quality.

### **Remote Tooling Capability Build-up**

This has taken place with procurement and utilization of softwares for Dynamic simulation of remote tooling applications, impact loading i.e. drop simulation



of shielded transportation flasks, and in-house programming of automatic manipulator.

### Indigenization initiatives

Indigenous development of imported items or alternate vendor development for critical components/equipment has seen further progress as follows:

#### End Shield Tube Sheet Plates forging for 700MW PHWRs

Development order was placed in March 2017 thru public tender for development of End Shield Tube Sheets Plates for future 700 MW PHWRs. Ingot casting for all plates were carried out meeting low cobalt requirement. Slabs were forged for all plates and preliminary Ultrasonic Testing (UT) was carried out before rolling. Although one plate rolled and developed successfully, development related issues still remain a challenge for few other plates while rolling. Issues are being resolved. Next set of plates rolling is expected shortly. Efforts are being made to complete the project by March 2018.



**Forging of ESTS plates and Forged Plate ready for further rolling at another unit**



**Rolled and final machined plate ready for dispatch (First such End Shield Plate developed in the country)**

#### Development of Venturi (Calibration of Steam Flow Element) for 700MWe PHWRs

A development order for main steam line Venturi for 700 MW PHWR is under execution since May 2017. Ingot casting was carried out meeting all requirements. Forging and preliminary heat treatment completed. Venturi is under pre-machining before final heat treatment.

#### Alternate vendor development for Primary Coolant Pump motor of 6.0 MW capacity

The PCP motor for 700 MW PHWR projects is under development by alternate vendor. All components of the motor viz., stator, motor frame, shaft, rotor, flywheel, heat exchangers, bearings, brake etc., after stage inspections and Non-destructive Testing (NDT) were assembled. The motor is placed on the test bed. After pre-commissioning checks, the motor will undergo various electrical qualifying tests including 100 hrs. of endurance test.



**Assembled 6.0 MW PCP Motor**

#### Alternate vendor development for Shutdown Cooling Pump (SDCP)

The shutdown cooling pump for 700 MW projects is under development by alternate vendor. Motor for the pump has been developed. All the components of the pump viz., casing, impeller, bearing, cooling insert, seals etc., were assembled. All stage inspections and NDT were completed. A dedicated high pressure and high temperature test bed has been erected at the vendor's works. Pump and motor were erected on the test bed. Performance test of the pump has been completed and results were satisfactory. At present, endurance test at rated pressure, flow and temperature is in progress.

#### Electronics based Differential Pressure Transmitter for Radiation and Severe accident qualification

Radiation qualification completed successfully at Board of Radiation & Isotope Technology (BRIT) and LOCA (Loss of Coolant Accident) qualification for severe

accident conditions at in-house R&D centre being taken up.

### Boiler Feed Pumps (BFPs) and Primary Coolant Pumps (PCPs)

Development order for indigenous development of BFPs for 700 MW reactors is placed. Development of PCPs for 700 MW reactors is in progress.

### Index drive mechanism for FM

Design completed. Specification/ drawings made and under review/ finalization.

### Development of Plasma Nitriding of Fuel Handling (FH) components

Samples for the plasma nitriding and wear studies supplied and initial trials started at Institute of Plasma Research, Gandhinagar.

### Construction Time Minimization

NPCIL has recognized construction time and cost minimization as an important activity and has strived to pursue the same.

### End Shield Calandria Integral Assembly (ESCIA)

Positive thrust to review modular concept which provides for both the options viz. follow conventional methodology or follow modular construction path

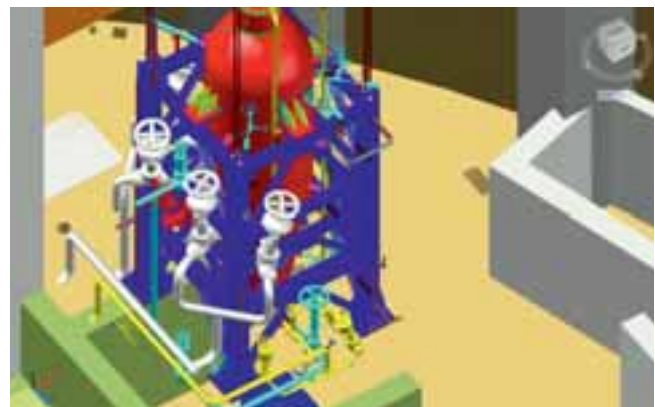


*Handling of ESCIA*

deserves detailed due diligence to reap the benefits for Construction time minimization. ESCIA which stands for End-Shield and Calandria Integrated Assembly addresses this challenge as it does not call for any major design change in reactor building civil design therefore this can allow for both options. As part of Technology Development evolution for 700 MW PHWRs, Modular Construction, a concept of ESCIA has been developed, which can facilitate in reducing the construction time. NPCIL with its experience of successful implementation of Preformed Ring Liner (PRL), Structural Steel Floor (SSF) and Integral dome lifting at KAPP-3&4, can yield significant benefit. Significant progress in detailing this has been carried out. Special Propping Module is designed to temporarily strengthen the FM Vault floor to take the load of ESCIA module.

### Bleed Condenser (BCD) module

Bleed Condenser in 700 MW PHWR is supported on a surrounding steel beam structure, at 115.5 M EI inside reactor building. This contains numerous nozzles from which lot of piping and tubing originates. The proposed module consists of BCD tank, some part of piping and support structure. Onsite welding of piping and tubing can be avoided by use of this modularization scheme. Fabrication sequence and handling scheme of such module is being developed.



*BCD Module for 700 MW PHWR*

### Interactive 3D Software Application (APP) for fabrication sequence of large equipment of 700 MW IPHWR

Proposed fleet mode for construction of 700 MW IPHWRs would require training of new manpower at

very fast rate. Towards this, to develop visual & interactive APPs for illustrating the fabrication sequence for major equipment of 700 MW IPHWRs, an interactive 3D software application is being used.

## Engineering and R&D in Electronics

### Ongoing 700 MWe Projects

Subsequent to the detailed engineering of KAPP-3&4 including stress analysis and seismic qualification of piping and equipment, Design Manuals of all the systems were issued. Design and engineering support including field engineering was provided for the construction and commissioning activities at site. Commissioning Procedures are being reviewed and concurred in a progressive manner. Detailed Procedures for First Approach to Criticality and Low Power Physics Commissioning Procedures are prepared.

Supply of Hardware modules, assemblies and panels for Computer Based Systems (CBS) manufactured by the package contractor were completed for KAPP-3 and installation and acceptance testing of these systems at site were completed. Verification and Validation of CBS system software for Process water systems is completed and validated software is loaded at site to facilitate site commissioning activities. Switchyard Electrical SCADA is commissioned and communication to Grid Authority is established.

Full Scope Training Simulators enhance the operator reflexes and provide a lasting mental model of plant transients thus improving operator understanding and efficacy. The Trailing Simulator for KAPP-3 is commissioned in December 2017 at Kakrapar Site after the installation of the hardware and the model software. Site will be starting the initial hands on training to KAPP-3&4 operators.

### Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) 1&2

Detailed geological and seismotectonic studies have been carried for GHAVP site. Detailed deterministic, probabilistic and site response analyses have been carried out to generate the Design Basis

Ground Motion (DBGM) which has been approved by AERB. Regulatory Review of design for the consenting stage of Excavation for GHAVP 1&2 was completed and excavation consent was obtained. Consultancy contract for the detailed engineering of the plant awarded. Based on the finalized plant layout and internal layout of various structures incorporating required changes with respect to the KAPP-3&4, the detailed engineering of GHAVP-1&2 is in progress. The detailed engineering is being done in 3D platform.

### 700 MW Fleet mode projects

Pre project engineering activities and planning for upcoming 700 MW fleet mode projects have commenced. Requisitions for Free Issue Materials (FIM) and equipment viz Steam Generators, End Shields, Primary Coolant Pumps, etc are being raised.

### Operating Stations

Computerized Maintenance Management System (CMMS) was redeveloped in-house using web technology. The new version of CMMS with improved features has been rolled out to operating stations.

### Control and Instrumentation (C&I)

Control and Instrumentation (C&I) Engineering of KAPP-3&4 and RAPP-7&8 was completed. KAPP-3&4 commissioning procedures related to PHT hydro test have been concurred. Up-gradation of TAPS-4 station Safety Related (SR) & Non-Safety Related (NSR) Programmable Logic Controllers (PLCs) completed. In Field Instrumentation Package of KAPP-3&4, delivery of various items is in progress. Supply of items related to Nuclear Instrumentation Package for KAPP-3&4 is in progress. KAPP-3&4 Fire Alarm System is dispatched after successful completion of factory validation.

Supply of Hardware modules, assemblies and panels for Computer Based Systems (CBS) manufactured by the package contractor were completed for KAPP 3 and installation and acceptance testing at site were completed. Internal validation of software for different types of modules for Computer Based Systems (CBS) is in progress. Verification and Validation of software for cluster IV CBS system, part of Cluster 3 and Cluster 2 system is completed and



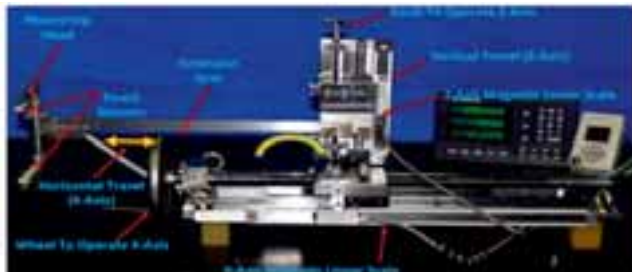
validated software is loaded at site to facilitate site commissioning activities. Switchyard Electrical SCADA is commissioned and communication to Grid Authority is established.

Software development for IO Nodes of Operator training Simulator was completed. Hardware and Software for Simulator IO Nodes are installed and commissioned at site.

## R&D relating to PHWR

A Three-Axes custom built Measuring Machine is developed to measure diameter at various sections throughout the length of the irradiated pressure tube of the PHWR, profile of OD of the tube and quantification of surface cracks/defects etc. inside Hot Cell.

Machine is equipped with USB Camera mounted to take photographs at the place of measurement on the surface of the tube to generate a 3D Model of the tube and can be mapped with respect to model for future references.



**3D Imaging & Profiling Machine**

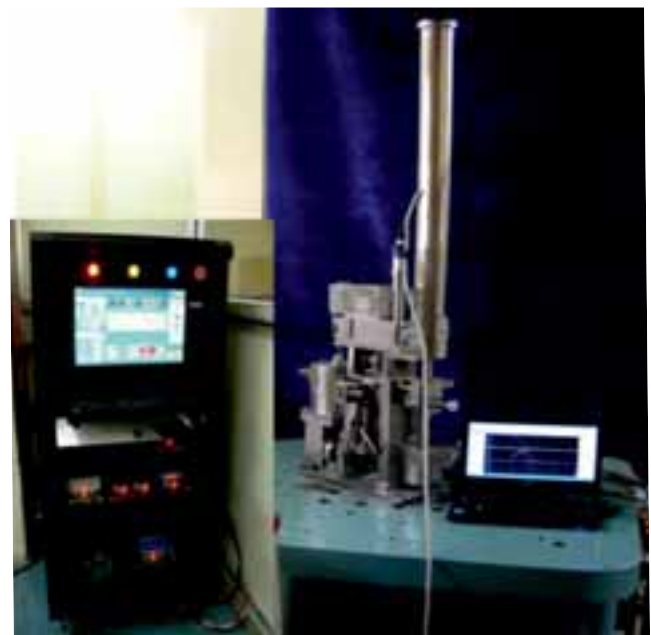


**Actual Operation in Hot Cell on Q15 KAPS-I Coolant Channel**



**3-D Modelling & Mapping Images of Q15 KAPS-I Coolant Channel**

Shut-off Rod Drive Mechanism (SRDM) design is qualified through prototyping and subjecting it to life-cycle testing on full-scale mock-up test station. Prototype SRDM was tested for more than 5000 drops and prototype CSRDM tested for motorized up/down cycles for more than 1000 cycles.



**Prototype SRDM with Test Console Undergoing Life-cycle Testing**



**Drive Mechanisms for Reactor Use**

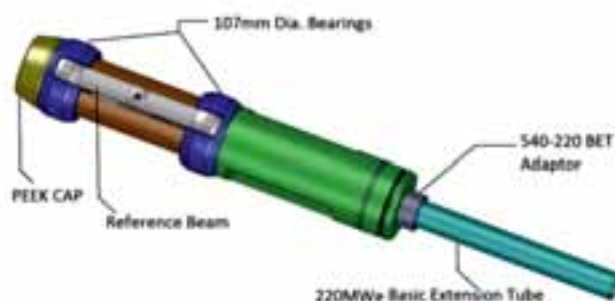
A miniature BARCIS system has been developed to carry out NDT experiments in the lab using mock up facility. It is a two axes system with linear and



**Compact BARCIS Drive System for Coolant Channel Inspection in PHWRs**

rotary movements for carrying out circumferential and axial scans. The system has a linear stroke of 400mm. This can be mounted on the End-Fitting and has water sealing and filling arrangements, and doesn't need any mounting structure or alignment, while deploying in the reactor during ISI. Standard BARCIS inspection head with Axial, Circumferential and Normal beam UT probes can be integrated with this system. The system can carry out scanning of 400mm region in one stroke. Full length of the Pressure Tube can be covered with additional extension tubes and can be interfaced with multi-channel UT system for synchronised collection of data for post processing.

Linear Variable Differential Transformer (LVDT) based Calandria Tube Sag Measurement tool 'CATSAM 220' was developed, function tested in the lab at BARC and later in the coolant channel mock-up facility at reactor site. The tool was successfully deployed in KAPS-2 and Sag measurement was carried out for 19



**A schematic of SAG Tool Head**



**CATSAM-220 recently used in KAPS-2 for calandria tube sag measurements**



**Miniature specimen impact test Machine**



**Miniature specimen creep test Machine**

calandria tubes. A schematic of the tool assembly and a photograph of CATSAM-220 are shown here. Two machines namely, Miniature Specimen Impact test machine and Miniature Specimen Creep test machine for material testing have been commissioned in BARC.

The Loss-of-Coolant-Accident (LOCA) can cause ballooning deformation and rupture of the Zircaloy-4 cladding under the impact of internal overpressure of fission gas inventory and high temperature due to insufficient cooling in a Pressurized Heavy Water Reactor (PHWR).



**Ballooned fuel**





*Fuel Pins failed due to ballooning & burst*



40 bar, 10°C/s, Argon environment

*Fracture surface of the clad*

Study of PHWR fuel cladding behavior under simulated LOCA condition was carried out to evaluate the response of Zircaloy cladding to thermal shock during water quenching after double sided steam oxidation at elevated temperatures, post quench mechanical tests like ring tensile, ring compression, impact etc. and its correlation with the evolved microstructure. Burst stress equation with the help of indigenous data has been developed.

Detailed Post Irradiation Examination (PIE) was carried out on a failed fuel bundle discharged from 540 MWe Tarapur Atomic Power Station PHWR (TAPS-3) after a residence time of 147 days and accumulated burnup of 3576 MWd/tU. Various non-destructive and destructive examinations were carried out to identify the cause of fuel failure.

Ultrasonic testing showed presence of cracks in the clad near the failure locations of the fuel pins and root crack and lack of fusion in the end plug weld region of one of the fuel pins. Strict control of moisture/H<sub>2</sub> in the fuel pins and better control on the welding parameters during pin fabrication was suggested to avoid such fuel failures.



*Upgrading column sections*

The most critical step in fabrication of high efficiency phosphor bronze packing internals was completed for 14 column sections for PHWR. Packing activation and performance testing were completed for six column sections.

## R&D relating to LWR

The in-service inspection of the weld joints in the upper shell region of the Reactor Pressure Vessel (RPV) of TAPS Unit # 1 was carried out during 24th Refuelling Outage (RFO). The ultrasonic examination was carried out using probe holder containing eight probes covering weld, heat affected zones on both sides and a significant region of parent material. One of primary objectives for carrying out the inspection of these weld joints was to confirm whether the flaws observed during the previous inspection (23rdRFO) have shown any growth in terms of their through-wall dimension. The B-scan images clearly showed that their signature matched closely and there was no change in the flaw size between the two inspections confirming that there was no measurable change in the through-wall dimension of the flaw indications in the weld joints since the last inspection. This information has provided vital inputs in carrying out the structural integrity assessment of the reactor pressure vessel for continued operation of the plant.

Required number of Control Blade assemblies for TAPS-1&2 were fabricated & supplied.

Flow Meter Test Facility for testing and calibration of indigenously developed flow meters of compact Light Water Reactor Project has been





**Flow Meter Test Facility**

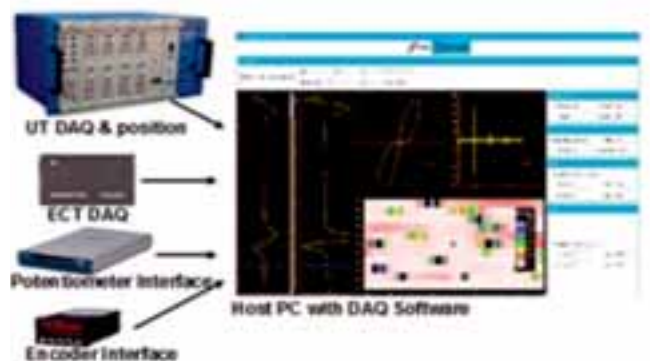


**GCIC with hanger assemblies**

commissioned at BARC. Flow in the facility is controllable from 10 lpm to 2500 lpm with an accuracy of 0.25% of the measured value. Automatic control of the flow in the loop is achieved by variable Frequency Drive (VFD) driven centrifugal pumps.

Installation of four indigenous Gamma Compensated boron lined Ionization Chamber (GCIC) with Hanger Assemblies for neutron flux monitoring for reactor control and safety for Compact LWR has been completed for project-1. Eight nos of GCIC-HA Hanger Assemblies dispatched to site for project-2.

An integrated system for Ultrasonic Testing (UT) and Eddy Current Testing (ECT) for inspection of Reactor Pressure Vessel weld joints was developed.



**Multichannel UT & ECT Data Acquisition systems**

Field trials were carried out at TAPS-1 during 24th RFO. The system acquires position encoded area scan data for characterization of internal and surface breaking flaws and record data for imaging and analysis.

The design, development, production, qualification and delivery of a plant wide networked Radiation and Gas Monitoring System for Compact Light Water Reactor Project-2 has been completed.



# CHAPTER NUCLEAR POWER PROGRAMME STAGE-II

2



*Central Surveillance, Safety and Health Physics building*





*Overall view of Prototype Fast Breeder Reactor*

## 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 Nabhiya 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

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 / components



*Overall view of Prototype Fast Breeder Reactor*

of PFBR, commissioning of various systems are in progress.

The major activities that have been completed during the year 2017 period are as follows:

#### Reactor Assembly

Trial pressure hold test of Reactor assembly was carried out and the identified leak paths were rectified. Subsequently, Reactor assembly pressure hold test was carried out by pressure drop method and flow compensation method. Pressure hold test was also carried out for the interspace region between Main vessel and Safety vessel by pressure drop method. Flow balancing of Top shield cooling system was performed. Sleeve valves of all four Intermediate Heat Exchangers (IHx) were operated for checking the total travel and indications in Distributed Digital Control System (DDCS).

Thermocouple probes which pass through the openings in central canal plug and sodium sampling point were fabricated and installed to measure the temperatures at core support structure, grid plate and mid-level of sub-assembly locations and the top of peripheral subassemblies.

Prior to preheating the main vessel and its internals, the total system along with the external preheating circuit was purged with nitrogen to replace the air present in the entire system. In this context, nitrogen purging was carried out for many cycles and the impurity in terms of oxygen and moisture in nitrogen was reduced well below the acceptable limits in the circuit.

Subsequently, preheating of Reactor Assembly was commenced with two blowers and three group heaters in service. The minimum temperature is at the crown region of main vessel and the temperature achieved in this region is 145°C. Primary Argon Cover Gas system pressure hold test was completed and system was filled with Argon. Load testing of Primary Argon Purification circuit compressor-1 and flow were established through cryogenic cell.

Main line heaters of all the four loops of Safety Grade Decay Heat Removal (SGDHR) circuits maintain

temperature at 150° to 170°C. Also, fin type air heaters in sodium-to-air heat exchanger (AHX) of all the four loops of SGDHR system were commissioned and AHXs have been preheated to ~130°C. All the heaters of SGDHR sodium purification loop-1 in Steam Generator Building-1 maintain temperature more than 175°C.

Operation of Startup Neutron Detector Handling Mechanism (SNDHM) was established through control panel. Functional testing of SNDHM at ambient temperature was completed. Six numbers of Delayed Neutron Detectors were erected in their locations in Roof slab.

Erection of Air Heat Exchanger steel chimney hood baffle plate was completed. Fabrication and erection of 250 Nos. of complementary shielding boxes in various cells of Reactor Containment Building were done and steel balls were filled in 178 Nos. of electrical complementary shielding boxes.

Retro-reflectors for Under Sodium Ultra-Sonic Scanner placed on the outermost B<sub>4</sub>C shielding sub-assemblies were integrated with the adjacent sub-assemblies to avoid untoward movement.

Mutual inductance type leak detectors in the interspaces of Reactor Vault - Safety Vessel and Main Vessel – Safety Vessel were installed.

### Reactor Containment Building

Trial Integrated Leak Rate Test (ILRT) of Reactor Containment Building (RCB) was carried out at 150 mbar. The leak paths identified were attended and subsequently Reactor Containment Building (RCB) proof test & ILRT was carried out at 250 mbar. Surface mounted vibrating wire strain gauges and electrical resistivity type strain gauges were installed on the walls of RCB and hooked up with the data logger in ILRT Control Room. Local Leak Rate Test (LLRT) was performed for Personnel Airlock, Emergency Airlock and isolation dampers. As part of commissioning of ventilation system in RCB, flow balancing and negative pressure test were carried out.

Surveillance testing of fire dampers and stay put dampers in Rad Waste Building (RWB), Fuel Building (FB), Steam Generator Building - 2 & RCB was

completed. Flow balancing of RWB exhaust system was completed.

### Sodium systems

Heater commissioning for Secondary Sodium Main Circuit, Secondary Sodium Fill & Drain Circuit and Steam Generator Tube Leak Detection System was carried out.



*Secondary sodium fill and drain*

All the tubes in eight Steam Generators have been preheated to 155°C and soaked for four hours by circulating hot water by operating motor driven boiler feed pump as a pre-requisite for filling sodium in secondary sodium loop. Subsequently, Steam Generator tubes were drained and filled with Nitrogen.

In Secondary sodium system loop-1&2, hot purging was carried out and cover gas purity was achieved [oxygen: < 50 ppm & moisture: < 50 ppm]. All the sodium circuits in loop-1&2 were preheated and maintained above 150°C. Sodium flow was established in Secondary sodium purification circuits. Subsequently sodium in both the loops was purified to the desired plugging temperature of < 105°C.



*Electro Magnetic Pumps*





In secondary sodium loop-1&2, sodium was filled up to Surge tank normal level using Electro Magnetic Pumps and the Secondary Sodium Pumps were operated. Purification circuit is in service.

In Primary Sodium Fill & Drain Circuit, heating of Argon Buffer Tanks was started. Also, heating of fill and drain line was done for hot purging of these lines.

### Fuel handling system

Alpha & beta angular positions of Large & Small Rotatable plugs to locate Core Flow Monitoring Mechanism-2 over selected blanket and storage sub-assemblies were established.

Final rail alignment of SSTM was completed. Commissioning of Spent Subassembly Transfer Machine (SSTM) has been commenced. End limits and span have been established for limit switch setting. Leak test of Fuel Transfer Cell was completed.

As a prerequisite for fuel handling tests at 150°C, thermocouple probes from central canal plug and sodium sampling port were removed.

Site Validation Tests for Inclined Fuel Transfer Machine (IFTM), Large Rotatable Plug and Small Rotatable Plug were carried out as a part of Verification & Validation process.

### Balance of Plant systems

Condensate Extraction Pumps-A, B & C were operated in minimum recirculation mode and flushing of

condensate loop was carried out up to gland steam condenser. Auto sequence commissioning of steam generator de-pressurization and nitrogen injection system from field instrumentation panel & DDCS was checked.

To ensure their healthiness, Turbine Generator on barring gear, Motor Driven Boiler Feed Pump and Condensate Extraction Pumps on recirculation re operated at regular interval.

In sea water system, after testing the performance of Condenser Cooling Water pump-2, endurance test of Condenser Cooling Water pumps-1 & 2 was carried out for 72 hours. Auto commissioning of Auxiliary Sea Water Pump – 1 & 2 was completed. Integration of fault tree carried out in ISOGRAPH for service water system.

### Level-I Probabilistic Safety Assessment (PSA)

Level-I Probabilistic Safety Assessment (PSA) report was revised and released. This report brings out the assessment made on the plant design and operation and the estimate on the core damage frequency against a wide range of design basis and beyond design basis events based on the reliability studies of frontline systems such as shutdown systems, SGDHR system, Operational Grade Decay Heat Removal system and other auxiliary systems.

Commissioning of sodium systems is in advanced stage and sodium is in circulation. Work is in progress for filling of sodium in Main vessel and running of the Primary Sodium Pumps. This will be followed by fuel loading towards approaching criticality, power generation and commissioning of PFBR.

All the commissioning activities are in progress and Main Vessel along with primary system is getting poised for filling sodium. 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)

During the period, Fast Breeder Test Reactor (FBTR) continued to play an important role in testing the fuels, structural materials and special neutron detectors for FBR programme.

The 25th irradiation campaign was completed, when one of the central experimental sub-assemblies and one Mark II fuel sub assembly reached their respective target burn-up. In this campaign, the reactor was operated at 27.3 MWt producing 6 MWe. During the campaign, there was an incident of tube leak in one of the steam generator modules. The reactor was tripped and the steam generator was isolated automatically.

After replacing the steam generator module with a qualified spare module, the reactor power was

raised to 27.3 MWt. However reactor was shut down, as sodium leak was detected from the thermal baffle region of the tube of the module which was replaced.

Root cause analysis was done for the failure and it was concluded that the sub-surface weld flaws would have originally existed in the fillet weld between the thermal baffle and one of the tubes of the steam generator module before the steam generator was put into service.

During the period, major surveillance tests were carried out. Replacement of exhaust filters of reactor containment building and checking of the efficiency of iodine and particulate filters were also carried out. As a part of ageing management, existing control panels of emergency diesel generator units were replaced with the newly procured control panels. In addition, the existing isolation valves of pre heating and emergency core cooling system were replaced with remotely operated pneumatic valves.

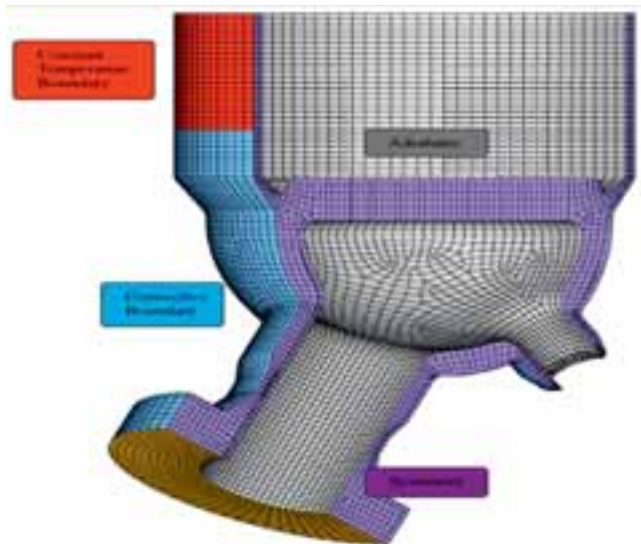
In 2017-18, the total operating time of the reactor was 376 hours. The total thermal and electrical energy generated were 8218 MWh and 1.8million units, respectively.

Proposal for commencing the 26th irradiation campaign is awaiting regulatory clearance due to pending replacement of steam generator module. The reactor core will be configured for this campaign by shifting the experimental sub assembly at core centre and the Mark II fuel sub assembly to periphery for in pile cooling. Two fresh Mark-I fuel sub-assemblies will be added in their place. Two more fresh Mark-I fuel sub-assemblies will be added to increase the core reactivity. Estimated reactor power is 30.2 MWt. In this campaign, irradiation of natural U-Zr sodium bonded metal fuel pins, Uranium metal pins, ternary fuel pin U-Pu-Zr and long term irradiation of impact specimens of 304 LN & 316 LN will be continued.

### R&D relating to PFBR

#### Technical support to PFBR Commissioning

After preheating the reactor assembly to 150°C, it was maintained at 150°C by inter-vessel heating by hot nitrogen and secondary sodium circulation in



**CFD prediction of transient temperature evolution in thick tube sheet of PFBR Steam generator during pre-heating**

intermediate heat exchanger. The amount of heat transfer from secondary sodium to reactor assembly by natural convection of nitrogen, temperature uniformity in reactor assembly, heat deposited by nitrogen in the inter-vessel space, adequacy of available inlet / outlet pipes, and nitrogen flow rate / temperature were verified by 3-D CFD simulations. The feasibility of heating the thick steam generator dished end and tube bundle, by electrical heating of the shell and the duration of heating were established by 3-D transient CFD simulations. Based on the plant measurements, heat and mass balance in the nitrogen pre-heating circuit, heat loss through various paths and heat deposited in reactor assembly were quantified as required by AERB.

### Plant Dynamics Analysis

Commissioning tests on shutdown systems were conducted and important system parameters were measured and taking this into account, plant dynamics analysis of the enveloping design basis events were carried out to ensure safety. The analyses provide input towards getting the regulatory clearance.

### Flexibility and seismic analyses of piping

As a part of commissioning activity, a 'seismic walk-through' exercise was carried out in Nuclear Island Connected Buildings (NICB). Inspections were carried out from the points of view of possible interaction between adjacent equipment and piping systems,

adequacy of anchorage for ground supported equipments, support arrangement for piping and non-safety class equipments. Seismic analysis of the as-built steam generator vent lines, flexibility & seismic analyses of safety grade decay heat removal system and flow induced vibration analyses of secondary sodium fill & drain pipelines were performed and design check was carried out as per RCC-MR piping design rules.

### Stress Analysis of Main Vessel

Stress analysis of 'Main Vessel - Roof Slab' junction was carried out for the as-built configuration and modified anti-convection barrier, as per the requirement of safety committee. It has been established that fatigue damage near the junction is within acceptable limits. When the fuel handling equipment tests are in progress, the reactor assembly is maintained hot by inter-vessel heating, leading to external pressure on main vessel. Hence, buckling analysis of main vessel was carried out considering the present load and temperature conditions. The critical buckling pressure was found to be 165 mbar while the actual external pressure is only 40 mbar, indicating that there is no risk of main vessel buckling.

### Safety analysis during first approach to criticality

An important safety analysis pertaining to first approach to criticality was performed for various initial core configurations. It is established that even if SCRAM signals fail, the transient does not lead to any severe accident and the reactor stabilizes at a very low power.

### Neutron strength and spectrum measurements using nested neutron spectrometer

The neutron source strength and spectrum were measured for inner core. The neutron flux at the measured location is  $55.6 \text{ n/cm}^2/\text{s}$  and the mean energy is 1.4 MeV. The measurement validated the source strength calculation.

### Commissioning & performance testing of shutdown systems and Neutron detector handling mechanism

Diverse Safety Rod Drive Mechanisms were





*Room temperature testing of neutron detector handling mechanism of PFBR*

commissioned at room temperature and integrated functioning of the mechanisms from the main control room was verified. The results of the commissioning tests were compiled and presented to review committee. Following these, high temperature performance testing of Control and Safety Rod Drive Mechanisms and Diverse Safety Rod Drive mechanisms were also carried out on pile at 150°C. Subsequently, performance of Start-up Neutron Detector Handling Mechanism was tested at room temperature, simulating reactor constraints and was handed over to BHAVINI for erection and testing on pile.

#### **Alternate scheme for handling components at 150°C**

Before primary sodium filling, many equipments have to be taken out/inserted into the leak tight boundary of main vessel for various testing purposes. A special handling procedure without using flasks was devised and the same was demonstrated using a test

rig. This procedure greatly reduced the preparatory works and handling time.

#### **Assessment of entrapped argon gas pocket in secondary sodium pipes**

Due to the sloping provided in the secondary sodium main line, entrapment of ~10 cubic meters of argon is possible between the pump and intermediate heat exchanger, during initial filling. Advanced transient CFD analysis of entire pipeline was carried out to observe any trapped argon pocket in the pipeline. It is seen that even with 20% pump speed, entire argon will be displaced within 3 minutes.

#### **Experiments to Measure Leakage in Hydrostatic Bearing of Sodium Pump**

During sodium filling in the secondary loop, there was a suspicion that the sodium leak rate through the bearing is more than the value computed. Hence, experiments were carried out in full-scale model of hydrostatic bearing. It was established that the leakage through the bearing was very close to the computed value and not affected by the rotational speed of the shaft.



*Measurement of coolant leak in hydrostatic bearing of PFBR main sodium pumps*

#### **Assessment of acceptable primary sodium heating rate**

The impact of primary sodium heating rate during power rising on structural damage to major reactor assembly components was assessed. The maximum acceptable heating rate was found to be 60 K/h and the shortest time required to bring the reactor to full power was 6.6 h.

## Seismic analysis of underwater trolley support structure

Seismic analysis was performed for the underwater trolley support structure using response spectrum method. Natural frequency, displacement and acceleration responses, stress intensities, reaction forces and moments were computed. Stress intensities were compared with appropriate codal limits and were found to be safe, ensuring structural integrity.

## Design of Future FBR

### Comparative Assessment of Design Codes

A comprehensive comparison of two design codes for the design of nuclear reactor components was made from the points of view of material specification, high temperature material property, effects of irradiation/forming tolerances, requirements for non-destructive examination, permissible weld joints, preheat, post-weld heat treatment and welding qualification etc. The exercise is for assessing the gaps and is improving based on the experience gained so far.

### Mapping of FBR Safety Criteria against GEN IV Safety Design Criteria

A detailed comparison between safety design criteria for GEN IV reactor systems and draft safety criteria for future MOX fuelled FBR was carried out. Eighteen clauses were identified for inclusion in the revised safety criteria. The document is currently under review by AERB.

### Hydraulically suspended absorber rods

Hydraulically suspended absorber rod is a shutdown device that is being designed to ensure passive shutdown of the reactor in case of loss of flow event. Detailed pressure drop estimation in the device was completed and the orifice designs which will be incorporated in the foot of the subassembly were finalized.

### Equipment layout in fuel building & decontamination building

Subsequent to the selection of the reference plant layout, equipment layout in various buildings was

taken up. Preliminary layouts of equipment in fuel building & decontamination building were finalized.

### Structural mechanics analysis of components

3-Dimensional structural mechanics studies were performed to optimize the stiffener parameters of grid plate with respect to displacement, slope, buckling of stiffeners and thermal deformation. The number of stiffeners employed in load transfer was optimized and design check was carried out for the optimized design.

Fretting wear of intermediate heat exchanger tubes at support locations under various excitation mechanisms was determined. The fluid elastic instability is found to be the dominant mechanism. A comprehensive comparison of two different concepts for roof slab, viz., box type and dome type was performed to facilitate the relative merits of both the design concepts. Various aspects like design, material, fabrication, influence on other connected systems, manufacturing time and cost, in-service inspection requirements and feedback from PFBR experience were paid critical attention.

### Development of an Integrated CFD model for Steam Generators

In order to quantify the thermal loading in steam generators, a 3-D thermal hydraulic model of steam generators was developed by integrating the commercial code with the in-house developed design code. By providing proper orifice in the water tubes and tie rods in the bundle periphery, the steam outlet temperature variation was reduced from 70 to 35°C. Similarly, the thermal loads in the tubes were also reduced. The model was validated in the steam generator test facility.

### Design of facilities for component qualifications

As an import substitute, a bearing measuring was designed & developed successfully. Towards demonstrating the indigenous large diameter bearing, a qualification rig was designed and detailed structural analysis was completed to optimize the structural members.

A test set up was conceptualized for the study of reverse flow blockage mechanism for Primary Sodium Pump. In-vessel shield, optimization was carried out using advanced shield material in the axial and radial directions. In the radial direction Ferro boron of density within the available space was found to be sufficient to meet the limit on secondary sodium activity, whereas in the axial direction a combination of B<sub>4</sub>C and tungsten carbide were found to be required to meet limits on secondary sodium activity and sufficient detector counts at control plug detectors.

### Assessment of Desalination and Power Generation Options for 100 MWt test reactor

Conceptual design of a 100 MWt test reactor with metal fuel as the driver fuel was evolved earlier. This will ensure the continuous availability of 'fast neutron spectrum test reactor facility' in DAE after the end of life of FBTR. Various options were contemplated such as power generation or desalination or dual use for the proposed reactor. Major thermal and membrane based desalination technologies were evaluated for their suitability and possible interface with the test reactor. A dual use of power generation and desalination option with co-located facilities was also studied by considering sharing of seawater intake, outfall, chlorination and screening facilities. Seawater reverse osmosis based desalination facility, electrically coupled to the test reactor and the grid, was also studied as it does not alter the reactor or plant design for power generation option, and offers design flexibility, cost-effective desalination and independent operation. The final option recommended is the single use of power generation.

### Research & Development

Shake table experiments were performed on model high pressure piping system to understand the failure of the system due to seismic ratcheting phenomenon. The piping was filled with water and pressurized. Experiments were performed for safe shutdown earthquake loading. Strain values were observed to increase in each cycle indicating the ratcheting phenomenon and failure was found to occur when the strain was 8%.



*Seismic ratcheting experiment on pressurized piping system*

## CBR-1&2: Conceptual Design Features of 600 MWe FBR

### Metal Fuelled Test Reactor

#### Establishment of Irradiation Capsule Fabrication Facility

Irradiation Capsule Fabrication Facility was established in IGCAR exclusively for encapsulation of fuel pins in irradiation capsule to enable irradiation in FBTR. Fully sealed, qualified and leak tight fresh nuclear fuel pins only will be handled in this facility during fabrication of the irradiation capsules. Regulatory clearance from AERB was obtained for the first two campaigns in this facility.



*Irradiation Capsule Fabrication Facility*

### R&D on FBRs

#### Dissimilar Metal Weld Inspection Device for PFBR

A dissimilar metal weld inspection device was developed for carrying out periodic remote visual examination and ultrasonic testing of dissimilar metal weld between the roof-slab and main vessel of PFBR, above the anti-convection barrier. The room temperature trials were conducted successfully and validated at BHAVINI.





*Dissimilar metal weld inspection device*

### **Hydraulic performance evaluation of failed fuel localization module of PFBR**

An experimental study was carried out in a full scale model of Failed Fuel Localization Module, using water as the working fluid to estimate the percentage dilution in various alignment conditions of selector plug with respect to the guide sleeve. The pressure drop of sodium in the sampling mechanism up to the suction of the electromagnetic pump was also estimated. The pressure loss coefficients were evaluated for different flow rates for both aligned and misaligned conditions of the selector plug.

### **Demonstration of carbon removal from liquid sodium**

Small scale engineering experiments were conducted with hot trap to demonstrate the removal of carbon from static liquid sodium. Removal of carbon impurity from static liquid sodium using hot trapping process was also demonstrated with 1 kg of sodium. The results suggest that commercial sodium can be purified to nuclear grade sodium using hot trapping process in an economical manner.



*Carbon removal experimental setup*



*Valve after manufacturing*

### **Development of 450NB frozen seal butterfly valves**

Butterfly type sodium service valves with frozen seal and back up gland packing are used in the secondary sodium system of Indian FBRs. As part of indigenous technology development for usage in future Indian FBRs, a 450NB frozen seal butterfly valve was designed and manufactured successfully in collaboration with industry. The valve operated 250 times at room temperature and ensured the trouble free operation confirming the adequacy of clearance provided. Overall cost of the valve is estimated to be one third of the import cost.

### **Commissioning and Operation of Sodium Facility for Component Testing**

A multipurpose sodium facility was commissioned to provide impetus to mandate on testing of components for future Fast Breeder Reactors.

### **Studies on PFBR source pin wettability using sodium as test medium**

In PFBR sub-assemblies antimony-beryllium neutron source is used to obtain a minimum count rate of 3-10 cps at the neutron detector location during reactor start-up. Heat generated inside the source pin has to be removed for which sodium is selected as the conducting medium between the capsules and the clad. However, entrapped gas bubbles in the annular space may reduce the heat transfer. Hence experimental investigation of the flow pattern and wetting behaviour in the annular space was conducted using sodium. It was found that the percentage of bubbles in the annular space was within acceptable limits.

### **Performance evaluation of 200 NB size Samarium Cobalt (SmCo) type PM Flow meter**

In order to reduce the size and weight of 200 NB pipe flow meter, a high sensitivity samarium cobalt flow meter was designed, manufactured and tested in sodium. The sensitivity is 40% higher and the overall weight is 37% lesser than that of conventional permanent magnet flow meter.

### **Qualification of wire type leak detector layout for dished ends**

Sodium leak experiment with wire type leak detector layout was carried out and sodium leak was detected in 25 minutes. This will help in suggesting an optimized wire type leak detector layout for the dished ends of different components used in FBRs.

### **Feasibility Study to detect sodium leak in nitrogen atmosphere using Sodium Aerosol Detector**

Feasibility of utilizing sodium aerosol detector for detecting sodium leak from main vessel into the inter vessel space having nitrogen atmosphere was studied in a test vessel in a sodium loop. The response of sodium aerosol detector at various sodium pool temperatures at 200 mbar nitrogen pressure was studied and found to be satisfactory. The study will open the path for application of sodium aerosol detector in PFBR for detection of main vessel leak as an additional leak detection system.

### **Performance evaluation of Start-up Neutron Detector Handling Mechanism of PFBR**

Start-up Neutron Detector Handling Mechanism (SNDHM) is used for inserting three numbers of neutron detectors into the reactor core for monitoring the neutron flux in the core during initial core loading. SNDHM was tested to check the raising and lowering of mobile assembly with control panel, functioning of sensors to cut power supply to motor automatically and leak tightness with argon gas. The assembly was successfully tested and dispatched to BHAVINI. It is presently erected on pile.

### **High temperature testing and qualification of Eddy Current Flow Meter (ECFM) of PFBR Primary Sodium Pump**

ECFM probe placed at the discharge of PSP measures the sodium flow and provides SCRAM signal in the event of primary pipe rupture. During Safety Grade Decay Heat Removal conditions the temperature of sodium near the pump discharge increases to 525°C and therefore it is necessary to qualify the probe upto 525°C. To qualify the device for reactor applications, vibration testing was carried out and verified that the probe is safe against the potential vibration damages due to pump operation and sensor output is independent of pump vibration. Experiments were also carried out to measure the response time of ECFM and its electronics in an air test rig. Test results show that values taken for plant dynamics studies of PFBR are conservative.

### **Argon and steam injection experiments in Sodium Water Reaction Test facility**

In steam generators of Fast Breeder Reactor (FBR), detection of steam/water leaks at the incipient stage is important to avoid wastages resulting from sodium water reaction. Acoustic technique can detect leaks in the small and intermediate ranges faster than other detection methods. Experiments were carried out in Impingement Wastage Test Section of Sodium Water Reaction Test facility by injecting argon and steam into sodium through a leak simulator tube. These experiments have provided confidence in qualification of leak detection system/algorithms using argon injection into sodium.

### **Demonstration of Alternate Handling Scheme for BHAVINI**

In BHAVINI, handling of components from/to the reactor will be carried out in inert atmosphere using special handling flasks. During pre-heating of main vessel, it is necessary to carry out removal & insertion of many slender components in the absence of handling flasks. It was decided to adopt an alternate handling procedure to meet this exigency based on similar experience in FBTR. A mock up with prototype DSRDM was carried out to demonstrate the safety of the adopted

scheme, in view of the fact that the exercise involved intervention into a large vessel containing hot (~150–180°C) inert gas which is released into the atmosphere during the operation. The assembly on the reactor control plug was simulated. The exercise demonstrated that removal and introduction of equipment into vessel in inert atmosphere at 180°C can be safely carried out using the proposed alternate method.

### **Investigation on heat removal capability of core catcher through natural convection**

A simulation experiment was conducted with woods, metal debris bed in 1:4 scale main vessel assembly with water, to investigate heat removal capability of core catcher through natural convection in presence of debris and reactor internals. The debris bed was heated by using heaters (heat source) mounted below and steady state temperatures were achieved at 45°C and 56°C. This study is useful in understanding the effect of internal components on passive heat transfer from porous core debris.

## **Control systems & sensors**

### **Dual Frequency Remote Field Eddy Current (RFEC) Test Instrument for inspection of Steam Generator Tube in PFBR**

In PFBR, secondary sodium circuit steam generator, wall thinning, small cracks and other degradations may occur due to highly reactive nature of sodium with water or steam. Instrument was developed indigenously based on RFEC technique for the purpose of Inspection. Testing was done on calibration with flaws with various scanning speed and the instrument was able to detect flaws.

### **Design & Development of SHAKTI processor based CPU card for Computer based I&C systems of FBR**

Obsolescence of electronic components is the major challenge in Computer based Instrumentation & Control of Nuclear reactors. To overcome this, it is proposed to use the open source RISC-V Instruction Set Architecture based soft core processor, developed by

IIT-M for Fast Breeder Reactors. Piggy back board was designed using C-class variant of the processor in collaboration with IIT-M. This piggy back board is compatible with existing MC68020 Central Processing Unit (CPU) used in computer based systems of Prototype Fast Breeder Reactor.

### **Physical Protection System for FBTR**

An IP based Integrated Physical Protection System, comprising CCTV Surveillance system and Perimeter Intrusion Detection system, was installed and commissioned in FBTR, replacing the existing aged perimeter intrusion detection system.

### **Distributed Digital Control System for Instrumentation & Control (I&C) Systems of PFBR**

Distributed digital control system (DDCS) provides data acquisition & control of the entire plant through real time computer based systems housed at various locations which are inter-connected through plant network. DDCS also performs data processing using centralized servers and provides graphical user interfaces through various display stations for operator information & control.

### **Design & Development of 68000 soft-core processor based CPU Card for VME bus based Real Time Computers**

PFBR I&C systems are based on VME bus based real time computer consisting of Motorola 68020 CPU card. In order to overcome component obsolescence issues and maintain backward compatibility with the existing software, new CPU card was designed & developed using 68000 soft-core processor.

### **Design and Development of Indigenous TCP/IP Communication Module for embedded systems of Nuclear Power Plant**

Indigenous Network Module for TCP/IP Communication was designed, developed and tested for offloading the routine communication task from embedded systems used for various applications in the nuclear power plant. In comparison to the existing



imported network modules, this will provide better performance in terms of throughput and number of parallel connection support.

### **Development of large-scale test bed for Sodium Technology Complex (STC) Wireless Sensor Network (WSN)**

A large scale wireless network sensors test bed consisting of multiple nodes with Power over Ethernet was deployed towards implementing wireless sensor networking technology for temperature monitoring and for detection of sodium leaks in sodium technology complex. Various experiments are being carried out to test and validate the data reliability and interference immunity in dense network conditions.

### **3D Modeling and Animation**

Simulation, modeling and animation of fresh fuel and spent fuel handling system was completed and integrated with process, logic and virtual panel models of Full Scope Replica Operator training simulator for operator training. Modeling of uranium processing section of Fuel Reprocessing Plant of FRFCF consisting of civil structure and process equipment was done with animation of process-workflow.

### **Implementation of Virtual Desktop Infrastructure (VDI) solution and Network Access Control system**

A prototype network access control system was developed to provide secured access to campus LANs from end devices. In order to meet the desktop computing requirements of IGCAR, a high quality, secured, low-cost, low-maintenance virtual desktop infrastructure solution is being implemented with a centralized data center and ultra-thin clients.

### **Development and deployment of Utility Web Portals**

A unified high performance cluster portal has been developed for the efficient usage and management of high-performance scientific computing facility. A web based online recruitment management system has been deployed for automating the recruitment process including online submission, validation, back end processing etc. The revised version

of portal for submission and assessment of Annual Performance Appraisal Report (APAR) was developed and released. Verification & Validation workflow automation module and Configuration Management module were developed for various reports and soft codes of computer based PFBR I&C systems.

## **STUDIES ON MATERIALS FOR FBRs**

### **Estimation of atmospheric corrosion loss of carbon steel housing in the reactor vault of PFBR**

The theoretical estimation of atmospheric corrosion of carbon steel housing of under vessel neutron detectors in the reactor vault of PFBR was carried out. The average corrosion loss was found to be  $2.36 \mu\text{m}$  during the commissioning period, which will be even lower during the reactor operation period.

### **Development of Yttria coating with silicon carbide interlayer on high density graphite crucibles for U-Zr Alloy Melting**

An oxidation protective interlayer coating of silicon carbide was developed to enhance the life and durability of atmospheric plasma sprayed yttria coating on internal surfaces of high density graphite crucibles. The durability of yttria coating was successfully demonstrated in the melting of U-Zr alloy at  $1500^\circ\text{C}$ . The performance of the coating was satisfactory up to 5 melting cycles.

### **Development of 9Cr-1Mo steel-Zr-noble metal fission products-U metal waste form alloys for pyrochemical reprocessing application**

Optimized composition of 9Cr1Mo steel-noble metal fission product (Ru, Rh and Pd) powders and Zr were melted and homogenized. Required amount of uranium was added in the ingot and casting of metal waste form alloy was carried out in the arc melting furnace. Successful melting of Fe-9Cr-1Mo-12Zr-2Ru-0.7Rh-1.3Pd-10U metal waste form alloy was achieved. Melting procedure was repeated to achieve homogeneous melt.

### Development of sacrificial ceramic coating on core catcher materials by plasma spray technique for future fast reactors

Sacrificial ceramic coatings of  $\text{Al}_2\text{O}_3$ -28 MgO and  $\text{Y}_2\text{O}_3$  were successfully deposited over 316L stainless steel substrate with NiCrAlY bond coat, by plasma spraying for core catcher applications. The long term stability assessment of the ceramic coated specimens showed no degradation in molten sodium (at  $400^\circ\text{C}$ ) under inert atmosphere.

### Development of a fluorescence in-situ hybridization probe for the rapid identification of biofilms

A fluorescence in-situ hybridization probe was successfully developed for the rapid identification of *Bacillus* and *Pseudomonas* species of biofilms on reactor cooling water condensers. Towards this, 16S rRNA sequences of *Bacillus* and *Pseudomonas* species were isolated, amplified, sequenced and a complimentary sequence was labelled with a fluorophore.

### Development and validation of electrochemical biofilm monitoring probe

An electrochemical Biofilm Monitoring probe and instrumentation module for continuous monitoring of biofilm formation in the cooling water condensers was developed and tested in biofilm forming medium.



**Biofilm Monitoring Probe Setup with Source Meter and Probe (Inset)**

### Development of high performance Nano phase modified Fly ash concrete

High-performance concrete was developed. The Nano phase modified concrete showed an enhanced compressive strength, split tensile strength and reduced rapid chloride penetration as compared to conventional concrete. The thickness of the biofilm formed over the newly developed concrete specimen, showed  $0.1\ \mu\text{m}$  thick in comparison to  $45\ \mu\text{m}$  thick film in conventional concrete.

### Fabrication of Deloro 50 bushes through Additive Manufacturing

Structural materials exposed to sodium in FBRs are usually hard faced with suitable Ni-based alloys, to prevent self-welding and galling during service. As an alternative, it was decided to study the feasibility of fabricating hard-faced alloy components through 'Additive Manufacturing' (AM) in collaboration with RRCAT, Indore and measure their high temperature thermal stability and thermo physical properties.

### Consolidation and characterization of oxide dispersion strengthened (ODS) 18Cr steels

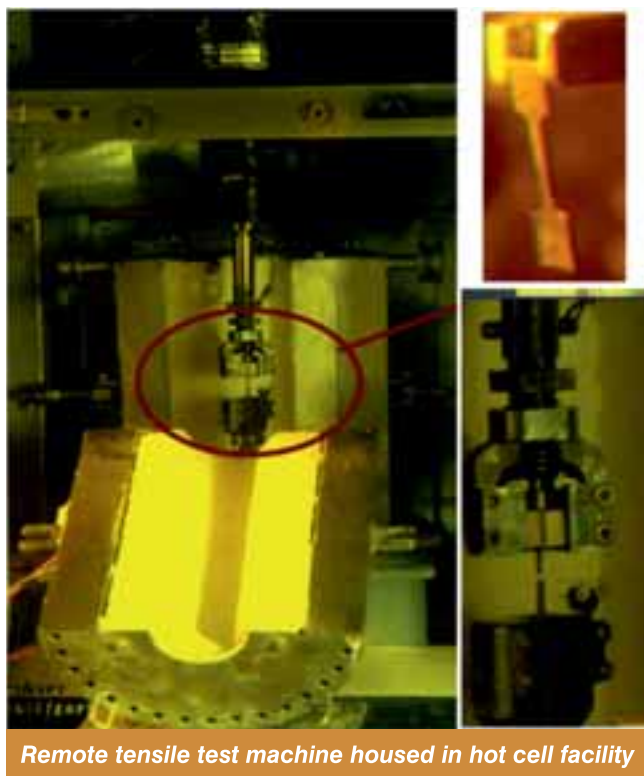
High Chromium containing 18 wt.%Cr ODS ferritic steels with high neutron irradiation swelling tolerance and corrosion resistance are being developed as potential core candidate materials for future fast reactor applications.

### High Temperature elastic property determination of SS304H Cu stainless steels

SS304HCu stainless steel developed for boiler tube application in advanced ultra-supercritical thermal power plants exhibits good high-temperature creep properties. Structural design and fabrication using this alloy requires a comprehensive knowledge of the variation in elastic properties up to very high temperatures; this data is not available in literature. Elastic, bulk and shear moduli were measured at temperatures up to  $1000^\circ\text{C}$ , and at pressures up to 35MPa using the resonance frequency technique. The data is of paramount importance for the selection of forming process parameters for the various components of supercritical thermal power plants.

### Performance assessment of PFBR core structural materials irradiated to low neutron dose

Towards assessing the effect of low dose neutron damage (1-5 dpa) corresponding to life-time fluence on permanent near core structures of PFBR, an experimental irradiation was carried in FBTR with pre-fabricated tensile and disc specimens of SS316 L(N) and SS304 L(N). Tensile testing was carried out on a test machine installed in the hot-cell facility. Disc specimens were used for transmission electron microscopy (TEM). Both base and weld metals of these steels exhibited increasing strength (hardening) and loss of ductility with increasing displacement damage up to 5 dpa. SS304 L(N) exhibited a higher rate of hardening and correspondingly a lower residual ductility compared to SS316 L(N). The strength of weld metal was generally higher and ductility lower than corresponding base metal at all dpa. Microstructural basis for this enhanced rate of hardening was investigated through TEM analysis – SS304L(N) base metal samples of 3.5 dpa showed a fairly high number density of irradiation induced dislocation loops while such loops were relatively less in SS 316 L(N) base metal of 5.0 dpa. This microstructural difference can in turn be correlated to the difference in solute content in the two alloys.



Remote tensile test machine housed in hot cell facility

Evaluation of hot cracking susceptibility of boron free E309 electrode recommended for fabrication of neutron shields was carried out using SS 304B4 containing 1.3 wt.% boron.

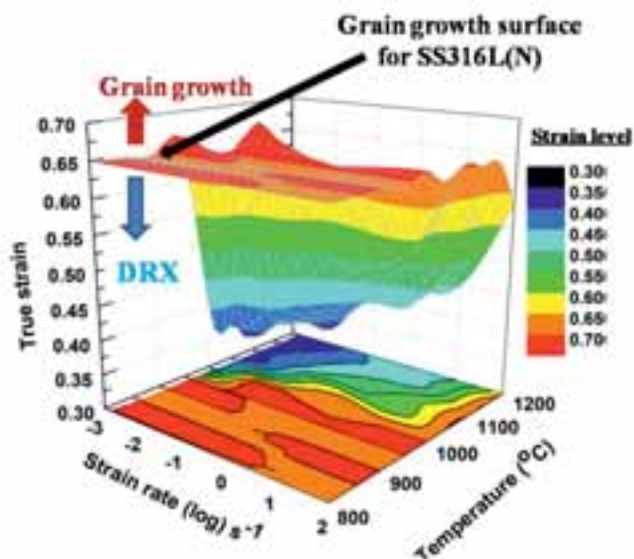
### Creep Properties of IFAC-1 Stainless steel clad tubes

One of the economic means of operating fast breeder reactors is to increase the fuel burn-up by increasing its residence time in the reactor. This necessitates development of clad materials that withstand high dpa of neutron irradiation and this is an evolutionary approach. To further enhance the irradiation resistance up to 100 dpa, phosphorus and silicon are added to Alloy D9, and thus modified alloy is named as IFAC-1 SS (Indian Fast Reactor Advanced Clad). Clad tubes of IFAC-1 stainless steels were manufactured at NFC, Hyderabad and were creep tested at 700°C at various stress levels. For most of the stress levels, IFAC-1 SS clad tube has shown high creep rupture strength in comparison to Alloy D9.

### A novel technique to demarcate the regions of dynamic recrystallization and grain growth in hot working domain

Deformation of steels at elevated temperatures, also known as 'hot working', is associated with Dynamic Recrystallization (DRX). DRX is a softening process which results in formation of small, strain-free grains. At elevated temperatures, DRX process is rapidly followed by grain growth, which is to be controlled if the resultant product has to meet stringent grain-size requirements of FBR structural components. Conventionally, the processes of DRX and grain growth have been treated as a single composite process. This approach makes it difficult to estimate the resultant grain size, necessitating subsequent processing. In order to reduce additional processing, a new technique has been developed to demarcate the regions of DRX and grain growth. This technique theoretically specifies a critical strain level below which the steel undergoes DRX. When mapped over the domains of deformation temperature and strain rate, this strain level forms a critical surface, termed the 'grain growth surface'. The grain growth surfaces for 316L(N) SS and 304L SS, were calculated and experimentally validated. These facilitate close control of grain growth during hot working.





*Mapping of grain growth and dynamic recrystallization regimes in 316L(N) SS as a function of temperature and strain rate*

### Thermal Ageing Effects on Low Cycle Fatigue Properties of 316LN Stainless Steel Weld Joints

Detailed investigations performed on the high temperature low cycle fatigue behaviour of 316LN SS weld joints showed that short-term thermal ageing (973K/2h) leads to an improvement in the cyclic life compared to the as-welded condition. Ball indentation technique was employed towards understanding the strain incompatibility between different zones of the joint. Cycling led to a significant increase in the yield strength of the base metal. This, coupled with the softening of the weld zone indicated that the base metal takes most of the cyclic strain. Ageing imparted significant softening of the weld region, leading to an increase in ductility of the joint and a considerable decrease in the cyclic stress response. This also led to a significant amount of plastic deformation within the weld zone, as reflected by a marked increase in yield strength of the same, upon subjecting the thermally aged joint to cyclic deformation.

### FBR - FRONT END FUEL CYCLE

In order to understand the fuel pin behaviour with designed linear heat rating (LHR) of FBTR, sodium bonded-metal alloy fuel pins with more fissile content containing U-Pu-Zr metal slugs were fabricated and qualified at IGCAR. The ternary alloy fuel slugs were received from BARC. The qualified fuel slugs were



*Slug retrieval facility inside a glove box*

loaded into the T91 clad tubes, encapsulated and sodium bonding was carried out. The single pin sodium bonding process was modified for multiple pins, reducing the cycle time and improving the bond quality. The bond quality was ascertained by radiography and eddy current testing. The qualified fuel pins were fabricated as capsule subassembly for irradiation in FBTR. The rejection of fuel pins after sodium bonding process is around 15-20%. Towards reuse of qualified slugs from the rejected sodium-bonded fuel pins, a slug retrieval facility was commissioned and demonstrated inside an inert atmosphere glove box. The retrieved sodium-wetted slugs were subjected to vacuum distillation for effective removal of sodium. The sodium removal efficiency close to 99.5% of total sodium was achieved by the batch process.

BARC supplied the required mixed carbide fuel for FBTR (Fast Breeder Test Reactor) at Kalpakkam. Up gradation of sintering furnace, gas supply line, de waxing furnace and modernization of quality control equipments has been carried out in the fuel fabrication



*Final compaction of FBTR pellets prior to sintering*



*Attritor for mixing & grinding powder*

facility. This has increased the through put of fuel fabrication facility and rejection rate has minimized. In this year maximum numbers of fuel pins have been fabricated.

Large volume radioactive waste drums with low/intermediate level of alpha activity generated in radiochemical laboratories at RLG are routinely screened before disposal using an in-house developed Segmented Gamma Scanner (SGS) and an Absolute Segmented Gamma Scanning methodology (ASGS).

From combined experiments and Monte Carlo simulations it has been established that the absolute efficiency of the collimated detector for a 200 L cylindrical sample can be well reproduced using a point source moving in a helical motion along the vertical axis of the drum at varying radial position. Efficiency was determined using a standard  $^{152}\text{Eu}$  point source. The ASGS methodology would obviate the need of standard 200 L waste drum as evident from similar efficiency curves for different geometries.

As a part of quality assurance of FBTR fuel, Seventy five (U,Pu)C samples were analysed for Pu, U contents and isotopic compositions of Pu and Am by using biamprometry, thermal ionisation mass spectrometry and alpha spectrometry.

As a part of chemical quality control of FBTR fuel and other nuclear materials, a total of about 140 samples were analyzed for 22 trace metallic impurities using D.C.arc - AES and ICP-AES methods.

## FBTR- BACK END FUEL CYCLE

Selective partitioning of minor actinides followed by their transmutation into

short-lived radionuclides is a widely accepted strategy for mitigating the long-term hazards of high level liquid waste. The development of extractant suitable for minor actinide partitioning is a challenging process, as it would require extractants with many specific properties.

In general, solvent extraction is employed for the recovery of metal ions from concentrated feed solutions in nuclear fuel reprocessing. However, extraction chromatographic methods are preferred for the separation of metal ions from dilute aqueous streams such as tail end purification of aqueous products.

### Sensors

In the light of steam leak incidence in FBTR, Electro Chemical Hydrogen Meters (ECHMs) were tested in sodium water reaction test facility for steam leaks of small, medium and high magnitude. The responses of ECHMs were also tested for hydrogen leaks in sodium both under off-power and on-power conditions of FBTR. The response of ECHMs are compared with Sputter Ion Pump (SIP) based hydrogen detection systems. In all these exercises, the response trend and behaviour of ECHMs were similar to SIP in monitoring hydrogen levels in sodium. Considering the simplicity of construction, operation, maintenance and reliability of ECHMs, they will be deployed in PFBR as planned originally.

### Properties of fuel & coolant

As part of continuing endeavour towards setting up a facility for the preparation of U, Pu mixed oxide microspheres, a new equipment for the measurement of crush strength of the microspheres was designed, fabricated and installed.

The thermophysico-chemical properties of the alloys of U are required in order to obtain optimized phase diagrams of multicomponent alloys of relevance to nuclear fuel. The system U-Al is relevant to the quaternary U-Pu-Zr-Al. The system U-Sn is relevant to the study on irradiated fuel.

Measurement of contact angle of liquid sodium over steel samples in the context of source pin wettability was carried out. Towards this, a contact angle

measurement system was set up in inert atmosphere glove box. Sodium wetting of these tubes is to be established to ensure reduced centerline temperature of antimony oxide and avoid any possibility for melting of antimony oxide capsules. Hence, liquid sodium contact angle measurement on SS316LN samples was carried out. The temperature dependence of contact angle was studied and the results obtained were corroborated with literature values. The results obtained confirmed wetting of liquid sodium on samples at high temperatures.

Primary components of fast reactors get contaminated due to activity transport of activation corrosion products occurring from the core to the out-of-core regions, thereby causing activity burden to the operation and maintenance personnel. Use of radionuclide trap minimizes the consequence of activity transport. Incorporation of individual radionuclide traps for each problematic radionuclide increases space requirement inside the reactor containment building. Hence, a suitable single trap material is preferred to scavenge the above radionuclides from sodium.

## R&D on Fast Reactor Fuel Reprocessing

### Holdup Measurement in Asymmetric Rotating Disc Column (ARDC)

Holdup is the important hydrodynamic parameter which affects contactor capacity and performance. Holdup was experimentally measured for ARDC. The effect of continuous and dispersed phase



*Asymmetric rotating disc column*

velocity on the holdup was studied and found that the dispersed phase velocity has greater influence on holdup compared to continuous phase velocity. Experimental holdup data was used to obtain a correlation for estimating the holdup within AARD of 6.61%.

### Modeling of Simultaneous Extraction of Uranyl Nitrate and Nitric Acid by 36 vol. % Tri-iso-Amyl Phosphate in n-Dodecane

The TiAP is considered as the alternate extractant to TBP. The extraction of uranyl nitrate by 36% TiAP in dodecane was modeled by considering the aqueous phase activity coefficient.

### Development and demonstration of uranous generation by catalytic hydrogenation method

Catalytic hydrogenation process was developed for the reduction of U(VI) to U(IV) in nitric acid medium using Pt/SiO<sub>2</sub> as the catalyst material. The Kinetics of reduction of U(VI) were investigated for various parameters. It was demonstrated that more than 96% uranous nitrate was generated in about 45 minutes at ambient temperature and 2 bar pressure under optimized experimental condition. Kinetic and mass transfer parameters were estimated from the analysis of experimental data.



*Glass autoclave setup for catalytic hydrogenation of uranyl nitrate*

### Fast Reactor Fuel Cycle Facility

Fast Reactor Fuel Cycle Facility (FRFCF) is being built at Kalpakkam, with the objective of closing the fuel cycle for PFBR. It is an integrated facility housing



all the radiochemical plants for carrying out various activities of the fuel cycle such as reprocessing, fuel re-fabrication and waste management.

In the nuclear plant buildings area, civil construction of all the plants is progressing well. Work orders have been placed for the construction of Fuel reprocessing plant and work also has commenced. Cumulative concreting of about 1.6 lakh cubic metres was completed in the nuclear plant buildings for the structural members such as rafts, footings, columns and tie beams. Simultaneously backfilling of soil is also being carried out in a phased manner in-line with the construction sequence and about 11.5 lakh cubic metres of backfilling has been completed. The construction of infrastructure facilities and utility buildings has been completed. On the housing front, construction of 5 tower blocks consisting of 600 units is in progress.

Procurement of major raw materials such as stainless steel plates required for fabrication of process tanks & equipment and lead ingots required for fabrication of shielding bricks has been completed. Orders were placed with NFC for the supply of special quality stainless steel pipes for in-cell applications. Manufacturing of optical quality glass slabs for radiation shielding windows is under progress and the first lot has been received, and the balance lots will be delivered in phases. Manufacturing of various types of Master Slave Manipulators, lead bricks, large capacity high level waste storage tanks and in cell process tanks etc., are under progress.



*High temperature MOX sintering furnace inside glove box*

Several Fuel fabrication process equipments have been delivered to site, being tested and integrated with glove boxes. Other equipment such as bell jar type high temperature MOX sintering furnace, hybrid microwave sintering furnace, robotic arm for product handling, laser based pin bow measurement system etc. have been received. Purchase orders have been placed for centre-less grinding machine and wire wrapping machine and are expected to arrive shortly. Similarly procurement of process equipment for Waste Management Plant, Reprocessed Uranium Plant and Core Subassembly Plant are also under progress.

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.



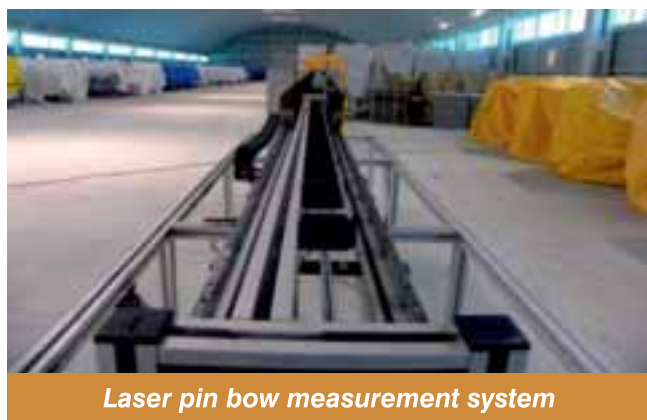
*Overall view of FRFCF site under construction*



*FRFCF Training centre*



*Central Surveillance Safety and Health Physics building*

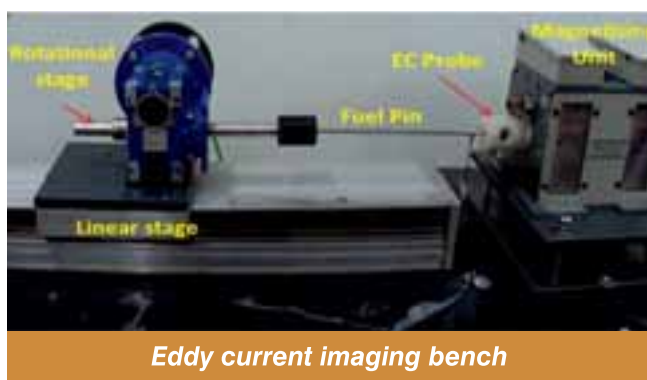


*Laser pin bow measurement system*

## REPAIR & INSPECTION TECHNOLOGIES

### Development of NDE techniques for quality assessment of sodium bonded metallic fuel pins

An Eddy Current (EC) imaging bench was set up for quality assessment of sodium bonded metallic fuel pins. EC imaging of the metallic fuel pins were carried out in each of the three stages of the sodium filling process. The EC imaging bench was also used for determining wetting of sodium in source pin for PFBR, revealing 85% wetting of sodium on an experimental source pin. X-Radiography was also carried out to assess the sodium meniscus height and fuel slug misalignment and fuel slug touching the clad tubes.



*Eddy current imaging bench*

### Magnetic Barkhausen emission technique for non-destructive assessment of residual stresses in ferritic steel welds

Residual stress measurements were carried out on weld pads of P91 steels with thickness of 3 and 6 mm under different heat treated conditions using X-ray Diffraction (XRD) and Magnetic Barkhausen Emission (MBE) techniques. The result indicates that MBE

measurements can be used for evaluation of residual stress in ferritic steels by considering the microstructural state of the steel.

### Inspection of dissimilar weld between the main vessel and the roof slab of PFBR

Non-destructive evaluation methodologies and suitable software were developed and successfully demonstrated for the inspection of circumferential dissimilar weld between the main vessel and the roof slab of PFBR, on a mock-up test facility. All modules, were interfaced with the control panel of the inspection vehicle, for remote operation and data acquisition.

### Development of ultrasonic guided wave based methodology for inspection of steam generator tubes

An ultrasonic guided wave based methodology was developed for rapid inspection of steam generator tubes of PFBR. The technique requires the placement of an ultrasonic transducer only at one end of an SG tube for inspection of the full length of the tube. Using the technique, long range propagation and the good sensitivity of detection for all possible defects were demonstrated in calibration tubes.

## HEALTH, SAFETY & ENVIRONMENT

### Radiological Safety

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD personnel monitoring services, covering about 3000 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 900 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for about 200 occupational workers were also carried out. In-situ/in-house testing of more than 160 HEPA filters in various facilities at IGCAR and 40 HEPA filters from NFC, Hyderabad was completed. Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated. Various samples around active facilities and

other samples for low level counting and determination of the radioactivity from different institutions and industries were also catered to. Radon measurements were carried out on natural samples to quantify the environmental radioactivity levels and thereby estimating the annual effective dose due to natural background radiation.

Environmental radioactivity measurements on east coast part of Tamil Nadu which aims to measure the natural radionuclides distribution in the beach sand samples of east coast part of Tamilnadu covering 100 km north and south of Kalpakkam has been carried out. About 200 gamma radiation monitoring instruments from various nuclear facilities in Kalpakkam, National Disaster Response Force (NDRF), Arakkonam and from Kaiga Generating Station (KGS) units 3 & 4 were calibrated. Nuclear counting and calibration facilities were extended to various institutions involved in BRNS projects, researchers and industries in southern region. Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Dr. Kalam Science Yatra starting from Rameswaram to Chennai was organized as part of radiation awareness programme in connection with third edition of IISF- 2017. The yatra covered about 1055 km distance and more than 5000 school and college students, faculty members and public attended. Indigenously developed Online Nuclear Emergency Response Decision Support system was demonstrated during offsite radiation emergency exercises.



# CHAPTER NUCLEAR POWER PROGRAMME STAGE-III

3



*TPLC 32 based prototype systems of ITS*



*Electro-Electro-Dialysis (EED) cell assembly for HI concentration*

## 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

## ADVANCED HEAVY WATER REACTOR

Integrated Test Station (ITS) comprising of full-scale prototypes of major C&I systems of Advanced Heavy Water Reactor (AHWR) has been setup at BARC for validation of AHWR C&I system architecture, system application development and integrated system testing of functional, performance and safety requirements. Prototype system's hardware based on qualified TPLC-32 platform has been installed and commissioned. ITS provide facility for interfacing with full-scope AHWR plant Simulator for testing and validating AHWR control algorithms through 'hardware in the loop' simulations.



*TPLC 32 based prototype systems of ITS*

## THORIUM FUEL CYCLE

As a part of the ongoing program on generation

of thermo physical and thermodynamic data for fluoride systems relevant to Molten Salt Breeder Reactors (MSBR), viscosity of molten coolant salt; blanket Salt and Fuel salt have been measured in the temperature range 500-600°C, 560-700°C and 590-710°C, respectively. Density of the molten coolant salt was measured in the temperature range 525-725°C employing a micro-thermo balance. The solubility of  $\text{NdF}_3$  and  $\text{SrF}_2$  in Fuel salt has been determined. Thermodynamic stability of several M-Th- $\text{F}_6$  compounds ( $\text{M} = \text{Ca}, \text{Sr}, \text{Ba}$ ) has also been determined.

## KAlpakkam MINI (KAMINI) Reactor

KAMINI reactor was operated regularly for neutron radiography of various pyro devices for Department of Space and also for users from within the department and outside. The reactor was also used for activation analysis and irradiation of various samples. The neutron detector developed and fabricated by BARC & ECIL was also tested in KAMINI. The reactor was shut down for replacing the existing computer based alarm annunciation and operator information system with a state-of-the-art Integrated Control and Information System. The system was commissioned successfully and regular operation of the reactor was commenced after obtaining necessary regulatory clearance.

## MATERIALS

Lithium iron phosphate ( $\text{LiFePO}_4$ ) is a safer and environment friendly cathode material for Li-ion rechargeable batteries. Carbon coated  $\text{LiFePO}_4$  samples were synthesized by sol-gel route. Ratio of concentration of Li: Fe is found to be lower due to sublimation of Li at higher temperature. To obtain stoichiometric compounds,  $\text{Li}_x\text{FePO}_4$  samples with varying Li content ( $x=1, 1.02, 1.05, 1.10$ ) were synthesized. The method was optimized by quantifying total Li content by Particle Induced Gamma-ray Emission (PIGE) method using 4 MeV proton beam from FOTIA, BARC.

An in situ current normalized PIGE method using F as current normalizer was employed for quantification of Li. PIGE is found to be a suitable,



sensitive and non-destructive method for this Low Z element and it involved measurement of prompt gamma-rays at 478 and 429 keV from  ${}^7\text{Li}(p,p'\gamma){}^7\text{Li}$  and  ${}^7\text{Li}(p,n){}^7\text{Be}$  reactions, respectively.

260 samples were analyzed for isotopic composition by using TIMS, alpha spectrometry, gamma spectrometry and Gallium by thermogravimetry to support various DAE programs.

## HYDROGEN ENERGY

Hix processing section of Iodine-Sulphur (IS) thermochemical process is the most important step as it dictates the overall efficiency of the process. The challenge lies in making the HIx ( $\text{HI}-\text{I}_2-\text{H}_2\text{O}$ ) solution over-azeotropic and increase the equilibrium conversion of HI decomposition, which is only about 22% at 450°C. Electro-Deionization (EED) process was developed for concentration of HI and corrosion-resistant alumina supported tantalum membrane reactor for enhanced conversion of HI to  $\text{H}_2$ . A 2 lph capacity EED cell was installed and commissioned in BARC. It achieved a concentration enhancement from 57 wt% (azeotropic composition) to 65 wt%. A 250 mm long single-tube (10 mm OD) tantalum membrane reactor achieved an enhanced HI decomposition (from 22% to more than 90%) and produced  $\text{H}_2$  at 2 bar pressure.



*EED cell assembly for HI concentration*



*Single-tube membrane reactor for HI decomposition*

## MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

A setup for evaluating effective thermal conductivity of lithium titanate ( $\text{Li}_2\text{TiO}_3$ ) pebble bed with internal heat source and helium flow was installed. Studies were conducted with internal heat source by introducing stationary stainless steel balls in the bed of lithium titanate pebbles under helium medium. Stainless steel balls were randomly placed in the bed to simulate random neutron irradiation as expected in the test blanket module.

Tritium Extraction System (TES) plays a very important role in realizing Test Blanket Module (TBM) development for ITER. Removal of impurities and subsequent separation of  $\text{H}_2$  isotopes from helium purge gas is one of the critical steps in nuclear fusion based fuel cycle.

A standalone experimental setup is being operated with helium gas for studying moisture removal using molecular sieve bed at room temperature. Effect of flow rate on overall separation performance has been studied and validated using mathematical model.

Mathematical model was developed and validated for adsorptive separation of  $\text{H}_2$  and  $\text{D}_2$  from Helium using palladium particle bed. The overall rates and efficiencies were estimated for adsorption of both the isotopes on particle bed.

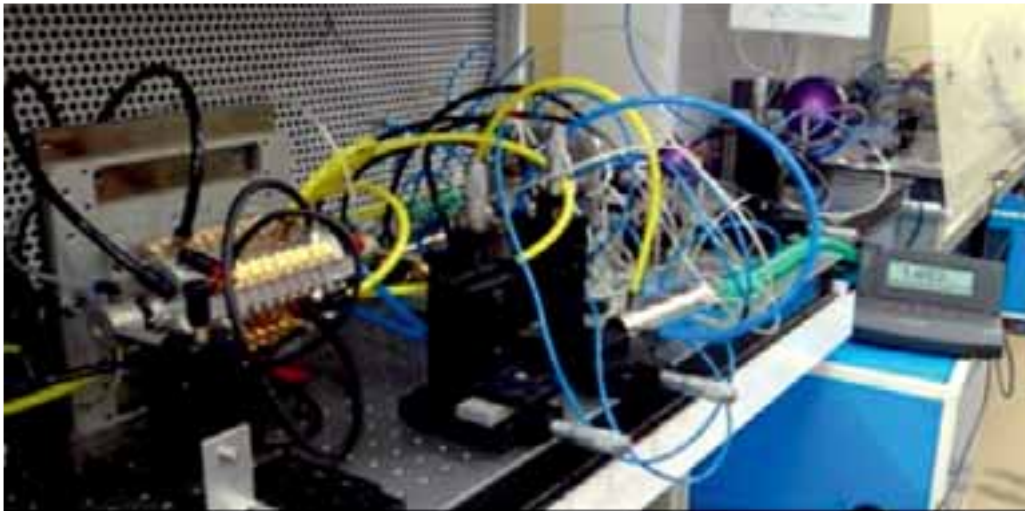


*Experimental setup to study pebble bed heat transfer with internal heat source*

# CHAPTER

## ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES AND THEIR APPLICATIONS

# 4



*Diode pumped fiber coupled high  
power CW Nd:YAG laser*



*Table top version of the liquid nitrogen powered cold capsule for the reefer application*



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

### DHRUVA

Research reactor Dhruva continued to operate with high level of safety with availability factor of around 74% and capacity factor of around 60%. Reactor was operated at the rated power of 100 MW(th) to support the researchers and isotope requirements. More than 630 samples were irradiated for radioisotope production. A number of research scholars from various academic institutions utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

Dhruva Simulator developed as joint project between ECIL and BARC is a full scope research reactor



*Dhruva simulator*

simulator, employing the hardware control console and Visual Display Units (VDU) technology. Major objective of this project is to improve the training and qualification programme for nuclear operators for Dhruva and development of human factors in support of safety studies. Simulator facility and the experiments performed on this facility are expected to improve human reliability through training programme.

Class-I power supply system of Dhruva was upgraded by replacing the Class-I panels (250 V DC bus-M & N and 48 V DC bus-S & T) and associated distribution panels as a part of ageing management and safety up-gradation. These panels are seismically qualified. The new 48 V DC panels are equipped with a system for automatic detection of ground faults.



*Upgraded Class I Panel*

On-line Vibration Monitoring System is expected to provide early warning of the faults in bearing for initiation of necessary actions in a timely manner. This system has been commissioned at Dhruva Reactor to monitor the dynamic behaviour and degradation in Main Coolant Pumps to improve the condition monitoring programme.

**MCPs online vibration monitoring panels**

A new inspection system based on eddy current testing was designed and commissioned to detect the fine surface flaw at the outer surface and the inner surface of the finned tube to improve product quality. The Micro-texture characterization of DHRUVA fuel was carried out using Electron backscatter diffraction (EBSD) technique to assure desired microstructure in metallic U and in turn qualify the process of B-quenching for randomization of grains in metallic U fuel.

The Process flow sheet for the fabrication of target plate elements for production of Fission  $\text{Mo}^{99}$  was developed. About 30 numbers of target plate elements with the desired loading and conforming to the specifications were fabricated and delivered to BRIT to carry out dissolution trials.

**Target Plate Elements****Container with Target elements**

For Nuclear Research Facility at North Site design, development and integrated testing of Trombay Programmable Logic Controller TPLC-32 based, Alarm Annunciation System (AAS), Reactor Regulating System (RRS) and Computerized Operator Information system COIS Data Acquisition Units (COIS DAQs) has been completed. These C & I systems have been

**Integrated test set up of AAS, RRS & COIS**

delivered to reactor site for installation and commissioning.

## Nuclear Research Facility

This research facility is 2MW (th) capacity and will fulfill the national demand of radioisotopes and R&D facilities for neutron beam research. Civil construction of the Nuclear Research Facility-N, lining of reactor pool, erection of reactor core structure, erection of all process equipment were completed. Control panels and electrical panels were installed.

## ACCELERATORS

The Pelletron-Linac facility at TIFR has recorded 77% uptime delivering various ion beams through Pelletron and Linac booster as per users' requirement. Pulsed ion beams such as  $^{34}\text{Si}$ ,  $^{56}\text{Fe}$ , 48, 50Ti and  $^{58}\text{Ni}$  were injected and accelerated through Pelletron accelerator. These experiments include proton irradiation of wheat and rice seeds to carry out mutation studies, proton irradiation of Multi-junction solar cells for satellites to study their post irradiation performance, testing of radiation hardened electronic devices for satellites with protons in collaboration with ISRO. Experiments were also carried out for corrosion study in low carbon steel feeder pipe for PHWR in collaboration with IGCAR. The 6M ion irradiation setup is being utilized to irradiate metal and non-metal samples.

Deuterium ion beam was recently accelerated for the first time to study D-D reaction at 30 keV to 100 keV beam energy as part of low energy Nuclear Physics experimental measurements. Experiments pertaining to measurement of cross sections for proton capture reactions, heavy ion irradiation in glass matrix and projectile X-rays spectroscopy were also performed.

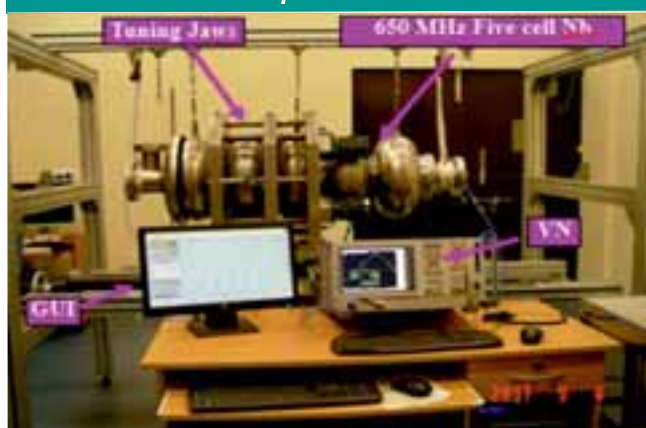


A 75 MHz, 25 kW, continuous wave RF amplifier has been installed and commissioned at BARC to power the prototype room temperature heavy ion RFQ (Radio Frequency Quadrupole).

At RRCAT, a prototype 650 MHz ( $\beta=0.92$ ) five-cell superconducting radio frequency cavity has been fabricated. This is the first 5-cell, high beta, 650 MHz cavity fabricated in the country. The fabrication involved forming of high purity niobium sheet into half-cells, machining of the formed components, machining of end groups parts, and joining half-cells and end groups components using electron beam welding.



**First 650 MHz ( $\beta=0.92$ ) five-cell SCRF cavity developed at RRCAT**



**Indigenously developed semi-automatic cavity tuning machine for 650 MHz SCRF cavity**

A semi-automatic cavity tuning machine for tuning of five-cell 650 MHz SCRF cavities has been designed and developed using the earlier experience of developing tuning machine for 1.3 GHz SCRF cavity. A five-cell 650 MHz SCRF cavity fabricated in niobium has been tuned using this machine. By changing the resonating frequency of the cavity from 649.615 MHz to 649.264 MHz the field flatness was improved from 42% to 90.6%.

A computer code has been developed and benchmarked for simulating the performance limiting phenomenon of multi-pacting in SCRF elliptic cavities. This code takes less computational time and requires less computer memory compared to the currently used computer codes.

A 100 kV, 20 A, compact, all solid state long pulse converter modulator and Marx modulator to drive high average power klystrons for future linacs of Indian Spallation Neutron Source (ISNS) has been developed and tested at low pulse repetition rate on dummy resistive load.



**Modulator setup**



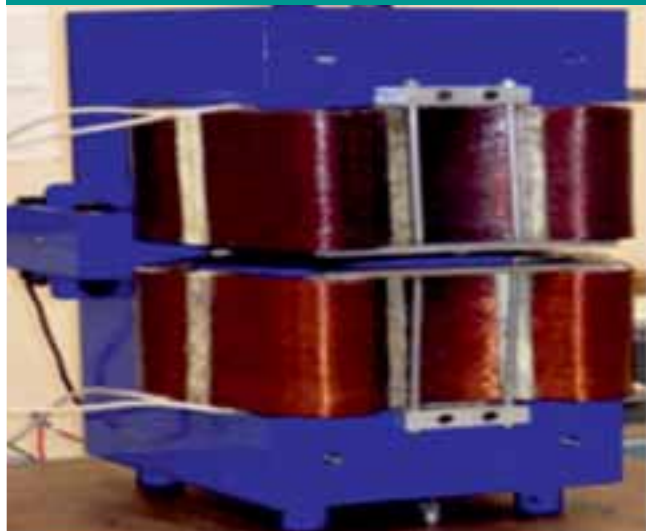
**Marx Modulator**

A filament arc discharge based multi-cusp H-ion source has been indigenously designed and developed to be used as an injector to the front end of H-Linac for SNS applications. The ion source was operated in pulsed arc mode with 2 Hz repetition rate and 0.5 ms pulse duration and extracted using 3-electrode extraction system. The control system for remote operation was developed and deployed. A high energy beam transport (HEBT) line has been designed to transport and match the 1 GeV, 1 MW H- beam from the exit of the injector linac, up to the injection point of the accumulator ring, ensuring that the uncontrolled beam loss is within 1 nA/m, such that hands-on maintenance of the accelerator will be possible.





**Front view of indigenous developed filament arc discharge multi-cusp H- ion source for Proton Linac**



**200-R Mass-analyser dipole magnet**

RRCAT has designed and developed nearly ten numbers of various dipole magnets with different bending radius and field value. These magnets are supplied to BARC for manufacturing of mass spectrometers.

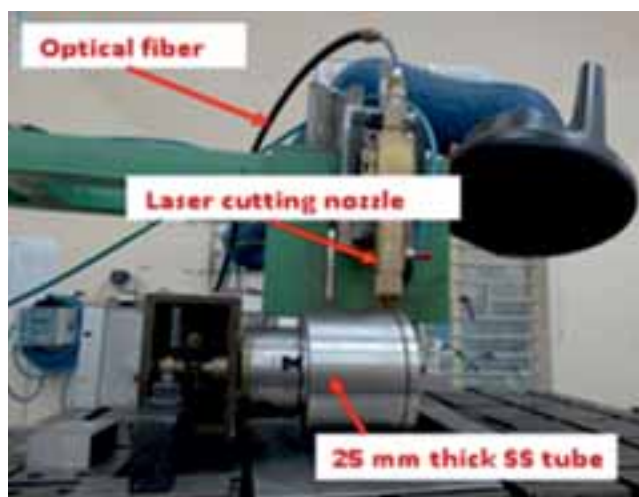
A microcontroller based inverted magnetron gauge controller and Switch Mode Power Supply (SMPS) have been designed and developed indigenously. The SMPS is rated for 3.3 kV, 100  $\mu$ A to power the gauge head. The controller has been tested to measure pressures in the range from  $10^{-5}$  to  $5 \times 10^{-11}$  mbar. This is an import substitute and will be deployed in calibration of gauges.

A beam profile measurement system has been developed and deployed for characterization of electron beam of industrial linacs developed at RRCAT. The system consists of two movable slit blades, one in horizontal and one in vertical direction, which scan the beam transversely. The slit blade is moved across the

beam and current signal proportional to the portion of the beam falling on it versus blade position is measured. The accuracy of positioning of slit blades is better than 100  $\mu$ m. The control electronics and the software developed for this system calculates and displays the beam parameters such as beam size, beam profile and beam position.

## LASER TECHNOLOGY

Two numbers of fiber coupled Nd:YAG laser systems capable of delivering 500 W average power and 10 kW peak power with pulse duration of 2-20 ms and pulse frequency in the range of 1-100 Hz have been developed and delivered to IGCAR for laser cutting of irradiated fuel subassemblies. Laser cutting of up to 25 mm thick SS tubes has been demonstrated using these lasers.



**Shows a view of laser cutting mock-up of 25 mm thick SS**

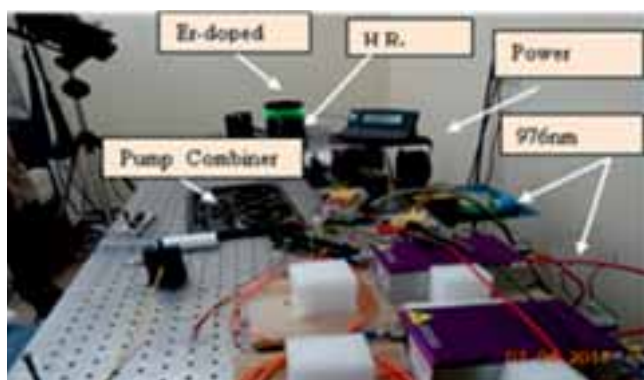
A compact Nd:YAG laser system with single lamp ceramic reflector pump chamber has been developed. This laser is capable of giving maximum energy of 12 J and the laser pulse duration is 10 ms. The



**A view of in-house developed laser welding system for brachytherapy assemblies**

laser system is developed for BARC and will be used for leak tight welding of radioactive iodine sources for brachytherapy treatment of eye and prostate cancer. The earlier system was made for BRIT, Mumbai which was used for welding of radioactive Iridium sources.

An all-fiber Er-doped CW fiber laser capable of delivering 25 W at 1600 nm and line width of 1.5 nm has been developed. In this development, commonly available pump diodes at 976 nm wavelength have been utilized instead of normally used costly 1480 nm pump diodes. Heat from Er-doped fiber is removed by coiling it on a water cooled spool. This laser has potential applications in remote sensing, range finding, skin surgery, and free space communication.



**Table-top view of Er-fiber laser**

The output power of the earlier developed thulium-doped all-fiber CW laser was doubled by multiport pumping and with improved heat sinking of fiber components. The laser is now capable of delivering power of 34 W. The optical-to-optical conversion efficiency observed is 50%. This laser has potential applications in plastic welding and micro surgery.

The output power of earlier developed 400 W CW Yb-doped CW fiber laser was enhanced to about 500 W. 500 W CW fiber laser will be useful in laser cutting of up to 6 mm thick SS and welding of up to 3 mm depth in SS.



**Table top view of all-fiber thulium-doped CW fiber laser**

An all fiber ultrafast oscillator-amplifier system at 1070 nm wavelength has been developed. The output from the oscillator is amplified in multistages. This laser system produces 42W of average amplified power at 40 MHz repetition rate. The pulse from the amplifier are highly chirped with 70 ps duration which can be compressed to 250 fs duration in an external grating-pair arrangement. This laser has potential applications in micro-machining.

A lab model of intra-cavity frequency doubled acousto-optic Q-switched Nd:YAG laser has been developed. The laser is capable of generating 260 W average power at 532 nm laser wavelength at 18 kHz repetition rate. The laser is designed in a thermal birefringence compensated linear resonator having two pump heads, each having 30 number of laser diodes for transverse pumping of Nd:YAG laser rod in fivefold symmetry. This laser has a potential for material processing of high reflectivity materials and pumping of tunable lasers such as dye laser, Ti sapphire laser etc.



**260W diode pumped solid state green laser under operation**

A multi pump module, diode-pumped fibre coupled high power CW Nd:YAG laser was developed. An overall output power of 1.92 kW at an optical efficiency of 35% and  $M^2$  value of 105 was achieved. The fibre coupling efficiency was 90%. This laser has potential applications in material processing namely sheet metal cutting, welding and cladding.



**Diode pumped fiber coupled high power CW Nd:YAG laser**



Several Power supplies has been developed for the lasers and its applications. These include: A 240 J, 5 Hz, simmer mode flash lamp power supply to drive a pair of xenon flash lamps in laser oscillator for laser shock peening applications, 15 kV - 20 kV, rise time < 100 ns, low timing jitter  $\pm 4$  ns, operating at 6.5 kHz power supply for copper vapor laser, 40 kV, < 200 ns rise time, at repetition rate of 0.2 Hz for triggering spark gap used for capillary discharge.

## Laser Applications

During En-masse Coolant Channel Replacement (EMCCR) campaign at Kakrapar Atomic Power Station-2 reactor, laser cutting of 603 bellow lip weld joints (9 bellow lips already cut during single coolant channel removal operations) was carried out successfully using the earlier developed laser cutting procedure. Laser based cutting resulted in enormous reduction in MANREM, time and cost.



***In-situ laser cutting of bellow lip weld joints at KAPS-2 reactor***



***A view of separated bellow lips***

Underwater laser cutting of pressure tube stubs of 11 No. of coolant channels was carried out successfully after en-masse coolant channel replacement of KAPS-2 reactor. Laser cutting of pressure tube stubs from each coolant channel was carried out in four circumferential pieces which took 4

hrs of laser operation. The post irradiation examination of pressure tube stubs near rolled joint area of pressure tube with end fittings was required to generate data on stresses and corrosion to improve the design of future PHWRs.

Laser cutting technology was deployed for removal of Q-15 and P-18 coolant channels of KAPS-1 reactor. For Q-15 coolant channel, end fitting having thickness of 18 mm was cut remotely near the rolled joint area in lead shielding flask and pressure tube stubs of P-18 coolant channel were cut underwater for post irradiation examination data. This resulted in minimum radiation dose consumption and in a very short time span without any airborne activity or radiation hazard.



***Laser cutting of 18 mm thick end fitting in lead shielding flask***

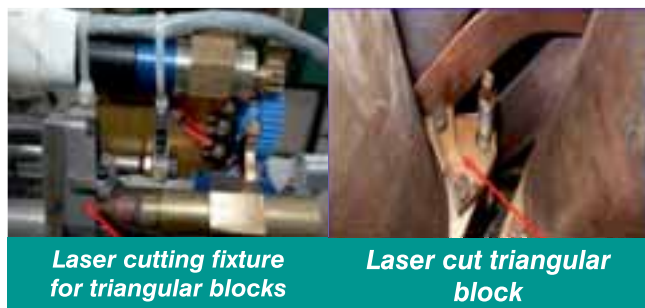
An in situ laser cutting system, using a compact tool with laser cutting nozzle and indigenously developed 250 W Nd:YAG laser, developed at RRCAT, was deployed for remote laser cutting of double check valve pipelines at four different locations of KKNPP-1 reactor at Kudankulam. Implementation of remote laser cutting technique has resulted in sizable reduction in cutting time, radiation dose consumption by the personnel, and lesser secondary waste generation as compared to conventional mechanical methods.

In-situ laser cutting of 18 number of 18 mm thick triangular blocks along with 1 mm thick washer (total 19 mm) was carried out successfully at Rajasthan Atomic



***Remote laser cutting of double check valve pipelines at four different locations of KKNPP-1 reactor at Kudankulam***



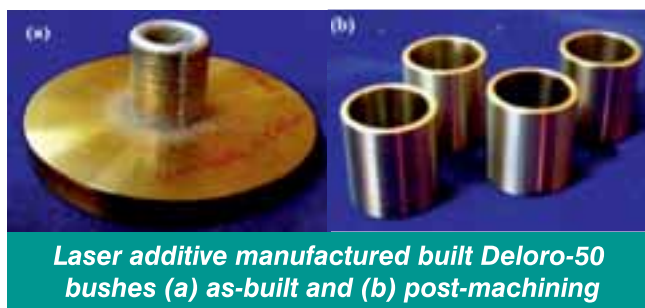


**Laser cutting fixture  
for triangular blocks**

**Laser cut triangular  
block**

Power Station-3 reactor with less radiation dose consumption.

The bushes of the transfer arm of the gripper sub-assembly of the fast breeder reactor have to be wear and corrosion resistant at high temperature. RRCAT has successfully developed a technology for the fabrication of these Deloro-50 bushes (OD 18 mm, ID 15 mm, and 20 mm length) using laser additive manufacturing technique. The bushes of Deloro-50 have been fabricated using 2 kW fiber laser with substrate at preheating temperature of 400°C. The LAM fabricated process has resulted in reduction in material wastage and machining of hard materials. Four such bushes were sent to IGCAR for field testing.



**Laser additive manufactured built Deloro-50  
bushes (a) as-built and (b) post-machining**

A fiber Bragg grating based temperature sensor system developed at RRCAT, has been installed at the radioactive waste storage vault facility at Solid Storage Surveillance Facility, Nuclear Recycle Board, BARC, Tarapur. The system is being used for round the clock monitoring of temperature (40 - 50°C, with accuracy of 1%) in the high radiation environment (dose rate 7000 to 8000 rad/hr) storage vault located about 3 meter below the ground level.

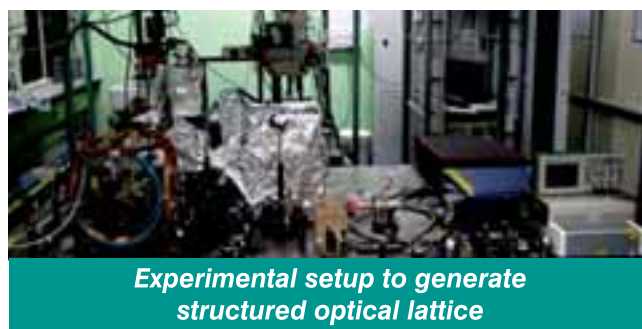
Inter-Granular Corrosion (IGC) is responsible for failures of many austenitic Stainless Steel (SS) components operating in corrosive environment. Significant suppression of Inter-Granular corrosion (IGC) susceptibility of sensitized 304 SS was achieved

through Laser Shock Peening (LSP) treatment using an in-house developed Nd-YAG laser. Hard chrome plating used for enhanced wear and corrosion resistance suffers from loss of fatigue strength, due to presence of high tensile residual stresses and micro cracks. LSP has been exploited as a surface pre-treatment for effecting about 47% increase in fatigue life of hard chrome plated 15-5 PH stainless steel specimens.

An atom-chip with improved thickness of gold wires (from 100 nm to 2  $\mu$ m) was fabricated on Si-substrate (size 25 mm x 25 mm x 700  $\mu$ m) and tested to enhance the current carrying capacity (up to 1.0 A) of the wires on the chip for better magnetic trapping of atoms.

A dual-isotope Magneto Optical Trap (MOT) for generation of cold fermionic (<sup>83</sup>Kr)-bosonic (<sup>84</sup>Kr) mixture of krypton atoms in metastable state has been successfully made operational for the first time. Nearly 105 atoms of each isotope have been trapped in the atom cloud in the MOT.

An optical lattice was formed by overlap of Gaussian and Bessel laser beams and a laser cooled atom cloud of <sup>87</sup>Rb atoms was trapped in the lattice.



**Experimental setup to generate  
structured optical lattice**

## ADVANCED TECHNOLOGIES

Chromatographic separation over Pd sorbent is envisaged as the potential process for H<sub>2</sub> isotope separation. This method offers the advantage of reduced energy load, pure elemental product and lower inventory. Experiments were carried out to validate mathematical model by comparing experimental and predicted elution curves. Validated model was used to optimize the product recovery for minimum Pd requirement for different feed mixtures.

Technology was developed to synthesize imidazolium based ionic liquids in microchannels. Upto



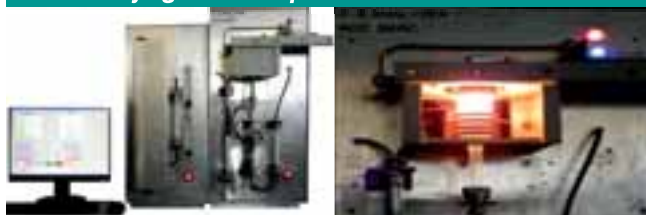
**Experimental setup for separation of H<sub>2</sub> isotope**

10 kg/day of these specialty chemicals could be synthesized continuously at high temperature without any solvent. The technology has been tested for ionic liquids.

A cost effective high temperature dilatometer (Temperature range: 300 -1373 K) has been developed indigenously and is being used for thermal expansion measurements of nuclear materials. Fully automated semi-adiabatic heat-pulse calorimeter has been developed indigenously for the heat capacity



**High temperature Dilatometer & Fully Automated Cryogenic Temperature Calorimeter**



**Carbon Sulphur Analyser System developed at BARC**

measurement in the temperature range from 10 to 300 K, requiring small amount (0.5-2 g) of solid sample for characterization.

The fully automated PC controlled Carbon Sulphur Analyser is designed for the analysis of steel and other solid samples for the determination of carbon and sulfur contents simultaneously.

It is based on melting of the sample by induction heating in oxygen atmosphere and measurement of the resultant CO<sub>2</sub> and SO<sub>2</sub> gases using selective IR detectors. It provides quick and precise analytical results. After performing the necessary calibration checks and analytical performance tests, the Carbon Sulphur Analyser has been deployed for routine sample analysis.

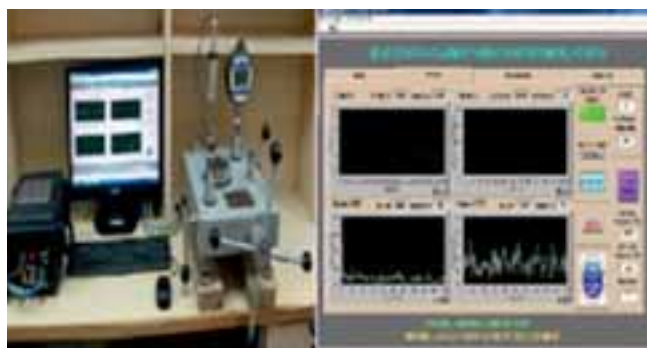
Satellite Communication SatCom terminal provides a stable and uninterrupted full-duplex communication link between Ground Control Station and the airborne vehicle through a geostationary satellite. Antenna is stabilized against Airborne Early Warning and Control System (AEWACS) body attitudes to point continuously in the direction of satellite with polarization matching. The 0.45 M Sat com terminal jointly developed by ECIL-BARC was installed on DRDO's indigeneous AEWACS and flight trials were carried out successfully.



**0.45 M Satcom Terminal**

BARC in collaboration with IIT Bombay has developed Parallel Model Checker (ParMC) Software for Hardware Description Language (HDL) designs that makes use of parallel computing systems in order to improve the scalability of model checking algorithms. Such software tools falls under technology denial regime. ParMC presently runs on the Anupam computer cluster in BARC. The software has been evaluated on a number of designs from DAE and on public-domain benchmark designs.





**Real time data processing and monitoring System for pressure pulsation & vibration Measurements**

Portable data processing and monitoring system for pressure pulsation and vibration measurements in Reactor Inlet Header (RIH) has been developed for Nuclear Power Plant. The system interfaces directly with the pressure transmitter and vibration sensor and performs real-time analysis to compute pump vane passing frequency and amplitude of pressure pulse. One prototype unit has been developed and measurements were taken at Reactor Inlet Header (RIH) of TAPS-3 and TAPS-4.

Five-zone induction heating furnaces are used in vitrification process for nuclear waste immobilization at WIP, Trombay. Electrical power to each zone of these furnaces is fed by an induction heating inverter. Ten units of inverter were integrated & commissioned with two numbers of furnaces.



**Induction heating inverter**

A new neutron powder diffractometer-I with a multi-detector system consisting of  $^3\text{He}$  neutron position sensitive detectors has been installed and commissioned at the beam hole TT-1015, of Dhruva reactor under National Facility for Neutron Beam



**The neutron powder diffractometer PD-I at the Dhruva reactor**

Research (NFNBR). The diffractometer is available for in-house as well as external researchers for the investigation of magnetic materials over a temperature range of 2 K to 320 K.

Capability of the Raman spectroscopy laboratory has been augmented with a high throughput and high resolution micro-Raman spectrograph resulting in opening up of new domains of Raman mapping, simultaneous Raman and optical microscopy, access to Raman spectroscopic information of the excitations over the sub  $100\text{ cm}^{-1}$  frequency region. High resolution Raman spectroscopy is used to investigate 2D layered materials, in particular; characterization of layer numbers, interlayer coupling and layer-stacking.



**Micro-Raman spectrometer**

A Time of flight – Secondary Ion Mass Spectrometer (TOF-SIMS) was developed for the routine use of scientists from all over DAE and other Industry. Development of Hemispherical Energy Analyser for the X-ray Photoelectron Spectrometer for



analyzing and detecting photo-electrons generated from X-ray bombardment on sample surfaces was developed indigenously. Diode Ion Pump based ultralow level  $H_2$  detectors for PFBR has been developed. Five systems have been manufactured and supplied to IGCAR, Kalpakkam. The detector works in the range from 80 ppb to 2500 ppb of  $H_2$  in air or steam environment and used as a first level safety system in the Fast Breeder Nuclear Reactors.

Three  $H_2$  sensor units have been delivered to DRDO and two of their personnel have been trained for



**$H_2$  Sensor Units**



**Purnima neutron generator**



**High current RF ion source**

installation and operation of these sensors. A Table top gas sensing unit has been developed that records responses from 16 gas sensing elements simultaneously at user defined operating temperatures and the technology has been transferred to industry. Purnima neutron generator has been upgraded to improve the stability of neutron yield. A high current RF ion source has been developed to produce deuteron beams up to 1 mA for the development of high intensity neutron generator. A system for special nuclear material detection through active interrogation technique using portable neutron generator has been developed.

A collimated neutron beam of 5 mm diameter having flux  $\sim 3 \times 10^8$  neutron/cm<sup>2</sup>/sec has been obtained for nuclear spectroscopy studies using beam-line R3001 at Dhruva reactor.

Technology Transfer of the following import substitute products to industry was carried out. High stability 5 kV high voltage module for analytical instruments, Full range Vacuum gauge (FRVG) and controller for measurements of low pressures from atmosphere to  $10^{-9}$  mbar, Compact Triode Sputter Ion Pump Power supply, Technology for growth of CsI:TI single crystal and Technology of Gas sensing unit which can record responses of 16 sensors at different temperatures.

The technology development of 'Indian Cargo Scanner' has been undertaken in Phased manner. Recently Phase 3 has been successfully demonstrated in house utilizing the diverse expertise of various Groups



**'Indian Cargo Scanner' Phase 2 & 3 accomplishments'**

in BARC and a setup as shown in the picture was specifically developed to demonstrate the technology. Phase 4 & 5 have are underway to demonstrate the technology at a sea-port.

The technology of air-plasma torch has been utilized to demonstrate conversion of cellulosic and electronic waste as a solution to municipality waste treatment besides their usage for in-house applications. The air-plasma torch, a patented development underway, has been utilized for the efficient reduction of the volume (typically 1 to 5 %).

12-channel Tele-ECG is a compact ECG machine which gets connected to a mobile phone through Bluetooth and records all 12-channels of ECG simultaneously. Device uses mobile network and is ideally suited for rural health care. Body Composition Analyzer (BCA) is an instrument to measure the proportion of various components (viz. water, protein, fat and minerals) of human body. These technologies were transferred to private domain.



**12 Channel Tele ECG**

## Cryogenics

Compact brazed aluminium plate fin heat exchanger have been developed through a local vendor for the operation of 50 lit/hr indigenous helium liquefier.



**Brazed aluminum plate-fin heat exchanger**

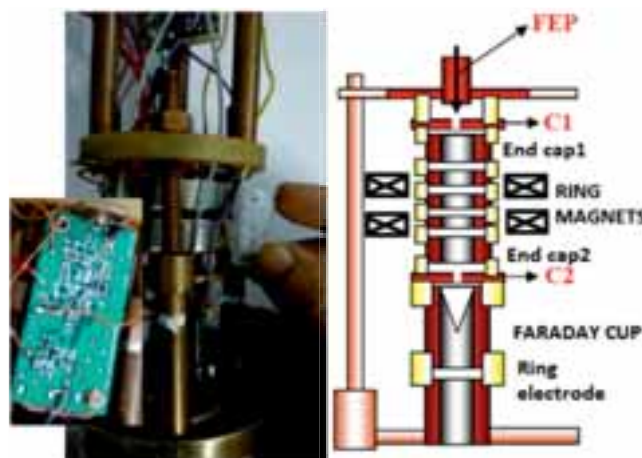
A train consisting of six heat exchangers has been integrated in the helium liquefier and trial runs are in progress. This development will help in import substitution of medium size helium liquefiers.

A method has been conceptualized for storage and transportation of fruits and vegetables using liquid nitrogen. This system has been tested for the temperature between  $-50^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ . This system is expected to have an advantage of simple manufacturing process and low operating cost.



**Table top version of the liquid nitrogen powered cold capsule for the reefer application**

A cloud of electrons has been successfully trapped at both the room temperature and liquid nitrogen temperature using an indigenously developed Penning trap and detection electronics system is shown in the picture. The performance of the indigenously developed detection electronics for Cryogenic Penning Ion trap operating at 4K is being studied. VECC cryogenic Penning Ion trap being developed for precision mass measurement and beta decay studies will be operated at 4K.



**Penning Ion trap assembly**



## 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.

Regular production and supply of various radio isotopes for medical, industrial and allied research applications continued in BARC.

20  $^{55}\text{Fe}$  X-ray sources (1.48 MBq each) were supplied to ISRO, Bangalore for use in Chandrayaan mission. 6  $^{55}\text{Fe}$  X ray sources (3.7 MBq each) were supplied to Physical Research Laboratory, Ahmedabad for space applications. Ce-141 sources (0.9 - 2.4 mCi) were supplied to RMC, TMH and KEM Hospital, Mumbai for use as structural marker in nuclear imaging procedures.



20  $^{55}\text{Fe}$  X-ray sources

Supply of I-125 brachytherapy seeds was continued for the treatment of eye cancer. Totally, 7 consignments consisting of 102 nos. of I-125 seeds in the activity range of 3.0- 3.9 mCi of I-125 were supplied to approved oncology centers.

## AGRICULTURE

### Crop Improvement

In breeder seed programme a total of 272 quintals breeder seed of 7 Trombay groundnut varieties (TAG 24, TG 37A, TG 38, TG 39, TPG 41, TLG 45 and TG

51) were produced and distributed to seed growing agencies like National Seed Corporations, State Seed Corporations, seed companies and farmers in Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Odisha and West Bengal.

Two black gram entries (TJU-67 and TJU-134) and a Mungbean entry TMB-136 were promoted to Advanced Varietal Trial (AVT-I) in MULLaRP spring trials for North-East Plane Zone. Two black gram selections (TRCRU 339 and TRCRU 22) recorded 40% more seed yield than the check DU 1 in multi-location trials (MLTs) and showed resistance to Yellow Mosaic Virus (YMV) during summer at University of Agricultural sciences (UAS), Raichur. TMB-146, TMB-141 and TMB-147 were found promising in MLTs for summer season in UAS, Raichur. Twenty four new crosses were made between genotypes resistant to YMV and powdery mildew diseases. Six lines with low phytic acid (4.97-6.89 mg/g), large seed size (>6 g/100 seeds) and high yield were identified. Large seeded and high yielding variety BGS-9 was irradiated with different doses of gamma rays to develop YMD resistant mutants. Twenty new selections with YMD resistance were identified.

Three very large seed size transgressive segregants (>30 g/100 seed weight) were identified in the F3 generation of the crosses PGCP-11 x TC1-26-E and PGCP-5 x TC1-26-E. Five high yielding lines (>40 g/plant) were identified in F5 generation and 9 high yielding lines were identified in F4 generation of the



Trombay Linseed Early Maturing Mutant





**Trombay Soybean Root Rot Disease Resistant Mutants**

cross PGCP11 x TC1-26-E. Monogenic dominance nature of resistance against CABMV virus disease was confirmed. Two early flowering segregants 5-3 and 10-9 from the cross PGCP11 x TC1-26-E were identified in F3 generation. Thirty-three high yielding plants (>40 g/plant) with more number of branches, white seed coat colour and early maturing (65 days) have been identified in F3 generation of the cross TC201 x RC101. Positive correlation was observed between Raffinose Family Oligosaccharides (RFOs) and Phytic Acid (PA) with drought contributing characters.

Screening of 100 soybean mutant lines for low phytic acid content was carried out. Two mutants lines TSG-62 (7.59 mg/g) and TSG-66 (9.62 mg/g) showed significant low Phytic Acid content as compared to the parent JS 93-05 (20.19 mg/g). Development & evaluation of 168 high yielding lines from PK-564 X DSB-12 and SL-742 X DSB-12 were conducted.

Development & evaluation of 122 good recombinants of three-way and double cross was carried out. Breeder seed multiplication programme of soybean varieties TAMS 98-21 and TAMS-38 was undertaken at Trombay and 5 kg seed of TAMS 98-21 and 2kg seed of TAMS-38 were produced. Low linolenic acid line TL-99 is promoted to AVT-1 in ICAR trials. Identification of early maturing mutant TL-142 with high yield and Identification of yellow seed mutant with high yield achieved.

Trombay Chhattisgarh Dubraj Mutant -1 (TCDM-1) rice was identified for release by UVIC of IGKV, Raipur in 2017 and proposal was submitted for release



**Field view of 'TCDM-1'**



**BARCKKV-13 (pre-released for Konkan, Maharashtra)**

to Chhattisgarh SVRC. TCDM-1 has yield advantage of more than 35% over Dubraj with semi-dwarf plant stature and enhanced tillering. One rice selection, BARCKV 13 was pre-released for Konkan region in medium slender and quality grain trials of Maharashtra State Rice Coordinated Trials, 2017. It has 19% higher yield over regional check variety Karjat 4. BARC rice selection, BARCKKV 13 was tested under farmer's field trial, agronomic trial in Maharashtra and AICRIP-2017 trial in all India, so as to facilitate the release in 2018 for Konkan region. Four rice selections were promoted in

AVT Quality of MSCRIP 2017 viz., TKR19, 20 and 21 (14-18 g test weight category) and TKR22 (below 14 g test weight) in Maharashtra. One of salt tolerant rice selections BARC KKV 16 was promoted to AVT salinity trails in the coastal centres of Maharashtra with more than 10% yield advantage and better salinity over state check variety Panvel 3.

BARC rice selections viz., TRR 101, 102, 106 and 107 are under AVT in Chhattisgarh. 5 rice mutants of Dubraj, Jawaphool and Safri 17 jointly developed by BARC and IGKV, Raipur were entered in Chhattisgarh State rice trials and 2 mutants of Dubraj and Safri-17 were entered into AICRIP 2017. Association mapping for different agronomic, quality and micro-nutrient of rice grain was completed in 218 traditional landraces of Chhattisgarh.

Standardization of dose rate for proton beam irradiation was completed and proton beam induced mutation breeding programme was initiated for rice varieties IBD 1, CSR 27 and Samudra Chini. Gamma ray induced mutation breeding programme was initiated for drought tolerant rice variety Dagardeshi. Mutation breeding programme was jointly initiated between BARC and DBSKKV, Dapoli to develop dwarf and early maturing rice mutant varieties in Vada Kolam and Mashuri rice varieties.

Improvement of yellow rust resistance in Indian wheat using induced mutations was carried out. Gamma ray induced mutant lines (M5) with enhanced resistance to yellow rust were developed in DBW-88 back ground and are being evaluated at IIWBR, Karnal.



**Yellow rust resistant mutant lines  
in DBW-88 background**

The M2 population (in recently released wheat varieties WH-1105 and HD-296) was raised at IIWBR Karnal and will be screened for resistance to stripe rust. Using Induced mutation, an early maturing mutant in C-306 was developed which allows escaping terminal heat stress. Using marker assisted selection (MAS) the earliness trait is being combined with rust resistance. Rust resistance gene Sr24/Lr24 was transferred from a closely related wheat variety HW-2004. Currently F4 lines are being evaluated for rust resistance and earliness trait.

For understanding the molecular basis of rust resistance, transcriptomics analysis of NILs of stem rust resistance gene Sr24 was carried out. Important genes responsible for disease resistance were identified and some important candidate genes are currently being validated using qRT-PCR.

In sugarcane, two radiation induced mutants of cv. CoC671 and Co 86032 (TAKS) entered into State level yield trials. Promising 16 mutants of cv. Co 86032 were multiplied for undertaking multi-location field trials at IGKV, Raipur and BARC field facility, Vizag. Induced mutants of cv. CoC85 (from Punjab University, Ludhiana) were evaluated for yield and quality traits.



**Promising mutants of sugarcane cv. Co-86032**



**Field view of TJP-1-5 sorghum mutant showing  
pearl white seeds possessing 100 seeds  
weight of 4.1 g as against control plants**



Mutation breeding using Gamma rays and EMS has been implemented in the improvement of post-rainy season sorghum for increased grain and fodder yield with better seed qualities. Advanced generation mutants of TCS-3002, TJP-1-5, TDSV-4, TJBV-44-1 and TJS-11-10 showed high grain yield (90-120 g/plant) against check 80 g/plant), bold seeds (3.9-4.1g/100 seeds against check, 3.5 g/100 seeds) and tolerance to charcoal rot disease.

In order to induce favourable mutations for physiological, yield and biofuel related traits, 1585 M2 plant progenies were evaluated at Experimental Gamma Field Facility, BARC, Mumbai, during 2017.

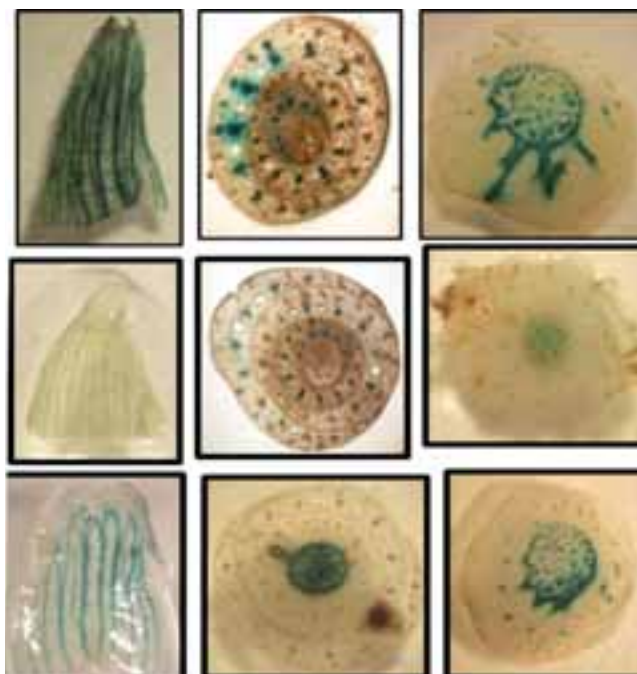
In foxtail millet, several promising mutants of var. PS4 were evaluated for yield in IVT and AVT of AICRP. Blast screening of mutants of var PS4 and Var. Prasad, Mineral content analysis and resistance starch profiling of promising mutants was undertaken. In mutation breeding programme for moringa, variety PKM-1 was treated with different doses and LD<sub>50</sub> was found to be around 400 Gy.

A rapid and convenient gel free system for screening single locus molecular markers based on SYBR green dye melt curve was developed. The method was demonstrated for markers linked to disease resistance, STMS markers etc. in both wheat and rice.

Ion beam irradiation has shown to be a potent tool for induced mutagenesis studies in plant breeding. H<sup>+</sup> beam irradiation was optimized in wheat using Pelletron Linac facility at TIFR. Mutagenized population of wheat variety NIAW-301 was created using 14 MeV proton beam, and currently M1 is being raised at ARS Niphad.

A Visual colorimetric biosensor kit was developed for qualitative detection of pesticides belonging to organophosphate & organocarbamate groups. An indicator was selected and optimized for integrating with acetyl cholinesterase enzyme inhibition based assay. In this kit, a colour codes were optimized. Currently this kit is optimized and calibrated for eight pesticides viz; organophosphate (Methyl parathion, Parathion, Monocrotophos, Malathion, Phosphomidon & Chlorpyrifos) and organocarbamate (Aldicarb & Carbaryl) in relation to their MRL value.

The Giant Cavendish radiation induced dwarf mutant suckers of 8 lines and 50 tissue culture multiplied mutant plants were sent to National Research Centre for Banana, Trichy, Tamil Nadu for evaluation. Gamma irradiated populations of Karibale Monthan variety of banana was raised and sent to NPCIL, Kaiga for evaluation. Banana embryogenic cell suspensions of Grand Naine and Rasthali were multiplied and used for different genetic transformation experiments.



**Analysis of transgenic banana harboring PMusaVND1 :: GUS , PMusaVND2 :: GUS and PMusaVND3 :: GUS. Transgenic banana harboring PMusaVND3 :: GUS was generated and different organs were stained with GUS staining buffer to study the tissue specific activity of these promoters. Note the xylem specific activation of these**

For increasing the iron content in banana, transgenic banana plants were regenerated with OsNAS1 and 9 transgenic lines of Gran Naine was grown up to fruiting and analyzed for the amount of iron in the fruits. Transgenic lines showed higher iron content in the fruits compared to control untransformed plants.

Mosquito larvicidal biopesticide formulation has been field tested in collaboration with municipal corporations of Mumbai and Chennai. The scale up of biopesticide has been successfully achieved using 1000 L industrial scale fermenter.



Mass rearing of melon fly is standardized. Radiation dose was optimized for inducing sterility in melon fly males. Sterility (>99%) was induced when melon fly pupae were irradiated at 70Gy.

A method has been developed in which garden waste is composted by the application of a formulation based on cellulolytic fungi *Trichoderma koningiopsis*. Dry leaves, including coconut leaves, were composted in 6 to 8 weeks by its application. The compost generated in this process is high in carbon content and water holding capacity. Hence it will be beneficial in enriching organic matter depleted soil and can be used as a soil conditioner. A total of 25 kg of formulation was made in the laboratory and used to process around 2000 kg of dry leaf matter at demonstration sites at TIFR Colaba and Kamgar Nagar Cooperative Housing Society, Kurla, Mumbai.

Taguchi optimization was carried out to increase the conversion efficiency of Kitchen Waste Oil (KWO) to Fatty Acid Methyl Esters (FAME). Using optimized conditions, FAME synthesis was carried out from KWO. The reaction was scaled up from 25 ml lab setup to 20 litre batch reactor.

## FOOD PROCESSING

One 10 MeV linac for irradiation of agricultural products has been already installed at the ARPF site near DABH fruit & vegetable mandi, Indore. The second linac to go here is under final testing.



**6.0 MW microwave system and electron gun installed at ARPF**

This year irradiation experiments on agricultural products with the electron beam facility were carried out for several users. These included several varieties of rice, ground nut and tuberose bulbs. These were irradiated in a wide dose range from 20 Gy to 500 kGy using 10 MeV electron linac. Further, bio-fertilizer samples, medicinal samples, medical samples, jute



**Electron beam irradiation of rice seeds**



**(A) E-beam Irradiated Ground nut TG 26  
(B) Parent and mutant large pod size in M6 generation.**

fabric and semiconductor materials were electron beam irradiated for various end use application experiments.

Quince fruit of Oblong variety after harvest was irradiated in the dose range of 0.3-2.1 kGy for extension in shelf life and delaying in ripening. The results indicated the control (unirradiated) fruits started decaying after 20 days of ambient storage while as fruits irradiated in the dose range of 1.8-2.1 kGy showed no signs of decay up to 40 days of storage.

A novel process was previously developed for shelf life extension of litchi at BARC. Based on this technology, a plant having a high throughput machine of 1 ton/ h treatment capacity was set up and commissioned at NRCL, Muzaffarpur by BARC-DAE and National Research Centre on Litchi (NRCL-ICAR). 15 tons of litchi fruits were processed at this facility. A DAE-Centre of Excellence was established at NRCL, where the products & technology of societal relevance developed by DAE is displayed.

A technology was developed for preparation of de-bittered karela juice having high bioactivity. The technique involves use of GRAS chemicals and enzymes. De-bittered juice has better sensory acceptability than other commercially available products, 40% higher anti-diabetic potential and a shelf life of one year.



***De-bittered karela juice***

Prebiotic idli using combination of moong dal, rice and irradiated (25kGy) psyllium husk powder was prepared. Sensory evaluation showed that the overall acceptability of the idli is comparable with traditional idli made from rice and urad dal. A probiotic chutney (lacto



***Prebiotic Idli***

chutney) was also developed to serve along with idli. The chutney is nutritionally rich and prepared using fermented ragi-soy combination slurry along with ingredients like roasted dal, coconut, ground nut, green chilli and coriander leaves. The taste was found to be well acceptable.

A Naso-Gastric Liquid Feed formulation (NGLF) in the form of ready-to-eat soup powder was developed for immune-compromised patients. It consists of cereals, pulses and vegetables and can provide balanced nutrition to such patients. The NGLF powder was irradiated for microbial decontamination. Nutritional as well as health beneficial activity (in terms of antioxidant properties and anti-mutagenic potential) was found to be well retained during storage.

A ready-to-eat product called Stuffed Baked Food (SBF) for natural calamity victims and the responders of the National Disaster Response Force (NDRF) was developed, which can be stored at ambient temperature up to 8 months. The developed product was tested by different units of NDRF and recommended for procurement.

A combination treatment was developed which includes ultrasonication, blanching, ascorbate dip and gamma irradiation to ensure microbial safety and extended shelf life up to 35 days for moong and chickpea sprouts and 21 days for alfalfa sprouts, when stored at 4°C. Nutritional, physico-chemical and sensory qualities were well retained in processed and stored samples; anti-nutritional factors were found to be significantly reduced. The developed combination could be an effective strategy for ensuring safety with better shelf life of these sprouts.



***A combination treatment of ultrasonication, blanching, ascorbate dip and gamma irradiation to ensure microbial safety and extended shelf life for moong and chickpea sprouts and alfalfa sprouts***

Xanthan gum is a polysaccharide secreted by the bacterium *Xanthomonas campestris* and is used as a thickener, stabilizer, emulsifier and rheology modifier



in food, cosmetics, oil, and pharma industries. A process has been developed for production of xanthan using a BARC-isolate of *Xanthomonas* and a semi-synthetic production medium which made this process cost effective. The technology has been transferred to a private firm.

Safety of irradiated foods issue was addressed through comprehensive molecular studies. Mutation analysis was performed in *E. coli* (up to 3000 generations) and in human lymphoblast line (up to 100 generations). No induced mutagenesis was observed in these cells due to various irradiated foods [Stuffed baked food (15kGy), Pulses (1 kGy), honey (25 kGy), Pepper and Coriander (10 kGy); Flesh foods (25 kGy-70 kGy): Mutton, chicken, pomfret, rohu and shrimp]. Similarly, no DNA damage was observed and DNA sequence was found to remain unchanged. Thus the findings affirmed the safety of irradiated foods which should boost the confidence of consumers.

## Radiation Processing 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.

During the current financial year, until December 2017, 3654 MT of spices and other products were processed. During next three months, facility is expected to process approximately 5000 MT of various products.

Surveillance audits for ISO-22000:2005 (Food Safety Management Systems) and ISO 9001:2008 were carried out at RPP, Vashi Complex, by certifying agency and was found to be in full compliance with the standard requirement.

Additional revenue obtained from GRPS related products and services were towards the production &

supply of 1.5 Lakh Ceric-Cerous Sulphate dosimeters to the various gamma irradiators in the country for absorbed dose measurements.

International order for supply & installation of 125 kCi Co-60 sources was received from Sri Lanka Atomic Energy Board. Work was successfully completed.



**Installation of 125 kCi Co-60 sources for  
Sri Lanka Atomic Energy Board**

Activities at Dosimetry Group of RPP included the Export of 2500 Nos. of Ceric-Cerous Sulphate dosimeters to Atomic Energy Regulatory Board, Sri Lanka Atomic Energy Regulatory Board, Sri Lanka. Also, 2000 dosimeters were exported to AERE, Bangladesh for their gamma irradiators for absorbed dose measurement in radiation processed medical and food products; Radiation Processing Plant recommissioning dosimetry was carried out in six plants in the country for low, medium and high dose application. Dosimetry for mango irradiation was carried out at M/s Irradiation Facility Centre, Vashi, for approval of the facility by USDA – APHIS for quarantine purpose; Plant recommissioning dosimetry was carried out for the sterilization of medical products and for microbial decontamination of spices at Sri Lanka Gamma Centre, Sri Lanka; Dose rate certification of two Blood Irradiators supplied to various cancer hospitals and three gamma chambers supplied to research universities was carried out; NABL accreditation for calibration of dosimetry laboratory was renewed till 2019 and Dosimetry studies of the radiation processing plant at Dry Sludge Irradiation Plant at Ahmedabad, Gujarat, and at SARC, Innova Plant at Delhi.



## New MoU for Radiation Processing Plants in Private Sector

A MoU was signed with M/s. Andhra Pradesh Med Tech Zone, Visakhapatnam, for setting up of Gamma Radiation Processing Plant for disinfestations, shelf-life extension of food products and sterilization applications of healthcare products. A MoU was signed with M/s Jamnadas Industries Pvt. Ltd., Dahod, Gujarat for a setting up of Radiation Processing Plant for disinfestations of food products and sterilization of healthcare products at Indore, Madhya Pradesh.



*A MoU was signed with M/s. Andhra Pradesh Med Tech Zone, Visakhapatnam*

## 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 radiopharmaceuticals 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. I-vitro Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) Kits and C-14 Urea capsules are used mainly for diagnostic use.  $^{18}\text{F}$ -Fluoromisonidazole (FMISO) is also produced, but the requirements for these are limited.

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  $^{99\text{m}}\text{Tc}$ ,  $^{68}\text{Ga}$  and  $^{188}\text{Re}$  radiopharmaceuticals.

$^{131}\text{I}$  as  $\text{Na}^{131}\text{I}$  is one of the important isotopes used for various thyroid disorders. Approximately 500 Ci of  $\text{Na}^{131}\text{I}$  and over 22500 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).

Currently, I-131 labelled therapeutic product, I-131-Lipiodol, which is used for the treatment of Hepatocellular Carcinoma, the most common type of Liver Cancer (single patient dose is 75mCi of I-131), was produced by RPhD, BARC and is supplied through BRIT in the reported period.



*Production facility of I-131 Lipiodol at RPhD, Vashi Complex*

Amongst the other therapeutic products supplied by BRIT includes Sm-153-EDTMP for bone pain palliation and new product, Lu-177-DOTA-TATE for treatment of metastatic (somatostatin receptor positive) Neuroendocrine Tumors (NET) which is launched by BRIT during the reported year. ~26 Ci in 256 consignments were supplied to nuclear medicine centres all over India until December 2017.

Another new alternative therapeutic radiopharmaceutical for bone palliation, Re-188-HEDP injection (as a part of technology transfer from RPhD, BARC) is expected to be launched by BRIT in collaboration with RPhD, BARC, by March 2018.

Factory acceptance test was performed for 2" thick, GMP compliant, lead shielded facility for the production of I-131 mIBG and other therapeutic radiopharmaceuticals. Some improvements in the in-cell gadget setup are suggested which would be completed by March 2018.

During the year 2017, more than 80000 cold kits for formulation of  $^{99m}\text{Tc}$  radiopharmaceuticals (19 products; BRIT Code-TCK) were formulated, lyophilized, QC tested and supplied to various nuclear medicine hospitals all over India.

Radiopharmaceutical Committee (RPC) approval is also obtained for the extension of shelf-life (expiry date) of Technetium-99m cold kits, namely, DTPA and Phytate injections, from the existing one year to two years.

Production of 'Kit for the preparation of  $^{99m}\text{Tc}$ -HYNIC-TATE injection', useful for imaging neuroendocrine tumors (NET), especially carcinoid tumors, started as a part of technology transfer from RPhD, BARC.

Nearly 450 Ci of  $^{99}\text{Mo}$ , in 2500 generators in form of Sodium Molybdate solution, for solvent extraction generator, Coltech generators and Geltech generators is supplied till December 2017.

More than 2,50,000 In-vivo diagnostic investigations are estimated to have been carried out this year with varied diagnostic radiopharmaceuticals, the major one being,  $^{99m}\text{Tc}$  based cold kits and  $^{99}\text{Mo}$ - $^{99m}\text{Tc}$

generator systems and around 17000 therapeutic applications are estimated to have carried out during the reported year using BRIT therapeutic radiopharmaceuticals including  $\text{Na}^{131}\text{I}$  for treating hyperthyroidism and thyroid cancer therapy.

The Medical Cyclotron Facility (MCF), Parel continues the production and supply of Positron Emission Tomography (PET) radiopharmaceuticals, mainly  $^{18}\text{F}$ -FDG and  $^{18}\text{F}$ -Sodium Fluoride and to a lesser extent  $^{18}\text{F}$ -Fluorothymidine (FLT) and newly launched  $^{18}\text{F}$ -Fluoro Ethyl-L-Tyrosine (FET). Regular and uninterrupted supply of about 545 consignments of PET radiopharmaceuticals such as  $^{18}\text{F}$ -FDG,  $^{18}\text{F}$ -NaF,  $^{18}\text{F}$ -FLT, and  $^{18}\text{F}$ -FET to various hospitals in and around Mumbai accounting for nearly 253 Ci of radioactivity during the year upto December 2017. More than 15000 patients benefitted with PET investigations in the reported year. Renewal of operation license for operating the medical cyclotron was obtained upto December 31, 2021. PET radiopharmaceuticals are now supplied to new users such as Breach Candy Hospital, HCG Apex, MPCT etc along with the users of PET radiopharmaceuticals already procuring from BRIT.

A clinical-scale (18.5 GBq)  $^{99}\text{Mo}/^{99m}\text{Tc}$  generator was developed using indigenously produced  $^{99}\text{Mo}$  by direct neutron activation route in the Dhruva reactor. A high capacity advanced sorbent material, mesoporous alumina was used as the column matrix in the generator. Quality of  $^{99m}\text{Tc}$  obtained from the  $^{99}\text{Mo}/^{99m}\text{Tc}$  generator met all the requirements of quality for clinical use. The indigenously developed  $^{99}\text{Mo}/^{99m}\text{Tc}$  generator has got the approval of Radiopharmaceutical Committee (RPC) of DAE for manufacture and supply.

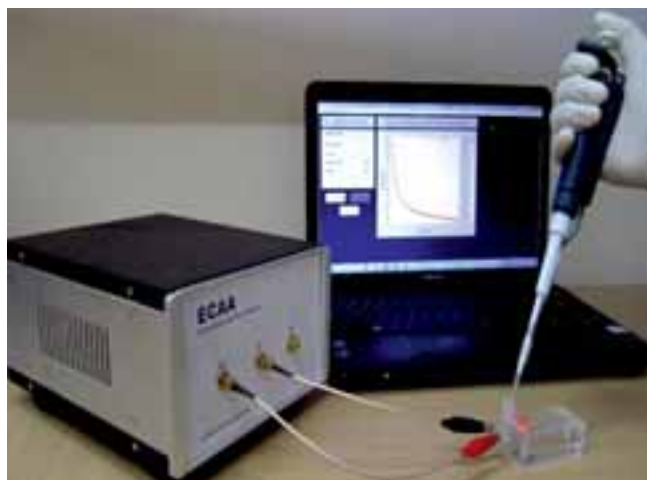
$^{131}\text{I}$  Lipiodol Injection is a therapeutic Radiopharmaceutical for Hepatocellular Carcinoma (HCC). Procedures for production and QC were developed at BARC and DAE-RPC approval was obtained for production and supply. Nine doses ((60-150mCi) were supplied to Nuclear Medicine centres for clinical evaluation studies. Twenty four and seventy two hour post injection scan reveal good retention of  $^{131}\text{I}$  activity in patient's liver indicating suitability of  $^{131}\text{I}$  labeled Lipiodol for further therapeutic evaluation.

A total of 14.1 TBq (382 Ci) of  $^{177}\text{LuCl}_3$  solution with adequate specific activity and purity was produced and supplied to 15 major nuclear medicine centres across the country. The radiochemical was utilized for the formulation of different  $^{177}\text{Lu}$  labelled therapeutic radiopharmaceuticals for cancer therapy using different ligands such as DOTATATE, Monoclonal antibodies, PSMA-617 EDTMP/DOTMP etc. More than 500 cancer patients have been given  $^{177}\text{Lu}$ -based therapy at RMC, BARC alone. Required technical support was also provided for the formulation of the  $^{177}\text{Lu}$ -radiopharmaceuticals at hospital radiopharmacy on request.

## Radiation technology equipment

### Portable Extra-Cellular Acidity Analyzer

Portable Extra-Cellular Acidity Analyser (ECAA) has been developed to differentiate cancer cells from normal cells in cancer diagnosis. The sensor is validated in mouse tumor tissues and is under testing for human tissues.



*Portable Extra-Cellular Acidity Analyser*

### 4D Dynamic Phantom System

Four-Dimensional Radiation Therapy (4DRT) is an advanced radiotherapy technique where temporal changes of anatomy during imaging, planning and delivery are monitored and accounted for to deliver the precise radiation dose to the moving tumour. The 4D dynamic phantom system is used for Quality Assurance (QA) of 4DRT systems. An improved 4D dynamic phantom system was designed and developed. This



*4D dynamic phantom system*

dynamic phantom system can locate the position of the moving tumour precisely during 4D CT imaging.

### A Unified Phantom

A unified phantom containing various test objects for performing comprehensive imaging QA tests on computed tomography (CT) scanners was designed and developed. This phantom consists of four modules which can be used for assessing high contrast resolution, low contrast resolution, image noise, CT number uniformity, CT number linearity and slice width of CT machine. The unified phantom can be used for performing all the recommended imaging QA tests of a CT scanner.



*Unified phantom for CT*

### Blood Irradiator

Five Blood Irradiators-2000 units with Cs-137 source (1600 Ci) have been supplied to hospitals in India during April 2017-December 2017.

### Radiography Camera

Production and supply of 46 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

Four units of GC-5000 was loaded with 47000 Ci of  $^{60}\text{Co}$  and transported to different institutions in India upto December 2017.

## Radio Diagnostic & Treatment Services

A total number of about 2200 radioimmunoassay (RIA) and immunoradiometric assay (IRMA) kits to serve about 1,22,450 in-vitro investigations, were supplied to various hospitals, research centres and immunoassay laboratories throughout India.

Regional centres at Delhi, Bengaluru, Hyderabad, Dibrugarh & Kolkata, continued the services of ready-to-use-radiopharmaceuticals to surrounding nuclear medicine hospitals, labelled compounds and radioanalytical certifications. 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 these cities.

At the Regional Centers for Radiopharmaceuticals (RCR), Kolkata, 304 Nos. of Technetium cold kits for formulation of  $^{99\text{m}}\text{Tc}$ -radiopharmaceuticals were sold this year (Apr. 2017 - Dec. 2017) to nuclear medicine centres at Kolkata.

Regional Center 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.

Regional Center, BRIT, Bengaluru supplied 75 Ci of ready-to-use  $^{99\text{m}}\text{Tc}$ -pertechnate to nuclear medicine hospitals and 851 TCK cold kits were sold through retail outlet and door delivery for the preparation of  $^{99\text{m}}\text{Tc}$ -radiopharmaceuticals to nearby nuclear medicine centers. Gamma irradiation services were provided for 617 blood bags to Kidwai hospital. Also, radioanalytical services for the measurement and

certification of residual radioactivity in various commodities such as food items for human & animal consumption, medicine, steel and other miscellaneous items were provided. Radioanalytical Laboratory analyzed and certified 110 samples for the measurement of residual radioactivity in various commodities such as food items for human & animal consumption, medicine etc.

Regional Centre for Radiopharmaceuticals, Delhi continued to supply clinical grade ready to use  $^{99\text{m}}\text{Tc}$ -radiopharmaceuticals in compliance with GMP and RPC for diagnostic nuclear medicine centres in Delhi and NCR regions. During the period, April 2017-December 2017, Regional Centre, Delhi has been involved in production & supply of 22.7 Ci of clinical grade, ready-to-use Tc-99m radiopharmaceuticals injections. The radiation protection procedure for operation and handling of  $^{68}\text{Ge}/^{68}\text{Ga}$  generator at Regional Centre, Delhi, has been applied to AERB for its clearance.

During the period, Regional Centre of BRIT, Hyderabad (Jonaki) continued to synthesize and supply  $^{32}\text{P}$  labelled nucleotides and a few molecular biology kits such as Taq DNA Polymerase, PCR master mix and enzymes, for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research of the country. It markets  $^{35}\text{S}$ -labelled amino acids products produced at BRIT, Vashi Complex. BRIT, has patented Fluorescence Resonance Energy Transfer (FRET) primer-primer method based on Real Time PCR Technology. In an attempt towards the commercialization of the patented method, its performance was validated for a) target detection of M.tuberculosis & b) mutation detection in Epidermal Growth Factor Receptor (EGFR) which is overexpressed in cancer tissues, thus helping in their early in-vitro diagnosis.

## Labelled Compounds and Diagnostic Kits

Labelled Compounds Programme of BRIT is involved in the synthesis & supply of a variety of  $^{14}\text{C}$ ,  $^3\text{H}$  and  $^{35}\text{S}$ -labelled products and various types of Tritium-Filled Self-Luminous sources. During 2017-18 upto December 2017, Labelled Compounds Programme has

supplied 15000 sources of 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. Custom synthesis of variety of labelled compounds along with  $^{35}\text{S}$ -labelled amino acids, having very high specific radioactivity and radiochemical purity, are also supplied. Labelled Compounds Laboratory is also engaged in the production and supply of  $^{14}\text{C}$ -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.

## Radio Analysis

Radioanalytical Laboratory (RAL) is carrying out the assay of man-made radioactivity in large number of food items, especially those meant for export. In addition to the above, Radioanalytical Laboratory carries out the measurement & certification of engaged in the measurement and certification of residual radioactivity content in water samples, uranium content in water samples, naturally occurring radioactive materials (NORMs) in environmental samples such as coal, fly ash, soil rock phosphate, gypsum etc. and Co-60 contamination in steel. Large numbers of environmental samples such as soil, coal, flyash etc. were analyzed during the year for the presence of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and 40K content.

During the year 2017-18, upto December 2017, RAL, Vashi alone has carried out more than 3000 tests on export/domestic commodities and 7000 tests on water samples (gross alpha, gross beta,  $^{226}\text{Ra}$  &  $^{228}\text{Ra}$ ). Radioanalytical Laboratory Services both, at Vashi Complex and RCR, Bengaluru, together performed approximately 4635 analyses of food and water samples for the presence of radioactivity.

## Radiation Sterilization Plant for Medical Products (ISOMED)

ISOMED facility, engaged in gamma radiation

processing services for terminal sterilization of the medical products has processed 3872 Cubic mtrs of products.

## New Projects

### Indigenous HDR Brachytherapy Equipment (IHDR)

Cold trial for HDR equipment is completed and the equipment has been tested with radioactive source as well. IEC compliance tests for HDR brachytherapy equipment; 'KARKNIDON' has been successfully completed. Certificates for the compliance of the equipment, IEC-60601-1-1, IEC 60601-1-2, have been received.



*IEC compliance test of HDR in progress*

Treatment Planning Software (TPS), exclusively for 'KARKNIDON' has also been received and the testing for the same is in progress by TMH, Parel and RPAD, BARC during the reported time. Approval for new design of miniature source housing Ir-192 has been obtained from AERB.



*TPS being evaluated at RPAD/BARC & TMH, Mumbai*

## Setting up of Fission based $^{99}\text{Mo}$ Production Facility

Civil construction of building is 90% completed & occupied. Civil modification to be incorporated so as to accommodate M/s. INVAP design layout of the processing equipment. Critical Design Review (CDR) has been completed & inputs have been implemented in design. Equipments are arriving at project site, 16 Shipping authorizations are given. Nine consignments containing SS hot cell boxes,  $\text{H}_2$  cell, overhead crane, special tubes & cables, MSM etc. already been received.



*External and Internal view of Fission Molybdenum Project (FMP) building*

## Advanced Facilities for Radiopharmaceuticals Production

The advanced Radiopharmaceutical Manufacturing and testing facility for new generation Radiopharmaceuticals with radioisotopes using  $^{90}\text{Y}$ ,  $^{177}\text{Lu}$ ,  $^{89}\text{Sr}$ ,  $^{131}\text{I}$ ,  $^{32}\text{P}$ ,  $^{153}\text{Sm}$ . etc. New Pharmaceuticals Services Facility area is commissioned. Hot cells in the Main Production Laboratory is refurbished and refitted with the new hot cells for production of new Ready-to-use Radiopharmaceutical product,  $^{177}\text{Lu}$ -DOTATATE injection.

## Biomedical Applications

A compact and portable computer based optical spectroscopic system was developed for screening of oral or cervical cancer.



*Tablet computer based, user-friendly cancer diagnostic system*



*Fluorescence imaging device for diagnosis of Tuberculosis*

A compact and portable fluorescence imaging device was developed for rapid diagnosis of tuberculosis (TB). It acquires fluorescence images of Mycobacterium tuberculosis bacteria (Mtb) from a patient's sputum smeared on a microscope glass slide following its staining with an appropriate fluorescent dye (Auramine O). The important advantage of the device is its significantly low cost  $\sim 1$  Lakh as compared to the fluorescence microscope (costing over 50 Lakhs).

A compact hand-held video microscope was developed for in-vivo imaging of micro-vasculature network and blood flow in human tissue. The tool is expected to be helpful in monitoring the onset and progression of various diseases like diabetes, septic shock, tumor etc.



*Hand held orthogonal polarization spectral imaging setup for in-vivo imaging of micro-vasculature*

An Inverse Spatially-offset Raman Spectroscopy (I-SORS) set up was developed for investigating the detection of urea adulteration in packeted milk samples. The results of this work indicate that the combination of inverse spatially offset Raman spectroscopy and chemometrics could be a promising tool for quantification of urea adulteration in packeted milk samples.



## Alternative Applications of Heavy Water

The first indigenously developed  $^{18}\text{O}$  production plant at HWP, Manuguru has reached the enrichment of  $^{18}\text{O}$  up to 39.3%. The first milestone of meeting the defense requirement has been achieved. The final product of desired quality as  $\text{H}_2^{18}\text{O}$  will find application in nuclear medicine and bio-chemical research i.e. in PET scanning and metabolic studies.



**O-18 Recombination Unit at HWP, Manuguru**

## 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 mission of TMC is to provide comprehensive cancer care to one and all, through the motto of excellence in its holistic services, continual education of medical and paramedical staff, and of research that is affordable and of relevance to our population. TMC is the main hub of over hundred centres that form a part of the Indian National Cancer Grid (NCG). The NCG has grown over a 5 year period and now boasts of 124 cancer centres across India. It has now become a strong, unified and powerful voice in the fight against cancer. Also a recent success as its offshoot, the Virtual Tumor Board (VTB) is a web-based

platform where upto 150 experts can log on at a predetermined time and date to discuss optimal treatment for patients across India.

The report of the 2nd International Peer review for TMC conducted in 2016 was tabled early this year. The review committee lauded the remarkable efforts by the institution in patient care that was comparable with that of western countries and also pointed out few lacunae for rectification.

Continuing its effort of taking TMC to the top 5 cancer centres in the world, a new program to “train the trainers” was instituted. It is the 360-degree evaluation of TMH medical faculty, to be conducted by an UK based professional agency. This will ensure maintenance of highest level of training imparted to fellows.

TMC is the Asian hub for the International Agency for Research on Cancer (IARC) and provides training facilities to other Asian countries on cancer registry.

The year saw the success of the TMC-Navya, the recently launched online second opinion services for the general population from cancer specialists.

The indigenous Bhabhatron, the Telecobalt radiotherapy machine, has been given to 20 centres till now and, has been used to treat a lakh of patients.

TMC has recently introduced a new specialized academic course, the KEVAT program in collaboration with Tata Institute of Social Sciences and the Tata Trust. This is an advanced diploma in Patient Navigation and aimed to providing patient-centric care to those afflicted with cancer.

TMH continued to provide services to cancer patients from low income families through the Mahatma Jyotiba Phule Jeevandayee Aarogya Yojana (MJPJAY) scheme launched by Maharashtra State from 1st April 2017. This scheme replaced the earlier Rajiv Gandhi Jeevandayee Aarogya Yojana (RGJAY).

The bed strength of TMH was 629 and 120 at ACTREC, with almost 70,000 new patients being registered; an increase of 3.85%. The institution manages more than 1500 patients daily and, almost 30,000 cancer patients were admitted for treatment.

There was also increase of second referrals for pathology slide reviews and for mammographic examinations. The majority of the patients come from the Northeast region of India; highest being from the States of Maharashtra and West Bengal. Mumbai contributes to almost half of the patients from Maharashtra State.

Progress has been made in keeping with the digital era in India by sending alerts through “sms” services to patients. The patients are notified and reminded about their appointments, finalized reports, sample rejection etc. More than 90% of our patients now deal in cashless transactions through the use of smart cards that we provided them with. The imaging department has become almost filmless and the hospital is paperless, except where legalities are involved. To facilitate locating various service and other areas within the campus, a new mobile phone based application – TMH Disha, was launched this year that works offline.

The surgical team of about 40 doctors expanded their reach by operating and providing their expertise in satellite centres in Sangrur, Visakhapatnam, Ratnagiri and Aurangabad. The Head & Neck surgical services are now being offered in the worlds' first hospital on train, the Lifeline Express or the Jeevan Rekha Express. More than 8, 000 major surgeries were performed. Till date, more than 700 Robotic assisted surgeries have been performed successfully.

The medical day care services for offering chemotherapy on outpatient basis continued to be a success and there was more than 20% rise in its utilization. The working of the paediatric medical oncology department was remarkable, as exemplified by the fact that the mortality rate was less than 10% and the treatment abandonment rate, less than 5%; a no mean achievement. Successful bone marrow transplantation was performed on 68 patients suffering from various types of blood cancer.

The clinical laboratories performed almost 45 lakh investigations. All the laboratories are accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL) and have implemented the External Quality Assessment Schemes (EQAS) to assess their own analytical performance. There was

almost 70% increase in the use of Molecular techniques for diagnosis, prognostification and prediction for solid tumors.

The Radiodiagnosis and Radiation Oncology departments are equipped with the state-of-the-art machines that provide faster and accurate disease assessment and treatment. The imaging department revealed an over 20% increase in its utilization. A new Digital Subtraction Angiography Suite was commissioned that replaced the earlier system that was consumed by fire.

Almost 30,000 patients were treated with Radiotherapy and the department is in the process of installing the latest Proton based therapy machine at ACTREC. The “Brain-Lab” facilitated Radiosurgery as noninvasive treatment for many brain tumors. Promise has been shown in the use of radioisotope tagged monoclonal antibodies for breast cancer and lymphomas. These isotopes may prove to be beneficial in their treatment in few years.

The Tissue bank, the largest and oldest in the country of the hospital provided over 10, 000 grafts to hospitals all over India. TMH was the first in the country to start a Pain management clinic that treats around 15, 000 patients annually for relief from pain due to cancer.

The institution strives to provide the best of education through its various teaching and postgraduate courses. There were 180 students for post-graduate courses. Inroads were made in super-specialization; new DM courses have been permitted in Interventional Radiology and Oncopathology, each having two seats. In addition to the 476 medical observers from across India, 32 foreign medical specialists came as observers to TMH from 19 countries. There were 114 graduate students pursuing Ph. D. degree in Life Sciences at ACTREC. The nursing training courses have become very popular and this year over 100 nurses enrolled for training.

The institution conducted 125 conferences, seminars and workshops. The staff publications numbered 386 (123 in National & 263 in International journals), and 2 books were authored. There were 149 research papers and 160 research projects were approved.

The Tata Memorial Hospital celebrated the 75th Year Platinum Jubilee 1941 – 2016). Various educational and social events were conducted for the same and the celebrations ended with the unveiling of the “Mumbai Declaration” and of the book titled, “Indelible Footprints on the Sand of Time” by the honourable Prime Minister, Shri Narendra Damodardas Modi on 25th May 2017.

The Homi Bhabha Cancer Hospital in Sangrur district of Punjab is functional and more than 4000 patients have been treated. The Homi Bhabha Cancer Hospital & Research Centre in Visakhapatnam continues to offer its services making use of some facilities of the Visakhapatnam Port Trust hospital and, treated over 2000 patients last year.

TMC officially took over the functioning of Dr. B. Borooah Cancer Institute, Guwahati in November 2017. The taking over of the Indian Railway Cancer Research Institute in Varanasi by TMC is complete and is expected to be fully functional by March 2018.

Work is in progress to set up the Homi Bhabha Cancer Hospital & Research Centre in Mohali, Punjab and the Mahamana Pandit Madan Mohan Malviya Cancer Centre in Varanasi.

### **<sup>60</sup>Co Teletherapy Sources for Cancer Hospitals**

Thirteen <sup>60</sup>Co-teletherapy sources with total activity of about 203 kCi in the range of 154 and 232 RMM were supplied to various cancer hospitals in India. Out of the thirteen CTS sources, two sources are exported to Kenya and Kyrgyzstan. Another nine sources are fabricated and ready for supply. Six sources with higher activity are planned to fabricate. Seventeen 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.

### **Cancer Awareness & Prevention**

TMC provides comprehensive cancer management through its various Disease Management Groups (DMG's) that apply evidence-based medicine guidelines to all patients, thereby, taking a step forward

to reach the goal of individualized management in cancer. The cancer care is comprehensive and begins from preventive measures, identifying high cancer-risk individuals, cancer education, early cancer detection, counselling to patients and their family, prompt initiation of appropriate therapy, socioeconomic support, rehabilitation, and palliation and towards End-of-life care. The government along with various philanthropic individuals and NGO's contribute socioeconomically in many ways to help the needy and also provide seed money to initiate treatment in deserving patients.

The recently completed TMC data analysis till year 2013 revealed that the incidence of cancer in males was of the mouth (buccal mucosa), leukaemia and lungs; and in females, it was of the breast, uterus (cervix) and ovary.

The Centre for Cancer Epidemiology (CCE) in Navi Mumbai is the first of its kind in the country that will identify cancer burden, its causative factors and formulate preventive strategies. This will be based on molecular studies using the first Biobank that will be an archive of various samples collected from across India. The main focus is on cancers of the breast, uterus, large intestine and gall bladder.

The Rural Outreach services continued with many camps in rural Maharashtra being conducted for screening of oral, lung, breast, upper digestive tract and uterine cervical cancers. Educative and social programs on tobacco and alcohol related to health and society, and its impact on cancer also continued. The Maharashtra State tied up with TMH to train rural doctors and other paramedical staff on cancer screening, chemotherapy administration and treatment protocols in 24 of their districts.

## **WATER**

### **Water Purification, Desalination of water & Isotope Hydrology**

BARC provided technical assistance in the installation and commissioning of two units of 500 m<sup>3</sup>/h Water Treatment Plant (WTP) at Holy Shiv Ganga Pond, Deogarh, Jharkhand. Hon' CM, Jharkhand inaugurated the WTP on 9th July 2017. The plant is performing well





**Water Treatment Plant at Holy Shiv Ganga Pond, Jharkhand**

and product water conforms to Indian Standards (BIS-2296) for outdoor bathing.

Multi Stage Flash (MSF) and Sea Water Reverse Osmosis (SWRO) desalination plants have been in operation. MSF plant produced 3,75,252 m<sup>3</sup> high quality water with less than 20 ppm TDS. Around 66,737 m<sup>3</sup> of MSF water was sent to Madras Atomic Power Station (MAPS) for its boiler feed make up water requirements. SWRO plant produced 97,557 m<sup>3</sup> of drinking water. Variable Frequency Drive (VFD) for 280 kW motor of SWRO high pressure pump A was installed, commissioned and taken online as energy saving initiatives.

In continuation to the ongoing project on radiation grafted adsorbent for treatment of waste water, two modular treatment setups were fabricated for efficacy demonstration of developed adsorbent. One of the setup is being tested for process parameter optimization for treatment of dye waste water in collaboration with textile industry at Surat.

Fluoride contamination in ground water above the permissible limit of 1mg/L is prevailing in several parts of the country. A safe, simple and low cost solution for remediation by removal of fluoride to make water potable using rare earth material as adsorbent has been developed. This method is superior to the other methods currently being employed such as Electrolysis, Membrane Filtration or RO systems due to its high capacity factor, absence of residual contamination or waste generation, low cost and non-electrical operation. The technology has been transferred to three entrepreneurs.



**Fluoride remediation demo plant at NCCCM**

Hybrid Biofilm-Granular Sludge (HBGS) technology was developed for treating industrial waste waters generated in DAE units. This new technology relies on the growth of microorganisms in the form of biofilms and biogranules (granular sludge) with faster settling abilities and offers compact layout and efficient treatment of wastewaters. The specific advantages of this system include smaller land footprint, lower capital and operational costs as compared to the conventional activated sludge process which is widely implemented in sewage treatment plants or effluent treatment plants. The HBGS technology removes organic carbon, nitrogen, and phosphorus from polluted water (i.e. sewage or industrial waste water) decreases colour, turbidity and microbial load in the sewage. The system concept was demonstrated in lab-scale bioreactors for formation of granules under different conditions and removal of various contaminants. Prototype pilot-scale sequencing batch reactor plants for demonstrating formation of Granular Sludge (GS) and Hybrid Biofilm-Granular Sludge (HBGS) are in operation for treating real sewage in the premises of DAE Township at Kalpakkam. Studies showed that HBGS technology is suitable for treating sewage and industrial effluents.

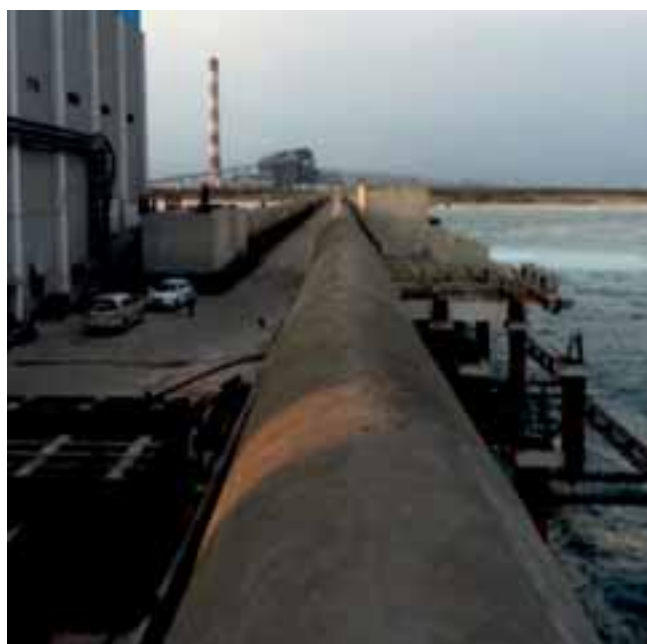
Cryogel filters of different polymer combinations were synthesized in monolithic form using radiation-co-cryogelation process and further surface functionalized with melanin using green-chemistry. Efficiency of these cryogel filters to remove U

in ppb concentration was studied. It reduced the U concentration from 100 ppb to 22 ppb at a flow rate of 5 mL min<sup>-1</sup>, which is below the acceptable limit of U in drinking water as per AERB guidelines. The results point to application of melanin-functionalized porous matrices as a potential filtration system for U removal. Optimizations for larger columns and flow rates are in progress.

## INDUSTRIAL APPLICATIONS

Co-60 based Radiography Camera using Tungsten & Depleted Uranium shielding has been tested and approval for Type B (U) Package has been obtained from AERB.

Radiotracer technique has been successfully applied for the first time in India to accurately measure the flow rate of water in two large diameter pipelines (dia: 3.6 meter) carrying sea water for cooling into a condenser of thermal power plant at Hinduja National Power Co. Ltd at Visakhapatnam, Andhra Pradesh. The technique helped to validate the efficiency of four different Vertical Turbine (VT) pumps (each of 12.5m<sup>3</sup>/s pumping capacity) installed at two pumping units and also to calibrate the installed flow meters. Short lived Iodine-131 based radiotracer was used for these experiments coupled with efficient, fast detector- data acquisition and analysis methods.



Pipe line of HNPCL, Visakhapatnam

## Radioisotope Sources supplied by BRIT

### Industrial Irradiator Sources

Sixty six irradiator sources with total activity of around 1101.54 kCi were supplied in eight consignments to various processing plants within the country. The irradiators to which these sources are supplied are namely, (a) AVPP, Ambarnath – 199081 Ci; (b) AIPL, Vasai – 154990 Ci; (c) SARC, Delhi – 124783 Ci (d) NIPRO, Pune – 199999 Ci; (e) Sri Lanka – 124462 Ci; (f) OGFL, Kolkata – 100000 Ci; (g) KRUSHAK, Lasalgaon – 97688 Ci and (h) Vietnam – 99999 Ci.

A total of 650 kCi of irradiator sources are planned to supply upto 31st March, 2018. These are: UML, Vadodra – 200 kCi; Aligned Industry, Bhiwandi – 120 kCi and MICROTOL, Bengaluru – 200 kCi and SARC, Delhi – 125 kCi.

### Radiography Sources

542 <sup>192</sup>Ir radiography sources with total activity 23693 Ci were supplied from April 2017-December 2017. Another 200 sources with activity 9500 Ci is expected to be supplied upto March 2018. Twelve Co-60 radiography sources with 662 Ci activity were supplied upto December 2017 and another two sources with 100 Ci is expected to be supplied upto March 2018.

### Custom Made Sources (CMR) and Reference Sources

Thirteen numbers of Custom Made Sources (CMR) of Co-60 with total activity of 739 mCi were supplied upto December 2017. Another four custom made <sup>60</sup>Co radiation sources with total activity of 250 mCi is planned to supply up to March 2018.

## Isotope Application Services

### Gamma Scanning of Process Columns

In the refinery of ESSAR Oil Ltd., Jamnagar, Gujarat, it was observed that the kerosene production was getting reduced to more than 40%, causing huge loss to the refinery. Gamma Scanning of crude distillation tower was carried out. To identify the cause, Gamma Scanning was done with the help of auto

column scanner. Heavy flooding was observed in the light kerosene section which could be due to dislodgement of tray and thus blocking the flow in down-comer.

Gamma Scanning and Flow Rate Measurement in PTA5 plant of RIL, Dahej, Gujarat was carried out.

Leak detection study from Heat Exchangers for Pollution Control was carried out in HPCL, Mumbai, HPCL, Vishakhapatnam, BORL, Bina, IOCL, Mathura



*Leak detection study from Heat Exchangers for Pollution Control*

refineries.

Radiometry tests of Spent Fuel Canisters and Discs for L&T have been carried out during 2017-18.



# CHAPTER BASIC RESEARCH

5



*Shri Giriraj Singh examining the plasma treatment  
of textiles (jute & khadi)*



*Installation of Medical Cyclotron at VECC*

The Department of Atomic Energy has contributed significantly towards strengthening of basic research in India. The Department pursues basic research in its R&D centers and aided institutions that ranges from Mathematics to Computers, Physics to Astronomy and Biology to Cancers. Following were the major activities and achievements of DAE in basic research, during the period of report.

## MATHEMATICS & COMPUTATIONAL SCIENCES

The non-continuum fluid transport (diffusion,  $D$ ) inside nanotube confinement has been linked with excess entropy ( $S_{ex}$ ). Results propose a universal scaling law that can be applied for all liquids and liquid mixtures inside Carbon Nanotube (CNT) confinement as well as in their bulk state. The equation captures the scaling relation for diverse set of hydrogen bonding fluids. Self-developed codes to estimate  $S_{ex}$  establish a fast alternate way of estimating excess entropy from power spectrum of diffusing liquid in scattering experiments. The proposed scaling relation would be very supportive for various related fields of liquid filtration, biological applications and nano technologies.

At the TIFR Centre for Applicable Mathematics, controllability (existence of a control to reach the desired state in finite time) for Linear viscoelastic flow models with variable coefficients in a bounded domain with interior control was studied. TIFR pursues research in pure (Algebra, differential geometry, number theory etc) as well as applicable mathematics.

Research work was pursued in the areas of computer science as well as systems science at TIFR. In the area of communication complexity an important open question about depth-2 threshold circuits was resolved. In communications networks, an optimal algorithm for choosing optimal server speed for utility maximization under job deadline uncertainty, was derived. In the area of Formal Verification, an algorithm for verifying array based programs was developed. A novel model of a biological system in cells called vesicle transport system (VTS), which has been studied by systems biologists was analyzed. In information theory, communication networks which can support

information theoretically secure computation were characterized. In the area of Mathematical Finance, simple and elegant approximate solutions to estimate default probabilities for corporates and consumers in real time were developed and rigorously analyzed. In applied probability a new approach to arrive at perfect samples for spatial Markov processes was developed. In the area of probabilistically checkable proofs in complexity theory, a new agreement theorem which extends direct product tests to higher dimensions is proved. In probabilistic computing, new algorithms for approximating partition functions that take inspiration from - and make new contributions to - the study of phase transitions in statistical physics were derived.

At IMSc, a new comprehension of certain distinguished bases for representations of the Lie algebras of traceless matrices and their current algebras were obtained. A new class of smooth manifolds, which are higher dimensional analogues of curves and surfaces that generalize the classical manifolds were studied.

The School of Mathematical Sciences (SMS) at the National Institute of Science Education & Research (NISER) continued to impart the mathematical programmes. In addition to formal courses and research, seminars were conducted regularly. In the seminars, outstanding mathematicians from throughout the world presented their latest research findings in various fields of mathematics. The major facility recently added to the research infrastructure was the High Performance Computing Cluster.

## PHYSICS

At TIFR, in the area of condensed matter, multimode superconducting circuits were shown to be viable as strongly coupled multi-qubit processing units. Magnetic anisotropy was shown to be an evidence of ferromagnetic Kitaev correlations.

In the area of cosmology and astroparticle physics, detailed studies of energy feedback in galaxy clusters to study the missing baryon fractions were performed. Dark matter and radiation interacting with neutrinos were shown to introduce a blue-tilt in the cosmological gravitational wave spectrum.



In the area of high-energy physics, a study of the physics potential of ICAL detector at the Indian Neutrino Observatory was completed. A universal framework for finding anomalous objects at LHC was constructed. Quantum numbers of recently discovered charmed baryons were predicted using lattice QCD.

In Astronomy and Astrophysics, ASTROSAT has been made open for observations for astronomers across India and abroad. All the detectors onboard ASTROSAT have been performing well in orbit and providing high quality data. TIFR Near Infrared Imaging Camera-II (TIRCAM2) was made available to the worldwide astronomical community for science observations since May 2017 under Early Science Cycle. The fabrication of TIFR-ARIES Near Infrared Spectrometer (TANSPEC) for 3.6-meter DOT is in an advanced stage. The Laboratory Model of the Infra-Red Spectroscopic Imaging Survey (IRSIS) satellite payload has been extensively tested and completed. Commencement of optical and mechanical design for a near-IR, multi-object spectrograph (MOS) for a large aperture (3.6-m & 10-m) ground-based Indian telescopes and for TMT. Conducted two successful balloon launches carrying TIFR far-infrared 100-cm balloon-borne telescope (T100) with a Japanese Fabry-Perot spectrometer (FPS) at the focal plane during February 2017 and November 2017. Two members of DAA contributed to the LIGO Scientific Collaboration and the Virgo Collaboration (LVC) efforts associated with GW150914 (the first detection of gravitational waves from merging black hole binaries). Conducted five balloon launches under BATIAL-2017 campaign using very small zero pressure plastic balloons of volume 300 cu.m and 3000 cu.m. Development of new load tape with 136 kg breaking strength with carbon fiber yarn as separate row for increasing self (radar) reflectivity. Design and fabrication of a zero pressure balloon with volume of 9,786 cu.m capable of carrying a maximum suspended load of 4200 kg that can reach to 10.5 km altitude using newly developed 380 kg load tapes. Designed and tested Telecommand encoder & decoder on a single FPGA board and also implemented safety mechanism in altitude encoder interface to ATC transponder.

At the National Centre for Radio Astrophysics, Pune GMRT discovers a new Giant Radio Galaxy: sky

imaging at 150 MHz using the GMRT has led to the discovery of one of the largest and most distant Giant Radio Galaxy (GRG) in the Lynx field. GMRT detects for the first time, absorption by neutral hydrogen (H I) in Gigahertz-peaked-spectrum (GPS) sources at high redshifts ( $z > 1$ ).

TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) telescope is used to search for VHE gamma-rays from various astrophysical sources. During the year, Crab Nebula, Mrk 421, Mrk 501, 1ES1215 + 305 and 1ES2344 + 514 were observed.

Continuous ground level intensity measurements of atmospheric secondary neutrons produced in the interactions of primary cosmic rays with the earth's atmosphere were recorded with 12IGY and Lead-Free Gulmarg neutron monitors (LFGNM) along with select meteorological parameters for data correction.

Angular anisotropy of fission fragments produced by different transfer or breakup induced fission reactions have been obtained separately in the rest frame of respective recoiling nuclei. Some of these anisotropies were found to be stronger than those of the inclusive fission. Overall angular distributions of transfer or breakup fission integrated over all possible recoil angles with weight factor proportional to differential cross section of the complementary breakup fragment emitted in coincidence in all possible directions were obtained. It was observed that overall FF angular anisotropy for each of these fission channels is less than or equal to the anisotropy of total fission at all the measured energies.

Fusion measurement at energies deep below the barrier were performed for extracting very low cross-sections for  $^{11}\text{B} + ^{197}\text{Au}$  system using an innovative method to reduce the background, for probing the occurrence of fusion hindrance in case of asymmetric systems. The results reveal a weaker influence of hindrance on fusion involving lighter projectiles on heavy targets. This data can be used as a unique tool to obtain the value of the nuclear potential at small distances and to study dynamics of overlapping nuclei.

BARC has played key role in heavy ion physics studies of the Pb+Pb and p+Pb collisions at 2.76 and 5.02 TeV using CMS detector at LHC (Large Hadron Collider). A series of systematic measurements of quarkonia states and their ratios in Pb+Pb collisions has helped establishing the colour screening behaviour of Quark Gluon Plasma (QGP). These studies have resulted in the observation of sequential suppression (as per their binding energies) of quarkonia states in Pb+Pb collisions and indication of final state effects in p+Pb collisions at LHC energies.

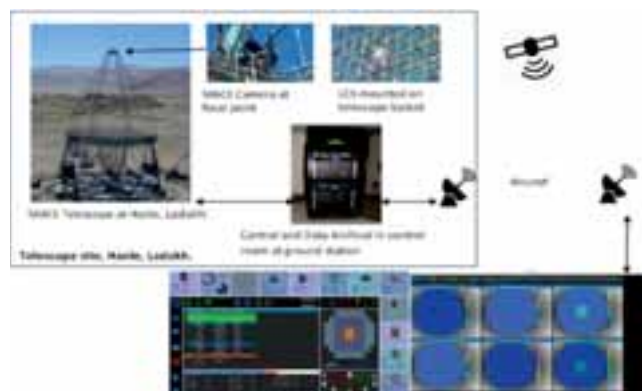
Phase stability behaviour of  $\text{ScVO}_4$ , a compound iso-structural to  $\text{YVO}_4$ , which is the most widely used laser host material has been investigated under non-hydrostatic compression. It has been shown that the fergusonite phase which is reversible under hydrostatic compression can be retained on pressure release if compressed non-hydrostatically.

Chemical synthesis and magnetic characterization of Y-Fe-garnets have been completed for use in Radiofrequency circulators. Bulk casting of these materials has been taken up for commercial testing.

Fission product angular distribution is an important observable to distinguish between the different Non Compound Nucleus (NCN) fission mechanisms, viz., pre-equilibrium fission and quasi fission, involved in a heavy ion induced reaction. However gross angular distribution of fission products/fragments cannot distinguish between these two processes.

To investigate dominant NCN mechanism in  $^{16}\text{O} + ^{238}\text{U}$  reaction at sub-barrier beam energy (85.3 MeV), mass resolved angular distribution of the fission products was measured. Measurement was done by recoil catcher technique involving irradiation followed by off-line gamma ray spectrometry at BARC-TIFR Pelletron-LINAC facility. The studies indicated quasi fission to be the dominant NCN fission mechanism in this reaction. This was further confirmed from the underestimation of experimental anisotropy by theoretical calculations even after including the pre-equilibrium (PE) fission.

Temperature dependent Field Cooling-Zero Field Cooling (FC-ZFC) magnetization measurements



**Installation of imaging camera for MACE telescope & remote operation from BARC**

were carried out on  $\text{Th}_{1-x}\text{Bi}_x\text{O}_{2-\Delta}$  ( $x = 0.1, 0.2$  &  $0.3$ ) solid solutions. It was found that samples exhibit ferromagnetic like transition close to 75K with FC and ZFC curves bifurcating around 50K.

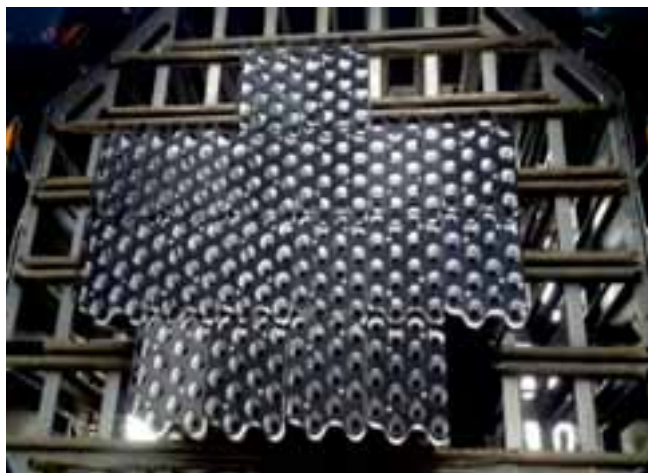
The Imaging camera of MACE telescope has been installed on the telescope at Hanle site with electronics for 188 channels. Event acquisition of the camera was tested with LED Calibration System (LCS) mounted in telescope basket.

Remote operation of MACE camera for configuration, monitoring and event data acquisition was carried out from Mumbai through Anunet. It is significant due to the remote location and harsh environmental conditions at Hanle, Ladakh and efficient usage of the telescope by scientific community with minimum support staff stationed at site.

The work related to the assembly of the MACE telescope is at an advanced stage at Hanle. All the sub-systems of 21m diameter MACE telescope have been assembled. Production and testing of 750 actuators



**Status of assembly of MACE mechanical structure at Hanle**



**MACE camera loaded with 18 CIM modules at focal plane**

have been completed at ECIL Hyderabad, out of which 410 have been transported to Hanle and further tested for their functionality. First level optimization of telescope servo control is completed by testing the system in closed position loop with limited acceleration range.

Rigorous user testing of 62 Camera Integrated Modules (CIMs) was carried out at ECIL Hyderabad. 46 CIMs have been transported to Hanle and after further testing at telescope site 18 CIMs have been installed on the telescope. Data archive system for the MACE telescope has been completely assembled, installed and configured at Hanle. Recent version of the operator console software has been tested for remote operation of telescope from BARC, Mumbai. The telescope was operated with Power ON Self-Test (POST), command sequence initialization, multiple observation run, time based sequence execution and auto shutdown mode.

Indian National Gamma Array (INGA) is a large national collaboration among various national institutes and universities in India to pursue the rich variety of nuclear structure studies using high resolution gamma ray spectroscopy techniques.

The second campaign of INGA at Variable Energy Cyclotron Centre (VECC) has started in December, 2017 using light ion beams from K-130 cyclotron. The unique feature of the reactions with light ions from the K-130 cyclotron at VECC, Kolkata, coupled with advanced state of art detector facilities of INGA, will allow to unravel wide variety of mysteries of the nuclei of different regimes of nuclear chart, which is not possible

to access with heavy-ion beams from other accelerator facilities in the country.

The VENTURE (VECC array for Nuclear fast Timing and angUlar corRELation studies) array of several fast timing  $\text{CeBr}_3$  detectors, developed under a BRNS project, has been used for the measurement of nuclear level lifetime few picoseconds. Such efforts, which is first of its kind in India, has been extended to the radio-chemically separated fission fragments, viz.,  $^{131,132}\text{I}$ ,  $^{131,132}\text{Xe}$ , that are produced with alpha beam from K-130 cyclotron at VECC. The experimental results have been important in understanding the nuclear structure around doubly closed  $^{132}\text{Sn}$ .



**VENTURE array used for the lifetime measurements in  $^{117}\text{Sn}$  and  $^{160}\text{Dy}$**

Experiments have also been performed with the VENTURE array by the members of Saha Institute of Nuclear Physics, Kolkata.

A perfect fluid dissipates the smallest possible amount of energy i.e. has a very small shear viscosity which converts part of the kinetic energy of the flow to heat. The fluidity is expressed as a ratio of shear viscosity to entropy volume density ( $\eta/s$ ). Recently, using the alpha beams from the K-130 cyclotron at VECC,  $\eta/s$  were determined experimentally for the first time for equilibrated nuclear systems from A 30 to A 208 at different temperatures. The shear viscosity was estimated from the  $g$ -decay of the isovector giant dipole resonance measured employing the LAMBDA spectrometer. The entropy density was evaluated from the nuclear level density parameter ( $a$ ) and nuclear temperature ( $T$ ). It was intriguing to find that the measured  $\eta/s$  values were comparable to that of the high-temperature quark-gluon plasma indicating that



strong fluidity is a universal characteristic feature of the strong interaction of the many-body nuclear systems and not just of the state created in the relativistic collisions.

The Saha Institute of Nuclear Physics and Uranium Corporation of India Limited have set up research and development facility at Jaduguda for experiments in fundamental physics involving rare event searches like dark matter search, neutrinoless double beta decay. The new physics laboratory in the uranium mine, the first of its kind in the country was inaugurated by Chairman, Atomic Energy Commission on September 2, 2017.



*New physics laboratory in the uranium mine at Jaduguda, the first of its kind in the country was inaugurated by Chairman, AEC*

In Condensed Matter Physics correlation between battery performance and basic physics of battery material (such as  $\text{LiCo}_y\text{Mn}_{2-y}\text{O}_4$ ) were established.

The Nuclear Physics Group of SINP successfully continued their activities in Accelerator based Nuclear Physics (In-Beam gamma spectroscopy and Reaction studies) using National and International Accelerator Facilities.

Research activities in the plasma physics at SINP encompassed a variety of theoretical and experimental topics in the field of linear and nonlinear wave propagation. Theoretical studies using Lagrange fluid description for various types of waves in unmagnetized and magnetized plasmas have been carried out to understand wave breaking phenomena due to phase-mixing processes.

Institute of Physics (IOP) is one of the major centers for research in basic and applied Physics stream in the Eastern Part of India.

IOP's high energy physics group remained actively involved in pursuing research in String Theory, Cosmology and Particle Physics.

Some of the topics investigated last year are dynamic phase transition in DNA, fluctuation theorems and phase transitions in driven lattice systems.

In experimental physics, major activities included studies on accelerator-based materials science, surface and interface physics, and nanosystems. Investigations in these areas were carried out by using the state-of-the-art facilities developed at Institute of Physics over the years. Some of the topics of current interest are ion beam-induced surface nanostructuring, pattern formation, epitaxial crystallization, and electronic structure studies of multiferroics, manganites etc.

The 3.0 MV pelletron accelerator facilities are being extensively used by University Faculty and Students through UGC-DAE consortium.

The Astrophysics group of Harish Chandra Research Institute (HRI) worked on various topics in astrophysics and gravitational physics, namely accretion astrophysics, analogue gravity phenomena, non-linear phenomena in large scale astrophysical fluids, theory of traversable wormholes, stellar astrophysics, and some aspects of cosmological constant.

The Condensed Matter Group of HRI have clarified the thermal physics of correlated Bose superfluids, the process of dielectric breakdown in a Mott insulator, and the effect of polaron formation on the phonon spectra of metals. The group has computationally designed a new antiferromagnetic insulator in the class of ternary transition metal trichalcogenides. Atomistic insights into the behaviour of a TaSi16 cluster on a graphite surface has been developed. Transport through a Josephson junction and other junctions made of Weyl semimetals were studied and how to tune them by periodic driving were also studied.

A number of important contributions have come from the High Energy Group of HRI in the context of new physics search at the Large Hadron Collider (LHC) as well as future proposals of an electron-positron and electron-proton collider experiments. The contributions have been mainly focussed in giving shape to new phenomenological frameworks beyond the Standard Model (BSM) of particle physics that involve extended scalar/gauge sectors, extra spatial dimensions and supersymmetry. The group has produced a good deal of important work in the field of neutrino physics.

The members of quantum information and computation (QIC) group of HRI has worked on topics like coherence measures based on max-relative entropy, a resource theory of non-orthogonal coherence, distribution of coherence in multipartite systems, coherence of quantum channels.

The Institute of Mathematical Sciences (IMSc) addressed the possibility of New Physics (NP) beyond the Standard Model of particle physics in rare decays of beauty quarks to strange Quarks and pairs of leptons. The precise role of electric charge in determining the conformational properties of charged polymers through a combination of large scale simulations and theoretical modeling was studied.

The School of Physical Sciences at the National Institute of Science Education & Research (NISER) continued the Masters and Doctorate programmes in various disciplines of Physics. Facilities recently added to the research infrastructure of School of Physical Sciences include Property Measurement System; SQUID magnetometer; Pulsed laser deposition system; Dielectric spectrometer and 400 keV ion implanter part-I.

## CHEMISTRY

A silver nanoparticle based optical test strip has been developed by synthesising silver nanoparticles in Nafion-117 membrane for quantitative assay of hydrogen peroxide ( $H_2O_2$ ) in aqueous solution. Detection limit has been calculated to be  $2.6 \times 10^{-8} \text{ mol L}^{-1}$  which is lower than the conventional enzyme based biosensors. The test strip has been found to be highly selective towards  $H_2O_2$  in presence of various inorganic

and organic species commonly present in biological samples. The test strip has been employed for the detection and quantitative assay of  $H_2O_2$  in milk.

The mechanism of change in Localized Surface Plasmon Resonance (LSPR) in presence of  $H_2O_2$  has been explored using time resolved Small-angle X-ray Scattering (SAXS) and radiotracer techniques. It is concluded that at this concentration of  $H_2O_2$ , its sharp oxidative sawing action is responsible for cutting off the nanoparticles into smaller fragments resulting in rapid reduction of absorption cross-section.

Time Differential Perturbed Angular Correlation (TDPAC) Spectroscopy has been used to determine the quadruple moment of 49keV level of  $^{132}\text{I}$  populated from the decay of  $^{132}\text{Te}$  nuclei produced via  $^{nat}\text{U}(\text{A}, \text{f})$  reaction followed by radiochemical separation.

An actinide selective aqueous soluble ligand ( $\text{SO}_3\text{-Ph-BTP}$ ) was synthesized. Solvent extraction studies indicated that this ligand can separate  $\text{Am}^{3+}$  and  $\text{Eu}^{3+}$  at the nitric acid concentration range of 0.1-2 M.

A novel tripodal diglycolamide extractant containing a 9-membered macrocycle (triza-9-Crown-3) ring was synthesized for the extraction of actinide ( $\text{Pu}^{4+}$ ,  $\text{UO}^{22+}$ ,  $\text{Am}^{3+}$ ) and lanthanide ( $\text{Eu}^{3+}$ ) ions from  $\text{HNO}_3$  solutions.

A novel 3-mercaptopropionylamidoxime (3-MPD) functionalized gold nanoparticles (AuNPs) was synthesized and characterized by UV-visible, IR and  $^1\text{H}$  and NMR spectroscopy, Transmission Electron Microscopy (TEM), X-ray Photoelectron spectroscopy (XPS) to develop a simple, low cost, sensitive and on-site as well as real time monitoring method for detecting ultra-trace levels of U.

As a part of quality assurance of FBTR fuel, a cyclic voltammetry technique for simultaneous determination of U and Pu in nuclear fuels using PEDOT:PSS (Poly-(3,4-ethylene dioxy thiophene)-Poly-(Styrene Sulphonate) modified glassy carbon electrode is developed. The technique is very precise, accurate, fast, require very small volume of solution without generation of analytical waste.

As part of determination of thermo-physical/chemical properties of fuel-fission product interaction products in Molten Salt Reactor program, the phase diagram for Ba-U-F is determined and a new compound  $\text{BaUF}_6$  is identified.

Secondary Ion Mass Spectrometry (SIMS) were utilized to investigate the corrosion mechanism in steel (SS304) samples exposed to various corrosive environments. Surface analysis shows pitting corrosion phenomenon in HCl treated steel samples. Studies concluded that SIMS has a great potential to investigate type of chemical attack and to find out root cause of corrosion.

Red-mud is produced as waste from Al production process. To develop sacrificial core-catcher materials for Indian thermal nuclear reactors, red-mud obtained from NALCO, India was conditioned by suitable thermal treatment and additives. Obtained bricks were found to be mechanically strong and did not show leachability with water. Melting point of the red-mud brick was found to be around  $1600^\circ\text{C}$ .

BARC has developed synthetic diamond based  $\text{H}_2\text{S}$  (range 0.5-20 ppm) sensor and tin oxide thin film based  $\text{SO}_2$  (range 1-100 ppm) sensors operating at room temperature to monitor these gases in petroleum refineries and other industrial establishments. Technologies were transferred to private domain.



**Portable  $\text{H}_2\text{S}$  Sensor**

Stable and sensitive gold nanoparticle embedded polymeric films were prepared for trace level Surface Enhanced Raman Spectroscopy (SERS) detection of pollutants such as Crystal violet (1 nM).

A methodology to investigate reaction kinetics with single molecule sensitivity was developed and demonstrated its potential in exploring complex quenching kinetics.

Studies on the supramolecular acridine dye-p-sulfonatocalix[4]arene (SCX4) assembly for the sensing of the biomolecule, acetylcholine (AcCh), based on fluorescence displacement assay demonstrating an efficient fluorescence "OFF/ON" switching mechanism was carried out.

A sensitive technique for the detection of these fibrils or plaques both in-vitro and in-vivo for diagnosis and therapy of amyloidosis was developed.

A simple and rapid visual colorimetric method based on using a complexing agent followed by pre concentration using a surfactant that results in the formation of coloured complex instantaneously was developed for the detection of U in ground water. The method has a potential for deployment in the U affected area of Punjab or other region for mapping U concentrations in the water bodies.

A very efficient catalyst for reduction of carcinogenic Cr(VI) species into harmless Cr(III) species by formic acid has been developed using nano Pd embedded in polyether sulfone beads. It could be recycled for 100 cycles without any loss of efficiency.

Bio-available and nasal drop formulations of curcumin and novel liposomal nano-formulations for chemotherapy drugs such as cisplatin, doxorubicin and paclitaxel have been developed.

In collaboration with India Government Mint (IGM) and CSIR-NPL, New Delhi, Certified Reference Standard of 9999 fineness (99.99% purity) gold was prepared.

The detailed conformational dynamics of the melted region in double-stranded DNA has been studied using a combination of ensemble and single-molecule FRET techniques that has been developed in house.

SINP Researches have recently reported a one-pot synthetic methodology leading to gold nano-structures of high anisotropy resembling 'hedgehog'



without using any seed or surfactant. These Hedgehog nanoparticles are non-toxic and cost approximately ₹ 600 per millimeter. The group is currently exploring the applicability of these gold nano-hedgehogs for selective killing of cancerous cells.

## BIOLOGY

A gold nanoparticle based zinc biokit was developed that can detect zinc up to 50 ppm. The biobeads are stable up to 4 months at room temperature.

A radiation dose response calibration curve for exposure to  $^{60}\text{Co}$ - gamma rays has been generated for biological dosimetry of suspected individuals exposed to radiation. The established method will be used for cumulative exposure scenario to estimate biological dose.

The ameliorative potential of TU towards NaCl stress was related with its ability to decrease Reactive Oxygen Species (ROS) accumulation in roots and increase  $\text{Na}^+$  accumulation in shoots. ROS accumulation at 4 h time point in root-tip region under different treatment conditions was measured.

At TIFR, studies into the mechanism of the enzyme SIRT1, which is known to be involved in aging, and many other aspects of metabolism-dependent gene regulation led to the identification of novel endocrine signals that mediate inter-tissue communication for insulin signaling through SIRT1 in a specific tissue, the liver/fat body. A network of regulatory proteins (transcription factors) that control the production of neurons (signaling cells) versus glia (support cells) in the embryonic mouse hippocampus, which is the brain structure for learning and memory was identified. Investigations on the role of intracellular transport in cilia formation and brain functioning in the insect *Drosophila melanogaster* helped to identify distinct modalities. A study on the axonal transport using the worm *C. elegans* revealed the mechanism of vesicle selection and transport towards synapse. Studies on the molecular mechanism of vesicle movement within a cell identified a relationship between the type of lipid composition on a vesicle membrane and its transport during phagocytosis and lipid metabolism.

Studies on the early developmental mechanisms and skin development using Zebrafish helped to identify a specific method of inducing polyploidy in developing fish embryos. Studies on cell removal from the epidermis of *Drosophila* embryos suggested interesting cross-talk between the membrane-associated proteins and cytoskeletal network. Studies on the molecular mechanism of cell division using the fission yeast *S. pombe* have identified novel interplay between some known molecules and the actomyosin complex during cytokinesis, the final step in a cell division process.

At the National Centre for Biological Science, Bangalore under Biochemistry, Biophysics & Bioinformatics some interesting findings include the work to analyse the effect of eusociality behaviour of honeybees on the evolution of olfactory receptors (Ors). In Development & Genetic, the major achievement include the work that provided a neuroanatomical description of the motoneurons and muscles contributing to proboscis motion of *Drosophila*. In the Neurobiology area the interesting research outcome was the work that provides mechanistic insight into neural processing of sequential spatio-temporal events. In Cellular & Signaling, the important finding include the work aimed at delineating one of the mechanism by which *M. tuberculosis* is able to resist delivery to lysosomes, and survive within macrophage phagosomes. In Theory & Modeling, one of the recent study described the hydrodynamics of actomyosin as a confined active elastomer with turnover of its components. In Ecology & Evolution, one of the significant findings was the study involving collection of genome-wide SNP data of wild Indian tigers revealed how genome-wide data and analyses can flag populations that may require urgent conservation attention (such as Ranthambore) and identify strongholds of variation (such as central India).

A new coumarin based turn on fluorescent sensor (R1) was reported for the detection of highly hazardous  $\text{Cd}^{2+}$  with excellent selectivity and sensitivity without any interference of other metal ions. For the first time, a  $\text{Cd}^{2+}$  induced FRET mechanism was observed and explained accordingly.

At IMSc, a new study on application of active matter ideas to the problem of collective phototaxis has

been initiated and it is hoped to stimulate research along similar lines into other problems involving the physics of collective bacterial motion. A discrete porosity based model that captures the physics of the fracture process of the bone and reproduces well the macroscopic response and qualitative features of experimentally obtained fracture paths, as well as avalanche statistics seen in experiments on porcine bone was developed and tested.

The School of Biological Sciences at the National Institute of Science Education & Research (NISER) offered 5-year integrated M.Sc program, Ph.D program and Post-Doctoral program to students. Facilities recently added to the research infrastructure of School of Biological Sciences include Behavioural Neurobiology facilities; High resolution imaging facilities; Multimode reader; Ultracentrifugation facilities and X-ray Diffractometer for Protein Structure Analysis.

## CANCER

The Advanced Centre for treatment, Research and Education (ACTREC) in Navi Mumbai is the research and development arm of TMC; its Clinical Research Centre (CRC) focuses on clinical and translational cancer research and on cancer treatment, and its Clinical Research Institute (CRI) performs basic and applied research on cancer. The hospital aims at innovative better and cheaper treatment options that would translate to better outcomes and survival for cancer patients. Various government agencies provided financial support to more than 200 clinical projects. Four hundred sixty (460) Serious Adverse Effects were reviewed from 37 clinical trials.

## SYNCHROTRONS & THEIR UTILISATION

The synchrotron radiation sources, Indus-1 and Indus-2, are being operated in round-the-clock mode as a national facility. Indus-1 is operated at 450 MeV energy, 100 mA current, and Indus-2 is operated at 2.5 GeV energy and current upto 200 mA. The facility underwent a major upgrade in 2017. This entailed installation and commissioning of the first indigenously developed RF cavity in Indus-2, replacement of the



*RF Cavity installed and connected to RF power station through transmission line*



*Modified Transport line-1*

microtron with an improved version and upgradation of Transport Line (TL-1) from microtron to booster synchrotron. During 2017, the Indus machines operated for 325 days.

The first 505.8 MHz. bell shaped copper RF cavity, designed and developed indigenously, was assembled with input power coupler, Higher Order Modes Frequency Shifter (HOMFS) and tuning system. The cavity was installed and commissioned in Indus-2. Necessary modifications in the vacuum chamber were done to integrate the new RF cavity in the long straight section LS-7 of Indus-2. The RF cavity has been integrated with high power solid state RF station through a 6-1/8 inch transmission line system. With this indigenous RF cavity deployed along with the existing four other RF cavities, more than 200 mA beam current at 2.5 GeV beam energy was achieved in Indus-2. Two more such cavities will be developed and installed to provide the extra power required for operation of Indus-2 with insertion devices.

Several types of specialized power converters and power supplies with improved performance were developed, installed, and commissioned in various sub-system of Indus-1 and Indus-2. This has contributed significantly to the improvement in reliability of sub-systems due to which beam filling events have reduced.

A betatron tune feedback system is used in Indus-2 to ensure electron beam stability and to maintain the betatron tune constant within specified band during machine operation. An enhanced version of betatron tune feedback system has been developed and successfully tested in Indus-2. The enhanced version performs ten times faster corrections of very small changes in the betatron tune ( $\pm 0.0005$ ) which may occur due to changes in the machine optics. The system will be now provided to users on a regular basis.

A Raman Optical Fibre Distributed Temperature Sensor (ROFDTS) has been developed and deployed for detection of hot spot in one of the dipole magnet vacuum chambers (DP-2) of Indus-2. A hot spot was detected 1.8 m from the entry point of electron beam and was arrested by correcting the beam orbit at that location.

Various web based software packages have been developed or upgraded. These includes e-Logbook for electronic logging and report generation of Indus operation; f-Logbook for tracking the faults occurred in different subsystems during round the clock operations of Indus-1 & Indus-2 and Indus-Online for providing the live, historical, statistical and diagnostics data of Indus-1 and Indus-2 in tabular and graphical format over RRCAT Intranet.

During 2017, upgraded versions of several subsystems of the Indus SRS facility have been developed and tested. These will be deployed in near future. Details of these subsystems are as follows:



*Upgraded pulsed injection kicker magnets*

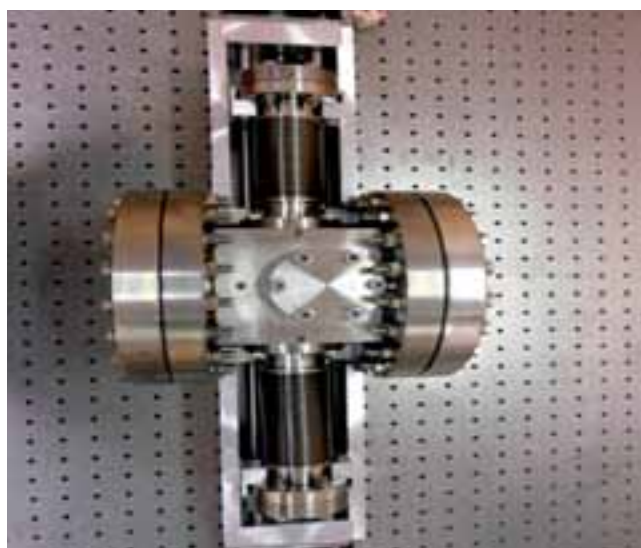


*Indus-2 dipole magnet vacuum chamber after modifications*

To facilitate the injection of the electron beam from the upcoming 30 MeV linac (in addition to the existing 20 MeV microtron), three new pulsed kicker magnets with low coupling impedances have been developed for the booster synchrotron. These magnets will replace the existing lumped kicker magnets which will improve injection efficiency into 700 MeV booster synchrotron.

To extract the synchrotron radiation from  $0^\circ$  ports, the existing dipole magnet vacuum chamber (approx. 3.6 meter length) of Indus-2, was machined by increasing the slot height and width using in-house developed tools and fixtures.

Beam scrapers are used in Indus-2 for measurement of dynamic aperture of electron beam. For example, these were used to decide the minimum physical aperture at the undulator section. Existing scrapers have served for almost 10 years and are limited to 60 mA of beam current. Upgraded beam scrapers have now been developed to allow their use at higher beam current of up to 200 mA at 2.5 GeV beam energy.



*In-house developed upgraded horizontal scraper for Indus-2*



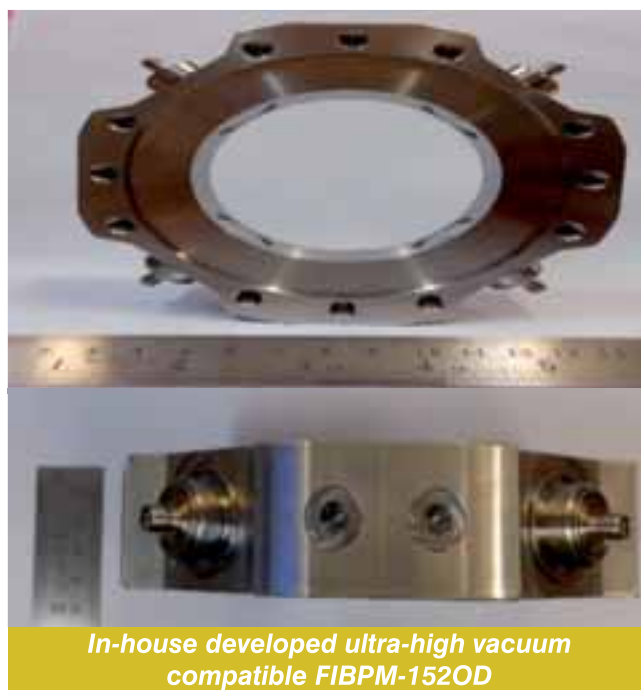


*In-house developed upgraded vertical scraper for Indus-2*

UHV compatible Flange Integrated Beam Position Monitor (FIBPM) has been designed and developed. In view of its small thickness, it can be installed in a limited space in an accelerator. Two versions of FIBPM have been developed in 70 mm OD conflat flange (FIBPM-70OD) and 152 mm OD diamond seal flange (FIBPM-152OD).



*FIBPM-70OD*



*In-house developed ultra-high vacuum compatible FIBPM-152OD*

An aluminium chamber (17 mm x 81 mm and 300 mm) for Indus-2 was Non-Evaporable Getter (NEG) coated using DC magnetron sputter deposition system. The challenge involved was the placement of the target coaxially inside the chamber. The NEG coated chamber was activated at 180°C for 24 hours and ultimate vacuum of  $3 \times 10^{-11}$  mbar was achieved.

A circulator is used for protecting high power RF amplifiers from the reflected power when coupled to a RF Cavity. A high power, three port 505.8 MHz RF circulator has been designed, developed and tested. The circulator was tested at high power where return loss of better than 23 dB and insertion loss better than 0.1 dB, with isolation of 25 dB for 60 kW input power was obtained.



*High power RF testing of 505.8 MHz circulator*

Indus -1 and Indus-2 are national facilities with 10 beamlines in Indus-2 and 6 in Indus-1 available to users. More than 700 user experiments were carried out in the calendar year 2017 leading to 120 research publications in peer reviewed international journals.

RRCAT in collaboration with Indian Space Research Organization / Indian Institute of Astro physics, has developed multilayers of tungsten / boron carbide (W/B<sub>4</sub>C) for multilayer reflective mirrors to be used in x-ray telescopes for astronomical applications. The performance of these mirrors have been evaluated in the energy range 9 keV to 16 keV using the BL-16 beamline of Indus-2, and measured reflectivity curves. The mirror reflectivity is found to be appropriate for fabrication of compact telescopes suitable for a space payload.

Some of the Indus beamlines have been upgraded to carry out more challenging and novel experiments by the users. The main improvements are described below:

The soft x-ray reflectivity beamline in Indus-1 has been upgraded by introducing the p-polarization measurement setup. The angle dispersive XRD beamline has been upgraded with the introduction of an evacuated flight tube at the detector side, to enable the measurement of diffraction patterns at low incident energies which will be specifically helpful in studies on the technological important 3D transition metals like iron, cobalt, nickel etc. The operation life of the toroidal mirror has been enhanced by more than a factor of two, thereby saving a large amount of expenditure (of the tune of ₹ 20 Lakhs) for the import of a new mirror. Two frontends one for BL-05 and other for BL-10 beamline, have been designed, developed, commissioned and operated up to a beam current of 150 mA in Indus-2. All the major components of both the front-ends are indigenously developed in RRCAT. Control system for remote operation of BL-10 beamline has been successfully developed.

An in-situ Extended X-ray Absorption Fine Structure Spectroscopy (EXAFS) setup has been designed and installed to probe heterogeneous catalysis reactions on-line at Indus-2 SRS at RRCAT, Indore.

A Grazing Incidence X-ray Absorption Spectroscopy (GIXAS) measurement facility has been set up at the Energy Scanning EXAFS beamline at Indus-2 SRS by employing a 2-circle goniometer with 5-axis sample stage in the experimental station of the Energy scanning EXAFS beamline (BL-09). This facility

would provide depth dependent XAS measurement facility on thin films and multi layers.

The protein crystallography (BL-21) beamline of Indus-2 SRS has been utilized by several research groups from all over India resulting into more than 42 structural entries into the international database (Protein Data Bank) and about 30 research papers in peer-reviewed journals. One of the recent significant outputs is the crystal structure of Human amino peptidase protein (XPNPEP3) associated with cystic-kidney disease at resolution of 1.65 Å.



*A miniature parallel-plate type Free Air Ionization Chamber*

A miniature parallel-plate type Free Air Ionization Chamber (FAIC) was designed and fabricated for standardisation of SR beams up to 25 keV energy. The performance of this chamber was found satisfactory and established as primary standard for measurement of air kerma rate of low energy SR beams.

## CYCLOTRONS & THEIR UTILISATION

### Initiation of Installation of Medical Cyclotron

The installation of the medical cyclotron has been initiated. As part of the installation program the M/s IBA make Cyclotron Magnet weighing 55 Tons has been transported to medical cyclotron site at Chalk Garia, about 20 Km from Bidhan Nagar Campus on November 28, 2017 and safely rigged onto the Cyclotron Vault in November 29, 2017. Subsequently, levelling of the piers, the orientation of the magnet, rough alignment and mounting of magnet mount support was completed. All



**Installation of Medical Cyclotron at VECC**

other necessary equipment related to the main machine have also be transported to the site.

### **Magnetic field correction of Superconducting Cyclotron**

The first harmonic field error in the magnet in the region of within 80 to 100 mm of radius of the Superconducting Cyclotron has been reduced to below 10 Gauss which is acceptable as per Beam Dynamics calculation. The correction was possible by introducing a rectangular cut (removal of iron) in one of the Large Hill Addition Pairs (in front of Sector C). The position and the dimension of the cut was obtained through many trials of simulation.

### **Fabrication and commissioning of Trimmer Capacitor**

The original 40-yr old trimmer capacitor consisting of 100-micron Silver Electroplated Aluminium Stator and Rotor with embedded LCW cooling, used for auto-tuning of RF resonator for Room Temperature cyclotron was replaced by in-house fabricated new set of Stator and Rotor, because of repeated leaks developed in the original capacitor. The new version have been deployed without Silver Electroplating as the calculation suggested that the heat generation with present operating frequencies does not require Silver Electroplating. This has reduced the cost of fabrication to a large extent and the fabrication and machining is completely under the control of VECC in-house facilities.



**Fabrication and commissioning of Trimmer Capacitor**

### **Development of EPICS enabled universal vacuum gauge controller**

An intelligent vacuum gauge controller module with state-of-the-art facilities e.g. inbuilt LAN connectivity, embedded EPICS interface, web based configuration etc. is designed and developed. The module is developed on the COTS type commercially grade ARM module. A detailed hardware design is done to interface the signals from the vacuum gauges to the ARM modules.

## **PLASMA & FUSION TECHNOLOGIES**

The various activities carried out in the Institute of Plasma Research (IPR) during the year are mentioned as under:

Completion of first stage of medical trials for cold plasma for human skin disease treatment

A Plasma jet developed (patent filed in India) by IPR has been used for skin treatment trials in IPGMER-SSKM Hospital, Kolkata. Following ethical permission, trials were conducted on three patients with skin fungal infection (Tinea family). The patients were cured in 2-3 sittings without any additional medicines/oointments. Infection did not recur even after one year and there were no observable side effects. Clinical and microbiological results confirmed that the patients were cured. The next step is to get Ethical Permission to treat 25 patients.



**Application of plasma jet on skin fungal infection**

### **Plasma treatment of textiles: Visit of Shri Giriraj Singh, Hon'ble MoS**

Following his deep interest in IPR's technologies during the Parliament House exhibition,





*Shri Giriraj Singh observing the plasma nitriding system*

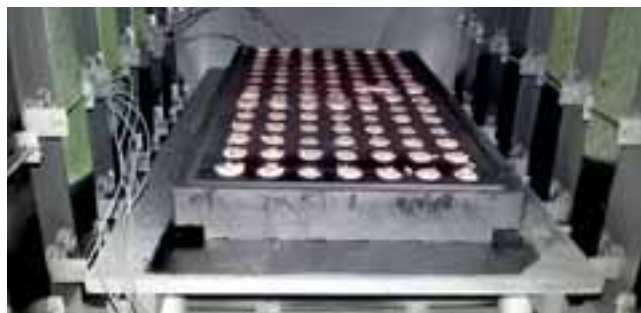
Shri Giriraj Singh, Hon'ble Minister of State (I/C) for Micro, Medium and Small Enterprises visited IPR. A live demonstration before the Hon'ble Minister showed that plasma treatment for 15 minutes allows the use of natural dyes like indigo on Khadi, which is of great interest to KVIC. He expressed interest in deploying such systems in training centres run by KVIC. He also expressed a desire to install IPR's Plasma Nitriding systems in all Central Tool Rooms operated by his ministry. IPR has sent offers in both areas.

### **Copper-coated tungsten rods for thermal spray applications**

Thermal Spray Coatings are widely used in industry. These use tungsten rods coated with high purity copper as electrodes. Such rods, which are in high demand, are usually imported at a high cost. A High Temperature Vacuum Furnace at IPR has been used to achieve simultaneous coating of 98 nos. of such rods. These rods have demonstrated satisfactory performance in the user industry.



*Copper coated tungsten rod*



*Batch production of copper coating*

### **3D computer simulations of Plasma Thrusters**

Plasma Thrusters are routinely used for attitude control & station-keeping of satellites. ISRO has so far imported these thrusters. IPR has developed good understanding of helicon-wave driven plasmas through basic experiments over the past several years. Leveraging this expertise, IPR has started in-house development of this critical system. An important step is the in-house development of three-dimensional software which has just been completed. This is providing new insight into the dynamics of such Thrusters, especially oscillations in Thrust. This insight will help in design/optimization of in-house experimental systems.

### **RHVPS for LEHIPA**

IPR-supplied Regulated High Voltage Power Supply (RHVPS) for the LEHIPA experiment at BARC has been re-commissioned for a new phase of experiments with LEHIPA. All sub-systems of RHVPS (i.e., power modules, transformers and controller) have been successfully tested and commissioned by a team of scientists and engineers from IPR. The operators have been trained for minor trouble shooting and repairs as well. A long (approx. 15 days) round-the-clock campaign has been successfully concluded. RHVPS is



*RHVPS with power modules in stacks*

now fully operational with 70 kV, 12 A, in pulsed mode (1, 2 and 3 Hz). The RHVPS has been used by the BARC team for conditioning of a klystron, yielding extraction of up to 300 kW beam.

### **Aditya upgrade Tokamak**

“Garlands” consisting of 16 magnetic probes (Mirnov coils) each have been placed and calibrated at two different toroidal locations in ADITYA Upgrade. Mirnov coils are used to detect magnetic fluctuations and for plasma position measurements. Two internal and one external Rogowski coils for plasma current measurement in ADITYA Upgrade tokamak have been calibrated. The cosine-sine coils, used for the plasma position have been designed, fabricated, installed and calibrated. A Major Vessel Opening work was carried out for installation of various diagnostic systems for Phase-II operation. Diagnostic systems such as spectrometer and fibres for High Z and low Z impurity monitoring, H-alpha array, Soft X-ray detector array, Bolometer array, Microwave interferometer radial profile, Thomson scattering diagnostic, different Langmuir probe arrays, IR imaging camera, Charge exchange etc. were installed. One additional poloidal ring limiter was installed during this major vessel opening. Installation work was completed for backing heaters and silicon jackets at the top, bottom, inner and outer radial sides of the vessel. A PID-based feedback control system was tested.

### **SST-1 tokamak**

#### **Cool-down of superconducting coils**

During the past 6 months, the focus was on achieving simultaneous cool-down of the TF and PF coils, so as to achieve superconducting operation in all coils. Cool-down of the Toroidal Field (TF) coils, Case and Poloidal Field (PF) coils were carried out simultaneously. The inlet and outlet temperatures of the PF5 and Case reached 15-16 K and 24 K respectively, and then stayed at those values for several hours. For studying the hydraulic behaviour of the PF coils at 5 K, flow was bypassed in the TF as well as Case circuits. The winding packs of all PF coils successfully reached superconducting temperature. Experiments of this kind have been performed for the first time on SST-1. In another experiment, the TF magnets were force-cooled

@ 2.7 bar with super-critical helium (without using Cold circulator) by controlling the valves in HRL. This experiment has also been done for the first time for the SST-1 TF magnet system.

### **Breakdown studies**

Breakdown has been an issue in SST-1. An electron gun was used for tracing magnetic field lines in Helium gas at the filled pressure  $1.3 \times 10^{-3}$  mbar to analyze the field error due to misaligned TF coils. For breakdown using preionization, a Helicon wave was launched (Power 200W at the filled gas pressure of  $2 \times 10^{-3}$  to  $8 \times 10^{-3}$  torr) through a spiral antenna mounted externally on one of the radial ports. Formation of Helium plasma discharge was observed locally inside the radial port extension. Multiple pulses of Ion Cyclotron waves (Power 150kW) were launched to test the capability of wall conditioning. Plasma breakdown with lower hybrid waves (Power 100kW with  $1 \times 10^{-4}$  to  $5 \times 10^{-4}$  torr of filled Helium pressure at the magnetic field 1.2T) has also been obtained. Preliminary analysis reveals that the density of plasma may be of the order  $10^{12}$ /cc; estimated by the observed Helium lines from spectroscopy diagnostics.

### **Divertor Technology development**

Under the Divertor technology development program, experimental studies on diffusion bonding of Inconel using the Gleeble 3800 system were continued for high temperature recuperator (heat exchanger) application.

Two Dimensional Digital Image Correlation (2D-DIC) studies using fast imaging optical camera are performed with a tensile test specimen installed on a Universal Testing Machine. Deformation rates observed by DIC technique are found to be in close agreement with those of UTM. The DIC technique is expected to be useful in case of detecting deformation in big sized vacuum chambers.

A side-looking focused ultrasonic probe has been procured and assembled with the specially designed flexible shaft for Ultrasonic Testing of materials and joints from inside of the 12mm ID copper-alloy tube of curved tungsten mono-block divertor (Radius of curvature  $\sim 500$ mm);

High Heat Flux Testing of tungsten coated Faraday Screen for WEST Tokamak (France) was completed for quasi-steady state as well as ELM-like transient heat loads (400 micro-sec duration).

### Neutral Beam injector technologies

Following the realization of acceleration of 2 A negative Hydrogen Ion Beams from ROBIN, the emphasis placed on ROBIN activities are on i) spectroscopy based characterization of the ion beam and the plasma in the ion source, ii) measurement of ion beam profile on the calorimeter, iii) optimization of Cesium consumption in the source operation, iv) achieving an electron-to-ion current ratio of 1 on a repeatable basis. The experiments are being performed with RF power input of 60 kW utilizing 35kV, 15A and 11kV, 35A DC high voltage power supplies for extraction & acceleration of ionic beam.. The experimental measurements indicate that the extracted ion beam has a divergence between 2-3 deg and further optimization of the ratio on the extraction to acceleration electric fields are in progress, for the realization of a further improved beam.



**200m long Nb<sub>3</sub>Sn Superconducting wire on a Bobbin**

A 200m long Nb<sub>3</sub>Sn based multi-filamentary superconducting wire has been fabricated by BARC.

## MATERIALS SCIENCE

In order to form uniform aluminide-alumina coatings on the inner walls of the tritium storage vessels of SS 316 alloy pack, aluminizing and subsequent vacuum degassing heat treatment techniques have been developed at BARC.

High pure gadolinium nitrate hexa-hydrate (Gd(NO<sub>3</sub>)<sub>3</sub>.6H<sub>2</sub>O) meeting the stringent specifications for burnable poison application in KAPP 3 & 4 has been prepared from indigenous resources following the hydrometallurgical processing routes. Reproducibility of the product and assay has been established in kilogram scale.

Erosion and corrosion resistant nano-crystalline Ni coating on intricate shaped Alnico-3 magnet rotor of tachogenerator has been developed, tested and deployed. Process for deposition of adherent and uniform coating of nanocrystalline UO<sub>2</sub> on 1S grade Al has been developed using DC electrolysis and tested for the fabrication of Fission Counters. Adherent SNM oxide coating on SS-321 Tubes was done by DC electrolysis.



**Corrosion/erosion resistant nano-Ni coated Alnico-3 magnets**



**SNM Oxide coated SS-304 Tubes (ID&OD)**





*Production facility of Sm-Co alloy powder at BARC*

Permanent magnets of Sm-Co find use in atomic energy, space and defence industries for a variety of applications. The technology for the production of rare earth alloy (SmCo<sub>5</sub>) using indigenous source of rare earth oxide (monazite - an ore of thorium) was developed in BARC. Based on the technologies developed by Bhabha Atomic Research Centre (BARC), a three ton per year production facility, Rare Earth Permanent Magnet plant (REPM), of Sm-Co magnets is being set-up at Vizag-BARC. The “reduction-diffusion” methodology resulted in lower energy consumption and lower Sm loss in comparison to the conventional “co-melting” route. A special production line with the same capacity (10 kg/batch) to that for the REPM plant has been setup and commissioned at BARC. Using the same line, one batch of Sm-Co alloy powder has been produced. This line will now be used to train personnel from IREL to operate the upcoming REPM plant.

Beryllia blocks of square cross section (72.3 mm x 72.3 mm) with a central hole (34 mm and 54 mm dia.) required for making BeO assemblies for use in



*Green MgO crucible shape formed by CIP*



*Sintered MgO crucible*



*Beryllia blocks fabricated by vacuum hot pressing*

NRF-N (upgraded APSARA reactor) was achieved through vacuum hot pressing technique. The total required quantity of BeO blocks (50 numbers) has been fabricated.

High purity magnesia crucibles of 1.2 L capacity are required for melting and refining of strategic materials. Commercially available dead burnt magnesia powder has been suitably processed to get the feed material for the shape forming through Cold Isostatic Pressing (CIP) of the powder. Green ceramic shapes were sintered to get density in the range of 75–85% of theoretical density. These crucible were also utilized in vacuum melting of Be. For this purpose, these magnesia crucibles were coated with high purity beryllia prior to the processing.

Zr-2.5%Nb alloy pressure tube spools were subjected to gaseous hydrogen charging and stress reorientation treatment to form radial hydrides in a specially designed fixture.

Characterization of the pressure tubes in terms of microstructure, hydride orientation, evaluation of the threshold stress for reorientation of hydrides, Delayed Hydride Cracking (DHC) velocity at 250°C and fracture

toughness in as-received and hydrogen charged condition has been carried out.

Few experiments were carried out to explore the possibility of a sub-critical crack growth in Zr-2.5Nb alloy due to oxide cracking at elevated temperature ahead of a sharp flaw.

Studies were carried out to determine the optimum window of hot working of 3Cr-0.7Mo-0.25V pressure vessel steel. It was seen that optimum hot working range lies between temperature from 1000 - 1200°C and strain rates from  $10^{-2}$  to  $10^{-1}$  s $^{-1}$ . Strain Rate Sensitivity (SRS) at 700 and 800°C was low and the flow stress high suggesting that working should be avoided below 800°C.

Alloy 693 is a modified version of Alloy 690 (used as electrodes of Joule Heated Melter for vitrification of high level nuclear waste) and possesses better strength and corrosion resistance at elevated temperatures than Alloy 690 due to the addition of Al, Ti and Nb.

Chemistry of the alloy has been reworked to suppress formation of phase and microstructural stability of the reworked alloy was demonstrated.

BARC has developed light weight ballistic resistant jackets (Bhabha Kavach), which are 20% lighter with respect to the existing ones. Bhabha



*Bhabha Kavach*



*Hot pressed boron*

*CNT-polymer*

Kavach uses Carbon Nanotubes (CNTs) and boron carbide which have been developed in house. The technology of Bhabha Kavach has been transferred to private domain for large scale production for Central Armed Forces.

Graphene oxide was synthesized using electrochemical multiple exfoliation technique. The graphite electrodes of specific geometry were fabricated to get the multiple exfoliation of graphite.

Pb-Li eutectic alloy has been proposed as coolant and tritium breeder for the fusion reactor technology. BARC has developed the technology of producing a batch of 20 kg of Pb-Li eutectic alloy using an innovative fused salt electrolysis and stirring method. A semi-automated fused salt electrolysis Inconel reactor, electrically insulating ports for cathode insertion, gas inlet/outlet and a specially made Inconel cage with hydraulic lifting mechanism were designed and fabricated. Using optimized parameters, robustness of the technology and reproducibility of the alloy was tested. Detailed chemical analysis has shown that composition of the alloys was within the acceptable limits.

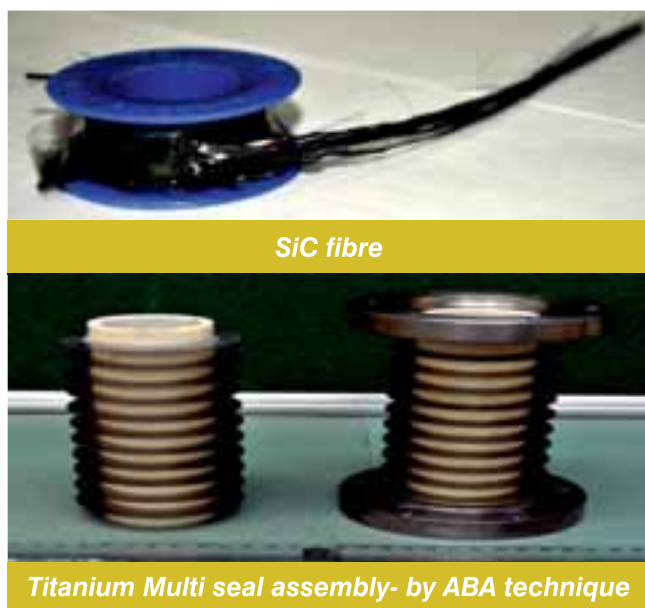
A data base for the thermo-physical properties of (Th,Pu)O $_2$  and (Th,U)O $_2$  Mixed Oxides (MOX) fuels up to 3000 K has been generated using atomistic simulations for the design of AHWR fuels with varying composition. A comprehensive simulation methodology has been chalked out to find out actual atomistic pathway for superionic transition in ThO $_2$ -based fuels to study their structural stability under extreme thermodynamic conditions where superionic transition temperature plays a decisive role.

Using Focused Ion Beam (FIB), sample preparation technique to prepare samples for 3-D Atom Probe (3DAP) and TEM has been standardized and 3DAP samples of irradiated pressure tubes have been prepared. The technique enables preparation of site specific TEM and 3DAP samples, while preserving sample surface modifications, such as those by irradiation.

Detailed microstructural characterization and heat treatment optimization of the RPV steels have been carried out. The fracture surfaces were analysed and the mechanism of fracture was assessed as a function of the heat treatment. A correlation was established between the fracture surface morphology and the fracture toughness value.

Yttrium loaded alumino-silicate glass microsphere of controlled size (20-35 $\mu$ m) were synthesized by conventional flame spherodization process for Hepatic Cellular Carcinoma (HCC) radiotherapy. Material shows satisfactory chemical stability and radionuclide purity after irradiation and comparable with commercially available THERESPHERE. The material is ready for pre-clinical investigation.

Well dispersed nano-sized alpha-silicon carbide powder for developing SiC based structural component for the nuclear reactor has been synthesized by reaction conversion method. The optimized process conditions resulted in >95% yield.



Reel to reel synthesis of composite SiC fibre (core-carbon with SiC periphery) of length 10m was carried out in automatic mode. Presence of hexagonal polytype of SiC in the fibre was confirmed by XRD.

The materials and process for joining of Alumina-to-Titanium by active brazing technique have been optimized. Multi seal assembly (of 22 joints) has been fabricated successfully by this technique. Helium leak rate of  $3 \times 10^{-9}$  torr.lit/sec has been achieved. The process can be utilized in making accelerator tube.

Large size single-crystal of  $\text{YB}_2\text{Cu}_3\text{O}_7$  (YBCO) high temperature superconductors for levitation, energy storage fly wheel and bearing applications were grown by top-seeded melt texture growth (TSMTG) technique.

At IGCAR, an advanced dual beam irradiation set up was developed to facilitate simultaneous helium ion injection from an indigenously built 400 kV accelerator and heavy ion irradiation from the 1.7 MV tandemron accelerator to closely simulate reactor conditions. Experiments were carried out to evaluate beam energy stability, determination of beam energy width, beam uniformity and extent of overlap of the dual beams spatially and in the intended range.

Micro and Nano-crystalline Diamond films with improved crystallinity and well-defined color centres were developed.

Vertically oriented few layer Graphene Nanosheets (VGN) of controlled morphology were grown by Plasma Assisted Chemical Vapour Deposition (PA-CVD) and their super capacitance was enhanced by post oxygen plasma treatment. An easily scalable methodology for transferring VGN structures onto flexible substrates was also established. Spectroscopically forbidden infra-red emission in Au-vertical graphene hybrid nanostructures was observed. The efficiency of quasi-one dimensional triphase pristine, doped and defective titania nanoparticles for  $\text{H}_2$  generation was studied by photo-assisted water splitting.

A prototype SQUID based time domain electromagnetic system for geophysical application has been developed and tested for the detection of conducting objects in the neighbourhood by recording the decay profiles.



A transient eddy current non-destructive examination system for the detection of defects in multi-layered structures was developed for the detection of an artificially engineered defect in an aluminium plate at a depth of 2 mm as well as 20 mm below the surface.

The change in resistance near superconducting transition temperature of reactively sputtered thin films were analysed based on superconducting fluctuations at various magnetic fields.

In multichannel Electro Echo Gram (EEG) measurements, automatic detection of the EEG signal contaminated due to eye-blink based on statistical properties of the signal was implemented. It automatically suppresses ocular artifact using advanced signal processing techniques.

### **Development of a thermally tunable grating using thermo-responsive magnetic fluid**

Towards development of temperature sensitive sensors and devices, a thermally tunable grating was fabricated. The ability of thermo-responsive polymer brushes to alter their conformation is exploited to achieve nanoscale reversible tuning.

### **Development of Nanocomposites for Radiopaque Fabrics**

Nanocomposites containing A-Bi<sub>2</sub>O<sub>3</sub>, B-Bi<sub>2</sub>O<sub>3</sub> and Bi nanoparticles as nanofillers in vulcanized silicone resin as a matrix were prepared and their diagnostic X-ray attenuation property was studied. Nanocomposites containing B-Bi<sub>2</sub>O<sub>3</sub> nanoparticles are found to exhibit higher attenuation than nanocomposites of A-Bi<sub>2</sub>O<sub>3</sub> and Bi nanoparticles of similar concentration. Thermal analysis of nanocomposites showed that the nanofillers interact with the matrix either by intercalating in the bridging polymer chain of silicone resin network structure or by occupying the interchain space.

### **Magnetic fluid hyperthermia**

An infrared thermography based non-contact temperature measurement methodology was developed for effective thermal mapping during magnetic fluid hyperthermia and an empirical data analysis protocol was also developed for the accurate estimation of heating efficiency.

### **A new approach for Effective Thermal Transport in Magnetic fluids**

A highly stable ferrofluid, which exhibits very high thermal conductivity to viscosity ratio was developed. Study shows that nanoparticle dispersions with high density interfacial capping, without larger aggregates, can provide very high enhancement in thermal conductivity, with insignificant viscosity enhancement due to minimal interfacial losses. Microscopic studies reveal that the larger particles act as nucleating sites and facilitate lateral aggregation (zippering) of linear chains that considerably reduces the number density of space filling linear aggregates.

### **Microstructural characterisation of proton irradiated Pure-Nb**

Niobium (Nb) and its alloys have been considered as one of the candidate structural materials for high temperature reactors due to their excellent high temperature strength, good corrosion resistance behaviour against the various coolants and good ductility. The present study deals with the evolution of the microstructure of the pure Nb metal due to irradiation with 5 MeV protons in low dose regime. Samples of pure Nb (100  $\mu$ m thick) with well recrystallized grains were irradiated using 5 MeV proton beam. It is observed that the domain size at the initial dose of irradiation remains almost unaltered even with the variation of dose by more than one order of magnitude. Both the microstrain and dislocation density increases initially and then decreases with dose. The increase in microstrain/dislocation density is attributed to the formation of defect clusters whereas decrease is due to the collapsing of large defect clusters to dislocation loops. The XRD results are corroborated with the TEM analysis, where the formation of loop is evident at the highest dose of irradiation.

### **Effect of Ar<sup>9+</sup> Irradiation on Zr-1Nb-1Sn-0.1Fe alloy characterized by Grazing Incidence X-Ray Diffraction Technique**

Zirconium-based alloys Zircaloy-2 (Zr-2) and Zircaloy-4 (Zr-4) are widely used in nuclear industry as cladding materials for BWRs and PWRs, respectively. Among the various properties that are affected by irradiation, the most important for Zr based alloys is the

irradiation enhanced growth. Irradiation using 306 KeV  $\text{Ar}^{9+}$  ion (range in sample 400 nm) from the ECR ion source was carried out on Zr-1Nb-1Sn-0.1Fe alloy samples to doses  $1 \times 10^{16}$  to  $6 \times 10^{16} \text{ Ar}^{9+}/\text{cm}^2$  to achieve dpa levels of 33 to 200 dpa respectively. The samples were characterised using GIXRD at three different incident angles to cover the entire damage depth. The microstructural parameters such as domain size and microstrain have been estimated using various XRD/LPA techniques. The variation of intensity with dose has been correlated with texture parameter. It is clearly observed that the domain size and microstrain which was expected to change due to the effect of irradiation remained almost invariant with dose.

Thermo-luminescence response of irradiated  $\text{Gd}^{3+}$  doped barium borophosphate glasses mixed with varying concentration of  $\text{Al}_2\text{O}_3$  were studied at RRCAT. The dose response of these glass samples exhibited linear behaviour in the dose range of 0 - 8 kGy.

The temperature dependence of electrical resistivity  $\rho(T)$  and heat capacity  $C(T)$  of the  $\text{Mo}_{1-x}\text{Re}_x$  ( $x = 0.20, 0.25$ ) refractory alloy superconductors were studied in different magnetic fields. Analysis of the results indicates the presence of a surface superconducting state in these alloys, where the flux lines are pinned in the surface sheath of the superconductor. Experimental evidence in support of the surface mixed-state or 'Kulik vortex-state' and the occurrence of a vortex-liquid to vortex-glass transition within this surface sheath was obtained.

BFO/PMN-PT nano-composite was fabricated and enhancement of ferroelectric, ferromagnetic properties and magneto electric coupling at room temperature have been demonstrated. The observed electric field poling induced magnetization exchange biasing makes this composite a possible candidate for spintronics and sensor applications.

A compact experimental assembly has been designed and fabricated for quasi-simultaneous measurement of magneto-photoluminescence and magneto-surface photo-voltage spectrum. The facility is being utilized to study the effect of temperature and magnetic field on the radiative and non-radiative recombination processes in semiconductor quantum structures.



*Photograph of PL emission from quantum dots embedded in polymer*

A femtosecond laser irradiation based process for enhancement of photoluminescence (PL) of CdTe quantum dots has been demonstrated. It has been shown that for a given power density, the rate of enhancement of PL is directly proportional to the absorption coefficient of the sample, indicating that the heat generated by the laser exposure plays a strong role in enhancement of PL. This technique is useful for improving the photoluminescence from quantum dots as it is fast, causes no size change, and the irradiated quantum dots are stable.

To obtain measurable Raman spectroscopy signal in nanostructures, Surface Enhanced Raman Scattering (SERS) can be employed using rough/nanostructure metal surfaces. The Langmuir Blodgett technique is employed in  $\text{TiO}_2$  nanostructures. Simulation studies on effect of temperature were carried out for predicting surface modification of InAs nanowire using laser irradiation. The surface modification was monitored by Raman spectroscopy.

From first-principles calculations it was predicted that  $\text{Co}_2\text{PtGa}$  possess low inherent crystalline brittleness as well as the high melting, martensite transition, and Curie temperature; all of these well above the room temperature, which makes it a promising material for application as a high temperature magnetic shape memory alloy. Using density functional theory based calculations, it has been established the implicit and important presence of RKKY interaction in Heusler alloys which are likely to exhibit magnetic shape memory effect.

Ultra-fast resistive switching with write and erase time  $\sim$  tens of ns (about 1000 times faster than

existing flash memory) has been demonstrated in Au / NiO / Pt devices at low switching voltages  $\leq 3V$ . The device may find potential applications towards development of upcoming memory technology for non-volatile data storage applications.

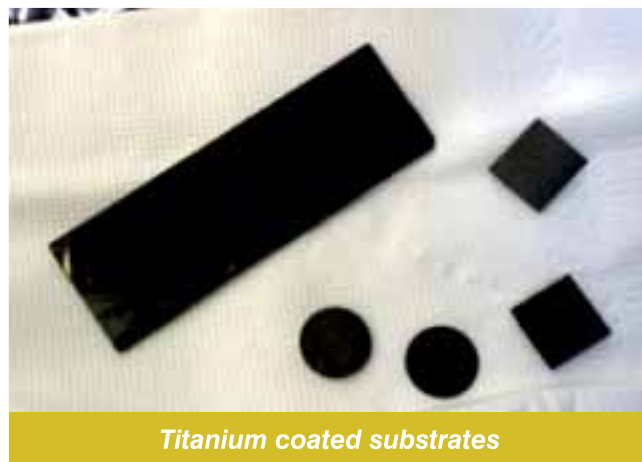
Detection of carcinogenic heavy metal ions (such as Hg, Pb, As), present in water due to natural or artificial processes, is important to maintain the pollutant free drinking water and aquatic ecosystem. It was shown that plasmonic gold nanoparticles can be effectively utilized as real time and cost effective sensor by monitoring their colour (plasmon resonance wavelength) change with  $Hg^{2+}$  concentration.

Schottky junction based InAsP/InP Multiple Quantum Well (MQW) photodetectors have been fabricated and tested for infrared detector applications. In this Au-Ge/Ni/Au metallic contacts were deposited on n-InP substrate to form Ohmic contacts. Schottky contacts were made of gold (Au) and Au wires were used to make the final electrical connection from both types of contacts. The measured spectral response of the fabricated detector show peak responsivity of 9 mA/W at around 1  $\mu m$  wavelength.

Undoped and rare earth doped Strontium Barium Niobate (SBN) single crystal were grown by optical floating zone technique for pyro-electricity based laser energy sensor application. Significant improvement in the detection sensitivity for pulsed Nd:YAG laser output (1064 nm, 7 ns) was observed in Gd doped SBN (29V/J) in comparison to undoped SBN (14V/J).

Platinum carbon aerogel with partial substitution by titanium (Pt/Ti-CA) for cost effectiveness was synthesized and tested for the H/D isotope exchange in experimental hydrogen-water test column. The 25% Pt substituted by Ti [Pt / Ti (75:25)-CA] catalyst was evaluated. Isotope exchange efficiency and volume transfer rate of 83% and 0.3  $m^3$  (STP)  $s^{-1}m^{-3}$  respectively were observed. The values are comparable to the performance of the Pt-CA catalyst tested under similar test conditions.

Cerium doped transparent YAG ceramic was developed in-house and tested for x-ray imaging on x-ray lithography beam line (BL-07) of Indus-2. With 0.3



*Titanium coated substrates*

mm thick ceramic sample, a spatial resolution of 15-20  $\mu m$  has been achieved. Radiographic images of dead houseflies and black-ant are recorded on transparent Ce:YAG ceramic.

Magnetron sputtering system was used for titanium coating on inner surfaces of DN 100 CF (stainless steel) circular chamber. Co-centric probe technique was used to measure the coating thickness. The measured thickness was found to be 0.8 to 0.9  $\mu m$ . The coating was analyzed for its composite of various elements using SEM EDAX. It was found to be Ti-92.97%, Al-1.7%, Si-4.27%, Mg-1.07%. Optimization studies are in progress for coating on kicker ceramic chambers of Indus-2.

## INTERDISCIPLINARY AREAS

During the year, some of the achievements of the TIFR Centre for Interdisciplinary Sciences, Hyderabad include introduction of robust pulse schemes for spin decoupling in solid-state NMR; Designed pulse schemes for simultaneous acquisition of multidimensional experiments in solid-state NMR; Built a unique effusive source of micron sized particles for laser plasma studies to enable the study of intense laser interactions with mesoscopic particles of any shape and size; Established a strong correlation between short and long time relaxations in glassy liquids; Proposed a novel method to study growth of amorphous order in glass-forming liquids; Developed a new triple quantum CPMG experiment to study methyl group dynamics in proteins; Developed an ultra-sensitive ammonia sensing platform using fluorographene. This work was noticed by international academia and industries initiating



collaborations with Boston Children's Hospital and University of California, Berkley; Developed new catalysts based on mesoscopic interfaces for catalytic reactions such as Hydrogen Evolution Reaction (HER), Oxygen Evolution Reaction (OER), and Oxygen Reduction Reaction (ORR), and development of cost effective water electrolysis and fuel cells with them, devoid of any benchmarked precious catalysts; Developed new assays for RNA and protein detection to study DNA damage responses and the cell-cycle, both in cultured cells and primary tissue; Developed a new tailored spin-diffusion experiment to compensate for the effect of chemical shifts at fast MAS in perdeuterated proteins with back exchanged protons; Set up the experimental thin film deposition cluster facility. A Molecular Beam Epitaxy (MBE) chamber is fully functional with the capability to grow thin films and in-situ vertical junction devices enabling us to make devices of minimum feature size of 30 microns using in-situ shadow mask; For the first time, experimentally established the presence of solid-on-solid contact during sphere-wall collision in a viscous fluid, as opposed to the common belief of lubrication; Designed refined pulse methods in solid-state NMR for spin decoupling using refocussing strategy; Introduced a solid-state NMR recoupling under very high magic-angle spinning frequencies ( $> 110$  kHz) for the first time paving the way for connectivity information in biomolecular systems keeping the resolution intact; Experimentally demonstrated dominance in field ionisation over collective mechanisms in ultra-short pulse cluster ionization; Demonstrated and characterized a nanotip based femtosecond electron source; Proposed a novel method to calculate the dynamic and static length scales in glass-forming liquids; Resolved the long standing issue of how benzene reaches the buried cavity in T4L lysozyme L99A using MD simulations; Discovered a new route for the development of high ionic conductivity solid electrolyte for ionic transport, such as Lithium, leading to the initiation of membrane research in the laboratory; Gained new insight into the cell-cycle dependence of DNA damage responses through High Content image analysis; Developed a method to image single mRNA molecules in primary tissue from *Drosophila* in collaboration with the Ray laboratory in TIFR Mumbai; Installed and commissioned cryogen-free scanning tunnelling microscope (STM).

Custom integration of the STM with our MBE is expected to be completed by March 2018, allowing in-situ transfer of samples between MBE and STM; Built a novel FCS setup to widen applications of single molecule experiments in various problems in biophysics; Developed a new strategy for sampling training sets for machine learning using genetic algorithm; DRDO project under Contract for Acquisition of Research Services (CARS) scheme for 'Frequency stabilization of Diode Laser for Atom Interferometry' and MoU agreement with Indian and UK groups under the Newton Bhabha Fund Collaboration Agreement.

## INTERNATIONAL RESEARCH COLLABORATION

The Photon Multiplicity Detector (PMD) has been taking data in the ALICE experiment at CERN. It has collected data with pp, pPb and PbPb collisions at different energies. During March-April 2017, a major repair work was undertaken at CERN for improving the common acceptance of the two planes of PMD upto 90%. This has been achieved by repair of the modules, readout electronics and HV system. With this new configuration, PMD participated in data taking till October 2017 collecting more than 250 Million pp collisions at 13 TeV centre of mass energy. The data quality was monitored during the run and presently the analysis work is ongoing.

During the current year, about 22 internal notes describing analysis details have been submitted by the Indian authors and accepted by the ALICE



*Photon multiplicity detector after repair in 2017*



*Ongoing repair work*

collaboration. This year, five students have been awarded/submitted theses on their works in the ALICE experiment. The major topics in which Indian students participated in analysis are (a) heavy flavour production (b) correlation of identified particles for understanding the particle production mechanism (c) resonance production among others.

VECC is playing a major role in building the muon detection system for the Compressed Baryonic Matter (CBM) experiment in the upcoming FAIR facility at Darmstadt, Germany. During the year, VECC has built three large size GEM chambers and tested one of them with p+Pb collisions at SPS-CERN. The detectors were connected with a self-triggered electronics using nXYTER ASIC. Tracks were formed using 3 GEM



*Two CRU boards despatched to CERN*

stations. Two more large size GEM chambers will be tested with proton beams at the COSY facility in Juelich-germany in February 2018.

In addition to GEM, during the year, VECC has also fabricated and tested large size RPCs for the CBM experiment with cosmic rays.

As a part of VECC's participation in the ALICE upgrade programme, FPGA\_based high density Common Readout Boards (CRU) are being fabricated by the Indian industry under the guidance of VECC engineers. So far, four boards have been built and tested. Two have been shipped to CERN.

During this period, for the first time, VECC has demonstrated the feasibility of using GEM chambers for X-ray imaging for medical purpose. During the year, a special GEM chamber (10cm x 10cm) with strip (width 80, 350 microns) readout with stereo readout was built and X-rays were passed through a kapton window on the detector. The data have been processed to reconstruct the structure and we could resolve the shape quite well demonstrating the feasibility of such a setup.

In addition, as a part of R&D for proposed Forward Calorimeter in ALICE for LS3, VECC in collaboration with BARC and BEL has designed, developed and fabricated a 20Xr thick sampling type silicon-tungsten calorimeter prototype. The prototype has been constructed and tested extensively at CERN-SPS beam line facility both with pion and electron beams of different incident energies during July, 2017. Primary results are quite satisfactory with prediction about calibration, electron responses etc.



*A 20Xr thick sampling type silicon-tungsten calorimeter prototype*



A solid state amplifier has been developed and installed at CERN, Geneva for energizing sub-harmonic, bunching system of the Compact Linear Collider (CLIC) drive beam injector. The amplifier provides up to 20 kW of peak power with pulse width of  $140.3 \mu\text{s}$  and repetition rate of 50 Hz. Amplifier features a 3 dB bandwidth of 58 MHz at centre frequency 499.75 MHz and gain of 59 dB at peak power. The amplifier has pulse to pulse phase and amplitude stability of better than  $1^\circ$  and 0.1 dB, respectively.

At the International Centre for Theoretical Science (ICTS), TIFR under LIGO-Virgo collaboration, direct contributions of ICTS include tests of Einstein's theory using near-simultaneous observations of gravitational waves and gamma rays.

### 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.

#### Developments at International Level

There has been visible progress of site construction and manufacturing activities. Physical progress of the ITER project is now at 48% for the components and systems necessary for First Plasma in 2025.

#### Progress in Procurement Arrangements (PA)

From the beginning of the project in 2007, a total 14 (out of 15) Procurement Arrangements (PA) have been signed. Eleven major contracts for the manufacturing of ITER components have been signed till date. Good progress has been made at manufacturing sites and some components are already delivered to IO or to other DA sites. Pre-procurement activities for remaining PA are going on. The summary of activities completed during the reporting period is given below:



*Lower Cylinder Tier-2 segments delivered at ITER site*



*Base Section Tier-1 setup completed and cleared for welding*

Six sectors for Cryostat Lower cylinder (Tier-2) along with Transporter frame have been shipped to ITER site. Welding of Cryostat Lower Cylinder sectors started at ITER sub-assembly workshop.

Support Ribs & Lower Brackets assembly for 1.1, 1.4 & 8.4 delivered to KO-DA and Support Ribs & Lower Brackets assembly for 4.4 delivered to EU-DA.

Manufacturing of Lot-1 Horizontal Centrifugal Pump (CHWS-H2 [4]) is completed. Shipment of Self-Cleaning Filters for Heat Rejection System, Lot-1 Water-Cooled Chillers [2] & Lot-2 Water-Cooled Chillers [2] Completed.

Factory acceptance of SNB, SNS & SNP are completed. Shipment of Nitrogen SNS Cryolines (For Bldg. 52 & 53) of Lot-Y1 is completed.



*Cryolines group X3 delivered at ITER site*





**CTCB internal assembly completed**

Erection of 13m vertical section of transmission line at ITER-India lab for 140 kVDC high voltage transmission lines. Final erection of SP-AGPS at NBTf site, Padua Italy.

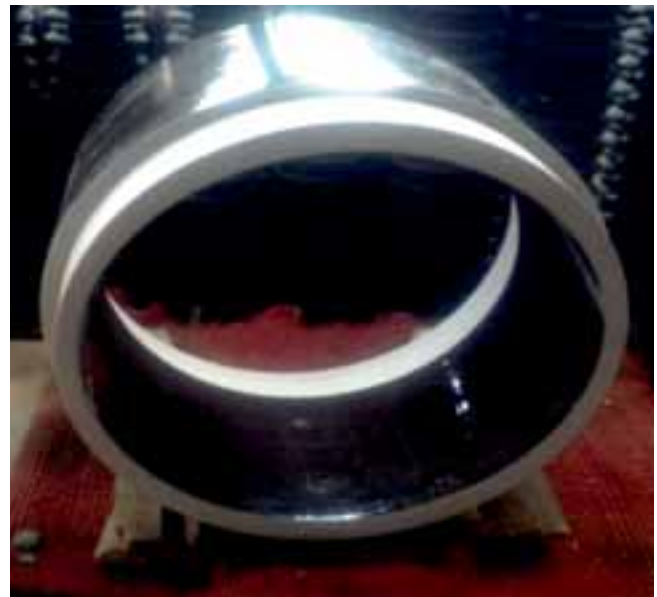
Demonstration of Lip seal laser welding for 1:1 size high voltage bushing flange and 1:3 size DNB vessel top lid. Completion of FAT and Delivery of first vacuum brazed cryopump (12 numbers). Completion of manufacturing, inspection and testing of accelerator post insulator, with threaded ceramic concept.

Indigenous development of Oversized Corrugated waveguides a scaled down prototype in collaboration with local industry. Development of a gyrotron simulator to simulate the test conditions and test the control system hardware and software applications.

Completion of Site Acceptance of waveguide components for ECE Transmission lines. Completion of testing of high temperature black body calibration source for ECE diagnostics.



**Demonstration of Lip seal laser welding for high voltage bushing flange a DNB vessel top lid**



**Porcelain ring (dia ~800mm) - in advance stage of manufacturing and testing**

### Fusion Blanket technologies

A scaled down mock-up of a fusion reactor FW component, having 10 channels (full model is having 85 channels) was successfully fabricated. This qualified the manufacturing technology along with inspection techniques. The fabricated model has also been successfully tested in high heat flux testing at KIT, Germany.

Various in-house R & D activities for Pb-Li technology development are under progress at IPR with the prime objective of using it as a coolant as well as tritium breeder in a future liquid breeder fusion blanket. A high temperature compatible sensitive flow meter, using a dipole Halbach array of eight permanent magnets has been fabricated. The Halbach array of eight large size bar magnets was carefully assembled by overpowering their huge repulsive/attractive force, equivalent to the force required to lift a weight of 250 kg. The flow meter is now being calibrated in a Pb-Li loop at an operating temperature of 350°C.

The first phase of Pb-Li heat transfer experiment has been completed and data analysis is being performed to characterize the heat transfer properties of Pb-Li. The preliminary results suggest that at low velocities of molten Pb-Li, gravity plays a dominant role in deciding the heat transfer; however, at high velocities the viscous forces become more significant.

# CHAPTER RESEARCH EDUCATION LINKAGES

6



*Graduation Ceremony of TMC, Constituent Institute of HBNI*



*Mandatory Induction Training Programme for Security Guards*



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

The human resource and knowledge management is developed through Homi Bhabha National Institute (HBNI), BARC Training School and the Administrative Training Institute (ATI).

The Board of Research in Nuclear Sciences (BRNS) an advisory body of the Department of Atomic Energy (DAE) provides financial assistance to universities, academic institutions and national laboratories for encouraging and promoting scientific research in the areas of relevance to the mandate of DAE.

The National Board for Higher Mathematics (NBHM) established under the aegis of DAE promotes excellence in higher Mathematics education and research in the country. The Board also provides grants for promotion of activities in pure and applied Mathematics under several schemes including support to research projects, travel grants for participation in workshops, conferences and undertaking collaborative research funds for organizing conferences etc.

## HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

### Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a deemed University, is a grant-in-aid institute of the DAE. It has completed successful 12 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. It nurtures academic programmes of eleven premier institutions of the DAE under a single umbrella making vast research and faculty resources within DAE available for students. It serves as a catalyst to accelerate the pace of basic

research and facilitates its translation into technology development and applications through academic programmes viz. Postgraduate degrees/ diplomas and Ph.D. degrees in Engineering Sciences, Physical Sciences, Chemical Sciences, Mathematical Sciences, Life Sciences, Health Sciences and Applied Systems Analysis. The unique feature of the Ph.D. programmes of HBNI is to encourage multi-disciplinary research, in which a large number of students are pursuing their academic programmes under two guides, from different disciplines. Besides providing valuable human resources to the S&T domains of the Country, the academic programmes of HBNI are also having a significant societal impact, for example, a significant fraction of the medical oncologists in the country have been beneficiaries of HBNI programmes.

During the calendar year 2017, 760 students were admitted in different academic programmes. More than 1500 students are currently pursuing Ph.D. in various disciplines under HBNI.

HBNI has awarded 187 Ph.D. degrees during the period. 71 Post-graduate medical degrees and 46 super-speciality medical degrees (DM / MCh) in the area of oncology have been awarded. Moreover, 36 Diplomas in Radiation Protection (DipRP), Medical Radio-Isotope Technology (DRMIT), Radiation Medicine (DRM), and Fusion Imaging Technology (DFIT) have been awarded during this period. HBNI has also crossed a milestone of award of 1000 PhD degrees, during the current academic year.

HBNI has signed several MoUs with National and International Institutes for academic collaborations.



*Graduation Ceremony of TMC,  
Constituent Institute of HBNI*

During this year a joint team of UGC-AICTE conducted a review of the activities of the HBNI as per UGC Regulations and deeply appreciated several of its academic features and has recommended continuation of the Deemed to be University status to HBNI.

## Training School

While the academic programme of the 60th batch of BARC was continuing, screening examination for 9 engineering and 5 science disciplines for the 61st batch was organized at 65 venues in 45 cities. This year one candidate was selected for the first time in Nuclear Engineering discipline, which was introduced last year.

DAE's outreach programme was supported by the officers from RRCAT, IGCAR, NFC and VECC in addition to those from BARC. It covered 168 colleges/universities, including north-east. Out of the 1,45,690 applicants, 84,570 appeared for the online examination. Out of the 18,644 applicants in science disciplines, 10,520 appeared for the examination. A total of 2,660 candidates appeared for the interview. A total of 164 candidates were selected for OCES/DGFS-2017. No candidate was found suitable for selection into DGFS. The 61st OCES Batch of BARC TS was inaugurated by Director, BARC as Chief Guest.

A total of 126 TSOs and 7 fellows of OCDF 2016 scheme, after successful completion of the training, were placed in various units of DAE. Graduation Function of BARC Training School was held on July 26, 2017 with Prof. Devang Khakhar, Director, IIT Bombay as the Chief Guest and Dr. Sekhar Basu, Chairman, AEC, and Secretary DAE as the Guest of Honour. Chief Guest gave away Homi Bhabha Prizes to the toppers of 12 OCES disciplines of 60th batch and the topper of the 13th OCDF course.

Work for OCES/DGFS-2018 programmes began in November-December, 2017 with the preparation of advertisement to be published in the first week of January 2018. A short advertisement in the Official Language in Hindi language daily newspapers in the Northern Hindi-speaking belt is planned to be released besides a long advertisement in 26 national and regional dailies in 46 cities and towns. A full page advertisement will shortly be published in 'Employment

News.' Campaign through DAE facebook page has been launched too. A leading net job portal was engaged to send emails to the target candidates and display a banner with link to OCES/DGFS-2018 online application portal, on its home page.

In order to promote DAE activities and thereby attract best talent to our fold, visits to as many colleges and universities as possible during January 6 to February 4, 2018 have been planned under the outreach programme. The Online examination, during March 28-April 3, 2018 is planned at 45 cities/towns with multiple venues in cosmopolitan cities.

By the end of March, 2017, foundation and core course work along with examinations for OCES 2016 had been completed. It was followed up with technical visits to DAE facilities at Tarapur, placement viva, elective courses, mini-projects, administrative workshop etc. The soft skills workshop for all the TSOs, introduced during OCES 2012, continued for OCES 2016 as well. The 4-month academic course work for OCDF 14th Batch, which started on August 1, 2017 along with OCES 61st Batch, had been concluded successfully. At present, the academic course work of 2nd semester of 61st Batch is underway, and by end of March, 2018, the end of semester examinations would be completed. During the present year, a total of about 150 of over 170 courses consisting of foundation, core and elective courses were taken by TSOs. About 600 faculty of practicing scientists and engineers were invited from various Divisions/Units of DAE. Mini-projects this year were allotted to TSOs in consultation with their prospective Divisions/Units. About 140 Scientists and Engineers supervised the project work of the TSOs.

At the request of NPCIL, a full year exclusive training to 21 civil engineering candidates selected by NPCIL is planned. These candidates called 'Executive Trainees' (ET-NPCIL) have been accommodated in TSH. They are being trained under a programme similar to OCES programme of BARC Training School. Their entire course work, mini projects, technical tours, welfare etc. are being looked after by a special committee constituted by Head, HRDD. The committee has coordinators from HRDD, NPCIL and AERB. On completion of training, they will be absorbed entirely by NPCIL.

Coordination of the summer training (1 to 2 months) and academic projects (2 to 12 months) of BE/B.Tech/M.Tech/ ME/Engg Diploma/MSc/MCA students from all over the country was carried out. In 2017, 956 students from different institutes visited BARC for training/project work.

Soon after formal joining in different Divisions/Units of DAE by the graduate TSOs, the process of allotment of M.Tech project work got underway in consultation with the respective Head of Division/Unit. The allotment of M.Tech Projects to all the eligible fresh officers from OCES 2016 has been completed. M.Tech (new) enrollments during the period were 77. A total of 65 candidates completed M.Tech during the period.

Two advanced courses under 9th set of QUEST course have been completed. Another advanced course was offered and completed by Prof. C. Ganguly. About 70 candidates benefitted from the course. One more course is underway.

Infra structural facilities including a well-stocked library, computer labs, a Nuclear Physics (RDM) and 2 Process Control Labs, a 540 MW PHWR (1:50) model for display were well maintained. Access control system consisting of 4 sets of flap barriers and one turnstile at TS Complex in addition to CCTVs in Training School Hostel (TSH) are functioning well. All the trainees staying in TSH are now provided with internet connectivity in individual rooms.

BARC conducts One-year Diploma Course in Radiological Physics (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. These courses are mandatory as per AERB regulations. BARC 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. It also offers human resources support for Courses / Capsules conducted under the banner of School of Radiological Safety Studies (SRSS), GCNEP, New Delhi.

National training course on Design and development of physical protection system of Nuclear Material & Nuclear facility was conducted from 6-17 Nov. 2017 at CTCRS Lecture Hall, Niyamak Bhavan, Anushaktinagar. The training course was attended by 31 participants from BARC, NPCIL and different units of DAE. Total 21 faculty members from various units like BARC, DAE, NPCIL, IGCAR, AERB, BRIT were involved for delivering lectures and carrying out exercises. One day field visit was arranged to Tarapur, NPP.

Thirty three Trainee Scientific Officers of the eleventh batch of BARC Training School at IGCAR have completed their training in five disciplines and were placed in various units of DAE. In the present academic year, twenty nine Trainee Scientific Officers are undergoing training at the Training School. In the current batch, 23 Research Scholars were inducted, to pursue their doctoral programmes in the frontier areas of engineering and basic sciences. Employees, who are pursuing higher studies under the aegis of Homi Bhabha National Institute, are also undergoing coursework at the Training School.

BARC Training School AMD Campus, Hyderabad continued its activity in the eighth year by imparting induction training to Geology (11) and Geophysics (4) Trainee Scientific Officers (TSO's). Human Resource Development has been continued with in-house (97 officers, 9 Scientific Assistants, 26 Technicians, 17 Work Assistants, 1 driver and 3 contractors) and external (29 officials) trainings in institutes like ISM, Dhanbad; NFC, Hyderabad; ATI, Mumbai; ASCI, Hyderabad; IIP, New Delhi; NIAS, Bengaluru; DGST, Hyderabad; TSFA, etc. 109 students from various universities and institutions were imparted internship, field / laboratory training in AMD. 102 students from universities visited laboratories at AMD Headquarters and Regional Centers.

Human resources development activities at RRCAT continued to contribute in a significant way towards development of quality scientific and technical manpower in the country. Trainee Scientific Officers (TSOs) are imparted one year training in physics, electrical and electronics disciplines, which also serves as one year course work towards the successful completion of M.Tech. and Ph.D. degrees of HBNI,





**Shri S. K. Sharma, CMD NPCIL, distributing certificates in the concluding function of OCAL-17**

Mumbai. In the 17th batch, 4 TSOs have completed the one year Orientation Course on Accelerators and Lasers (OCAL-17) and have been placed in various units of DAE. 3TSOs who passed out previously from various BARC training schools and joined RRCAT as SO/C have been awarded M.Tech. Degree. The number of Ph.D. scholars who have completed the one year pre-doctoral course are 6 and currently 4 Ph.D. scholars are undergoing the course work. During 2016-17, 10 scholars have been awarded Ph.D. degree by HBNI. RRCAT also provides the opportunity to M.Tech. /M.Sc. students of various universities and engineering colleges to carry out their one year/six months project work towards the partial fulfilment of their degrees. This year, a total of 110 students from various universities/institutions completed their M.Tech. Project work at RRCAT.

NPCIL, continued to achieve the organizational goal through its HR initiatives directed towards attracting, motivating and retaining the trained manpower. These initiatives included developing strategic and incremental packages from time to time for effective Human Resource Management to meet the aspirations of the employees. Optimization of manpower continued to be an important strategy towards best utilization of human resource. Accordingly, staffing has been done strictly in accordance with the optimized manpower models for Projects, Stations and Headquarters, including multiunit Sites.

NPCIL consists of 11481 strong and dedicated workforce with 3727 engineers and scientists, 5971 technical employees, 1539 non-technical executives

and staff and 244 Auxiliary support staff who spearhead the activities of organization. During the year, as a part of annual induction program of young talent to NPCIL, 231 direct recruits in Scientific & Technical categories and 10 direct recruits in the non-technical categories (Group A & B) were recruited through centralized recruitment process. In the career progression front, during the year, 1002 employees in Scientific and Technical categories were elevated to the next higher grade. 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 To minimize the grievances of employees, a structured mechanism for redressal of grievances is in operation which is sensitive and attentive to employee grievances at all levels.

Performance Linked Incentive Scheme (PLIS) linked to various production targets and construction milestones finalized by way of tripartite settlement between Management, Employees and conciliation Officers has been proved very successful and instrumental in improving the production by boosting morale of employees and executives. In addition to this, a good award scheme for encouraging employee to work toward achievement of organization goals in efficient and effective manner.

As in the past, the Institute of Physics (IOP) contributed in a significant way towards quality human resource development in the form of one year pre-doctoral course followed by the Ph.D. program. At present, IOP, Bhubaneswar has 41 Ph.D. students, 19 Post-Doctoral Fellows. IOP has 25 faculty members and more than 10 Sr. Professor visited during the year. This year nine scholars have joined the pre-doctoral program while seven doctoral scholars received their Ph.D. degrees.

### Administrative Training Institute

The Administrative Training Institute (ATI) of DAE, started functioning on 2nd July, 2007 with the

motto “Prashikshanesu Dakshprayate – Training Empowers”. Till date, ATI has organized over 825 programmes for more than 22,860 participants. ATI's other major achievement is “Training at Doorstep” for different units. During the year 2017-18, about 21 programmes were conducted at DAE's various outstation units. Smooth conduct of the various training programmes could be achieved because of the robust Training Management Information System (TMIS) at ATI. This takes care of major training activities right from drawing up Annual Training Calendar, preparation of training schedules, nomination data, confirmation, faculty database, feedback, budget and expenditure management etc.

ATI offers wide range of programmes starting from induction to post retirement & periodic in-service programmes and subject specific workshops ensuring depth and range.

Against 70 programmes scheduled for the financial year 2017-18, ATI will be conducting 64 programmes which would be completed by the end of January, 2018 and the target is expected to be achieved by February, 2018. This includes two programmes on Gender Sensitization & Equal opportunities in Govt. Service, two Mandatory Induction Programmes for Work Assistants, one Mandatory Induction Programme for the newly recruited Security Guards.

Some of the major highlights of the ATI training programmes included three programmes on GST (Goods and Services Tax); one programme on Government e-Marketplace (GeM); two Programmes for retirees on Retirement Benefits and Life Management post retirement; Workshop on Contract Labour & Outsourcing; two programmes on Heart of Effective



**Workshop on Government e-Marketplace (GeM)**

Living and three programme on Effective Living & Leadership Programmes at Initiatives of Change, Panchgani. All the programmes were well received. Under the Management Development programme, a one week programme for Group-A Officers was conducted at YASHADA, Pune. Two programmes on prevention of Sexual Harassment (Laws) were conducted including one workshop on the working of the Internal Complaints Committee through a blend of Internal & External faculty.

During the year 2017-18, special efforts have been taken to organize Management Development Programmes both by tying up with Institutes of repute as well as in-house programmes at ATI, thereby, honing up the soft skills of our work force and ensuring attitudinal improvement in their personalities which would result in enhanced and better job performance.

In order to strengthen the personnel working in DPS and AEES, total 8 programmes have been conducted separately for them. All categories of employees including scientific and technical personnel of all constituent Units/ Aided Institutes/PSUs under DAE have also been included in the programmes conducted by ATI.

Professional training for the Security Staff of the Department is another important programme which has been well received. This programme involves field visits to DAE units. The Induction Training for Security Guards is for a duration of 45 days culminating with a grand passing out parade organized with a purpose of instilling pride in their work. This is a flagship programme of ATI which has been highly appreciated.



**Mandatory Induction Training Programme for Security Guards Conducted during 30.10.2017 to 15.12.2017.**

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 with every passing year.

## SPONSORED RESEARCH

### Board of Research in Nuclear Sciences (BRNS)

Board of Research in Nuclear Science (BRNS) is an advisory body of DAE. Besides funding research projects, BRNS provides financial assistance to organize symposia/ conferences/ workshops on topics of relevance to the programmes of DAE. BRNS also awards projects to young scientists to initiate them in a career of research and Dr. K. S. Krishnan Research Associateship to identify and encourage highly talented young scientists and technologists. The DAE Graduate Fellowship Scheme (DGFS) is meant for inducting Graduate Level students doing M.Tech. at the IITs. The Raja Ramanna Fellowship of BRNS is meant 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 honourable services of Scientists and Technologists who have distinguished themselves at national and international levels.

During the calendar year, 112 new research projects were sanctioned. In all Six hundred and Ninety bills were forwarded for disbursing total grant of ₹ 6424 Lakhs towards new & Ongoing Research Projects, Technical Programme Discussion Meetings (TPDM), miscellaneous institutional support and other scientific activities. This includes grant for the Olympiad Programme of Homi Bhabha Centre for Science Education (HBCSE) and Centre for Basic Studies (CBS).

Fifteen new students were inducted under DGFS-Ph.D programme, bringing the total number of Ph.D. students under this scheme to 100. Total 14 students have completed Ph.D., since the inception of this scheme.

Financial support to the tune of ₹ 278 Lakh was extended to DAE as well as Non-DAE academic and scientific organizations for conducting 156 seminars on various topics of relevance to DAE. Out of these, 23

symposia were solely organized by the DAE fraternity and they were fully funded. Under the Raja Ramanna Fellowship scheme, grant for 64 scientists was disbursed, besides two Homi Bhabha Chairs.

### Promotion of Mathematics

The National Board for Higher Mathematics (NBHM) was established under the aegis of DAE in the year 1983 with the objective of promoting excellence in higher mathematics education and research in the country.

NBHM has been in charge of the Mathematics Olympiad activity for talented young students at higher secondary (the plus two) level. This activity is conducted with the help of the Homi Bhabha Centre for Science Education (HBCSE). Selection for participants of the Indian Team to International Mathematics Olympiad (IMO) is decided in two steps – (1) The Regional Mathematics Olympiad (RMO) and (2) the Indian National Mathematics Olympiad (INMO) at the national level. Selected students from INMO are offered further summer training in mathematics through a Nurture programme for the succeeding 4 years and provided scholarships and cash prizes.

This year a team of two members participated in the EGMO 2017 (European Girls' Mathematics Olympiad) held in Zurich, Switzerland during April 6-12, 2017. One member of the team won a bronze medal and another an Honourable mention for a perfect solution.

In the APMO 2017 (Asian Pacific Mathematics Olympiad), the top 10 students from IMOTC participated and won 3 silver medals, 4 bronze medals and 4 honourable mentions.

The IMOTC 2017 was held over 3 weeks from April 20th to May 18th in HBCSE, at the end of which a team of six students were selected to represent India in IMO 2017 in Brazil.

The pre-departure camp for the six selected students was held from July 6-14, 2017 in HBCSE. The team secured 3 bronze and 3 honorable mentions.

NBHM is conducting Madhava Mathematical Competition for the undergraduate students. This



competition is designed so as to generate interest in mathematics in early years of college. NBHM is in process of creating suitable infrastructure, in the form of human resources, for this purpose.

NBHM gives grants to various mathematical centers engaged in activities of promoting higher mathematics. The Chennai Mathematical Institute that runs a high quality undergraduate programme in mathematics is a regular recipient of grants from NBHM. The Kerala School of Mathematics, Calicut, The Institute of Mathematics and Applications, Bhubaneswar and the Bhaskaracharya Pratishthana, Pune, are the other institutes getting grant from NBHM based on various programme proposals.

Taking proactive role in spotting talent in the country, the Board provides scholarships and fellowships to the students, selected through nationwide competitive tests, to pursue studies at masters and Ph.D. levels. The Board also offers post-doctoral fellowship positions to the young mathematicians after their PhD degrees through the selection process.

During the summer vacation, active training programmes are also organized outside the regular educational framework at the undergraduate level, called Mathematics Training and Talent Search. Supplementary training activities are also undertaken for selected students at postgraduate level, in a coordinated fashion, under the Advanced Training in Mathematics (ATM) programme.

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.

NBHM has been providing grants to mathematics libraries around the country, enabling them to purchase the latest books and journals in mathematics. Around 96 such libraries take advantage of this scheme of NBHM and update their collections of Journals / Books in mathematics. NBHM also distributes selected books to various postgraduate institutions under its book distribution scheme.

Financial support was provided to 49 national and international conferences held in India, Travel grants were provided to 14 mathematicians to enable them to participate in conferences held in India and abroad. Post-Doctoral Fellowships were awarded to 48 new researchers, 34 candidates were selected for the pursuance of NBHM PhD programmes and 39 students received MA/Msc scholarships. One RTI query was received and answered during this period.

The new Web-based interactive system for communication, evaluation of proposals and administrative purpose is now ready. The two servers have been successfully installed at the HBCSE and TIFR computer facilities. The system is expected to go operational by March 2018.

## 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.

Establishment of Mahatma Pt. Madan Mohan Malaviya Cancer Centre in BHU Campus in Varanasi, Uttar Pradesh has been approved. The Department has taken over Dr. Bhubaneswar Borooah Cancer Institute (BBCI), Guwahati under the administrative control of Tata Memorial Centre (TMC), Mumbai.

The Centre for Cancer Epidemiology has been set up with a dedicated facility in Advanced Centre for Treatment, Research & Education in Cancer at Kharghar campus under Tata Memorial Centre, resulting in major insights into breast, cervical, colorectal & gall bladder cancer.

The Homi Bhabha Cancer Hospital in Sangrur District, Punjab has become functional. More than 3000 patients are registered annually. This is the joint successful demonstration of a spoke in District General Hospital for delivery of healthcare in every state.

### 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 2017-18 for such partial financial assistance is to the tune of ₹ 20.98 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

The Olympiad teams representing India in the international Olympiads continued their run of successful performance. India was the 3rd ranking country in the International Junior Science Olympiad, 5th in the International Physics Olympiad and 5th in the International Olympiad on Astronomy and Astrophysics. Overall, in all subjects, of the 30 participants from India at the International Olympiads in 2017, 26 participants had won medals including 10 gold medals.

## INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

At VECC, a new High Performance Computing



**Inauguration of High Performance Computing System by Chairman, AEC and Secretary, DAE**

System with Theoretical Peak Performance of 90 TFLOPS have been commissioned and deployed to users. The Computing Node has 96 servers with 2256 computing cores and HPE XL230a Gen9 series servers. There are 2 active Head/Management Node with HPE DL360 Gen9 Server. The Backend connectivity has Infiniband, FDR 56Gbps per port link speed and the storage space has total usable capacity of 500TB, using Lustre parallel FS.

As part of e-governance initiatives of IGCAR, automation and integration of the activities in the areas of Administration, Accounts, Stores and Purchase with a software named as "Automated Workflow Management System (ATOMS)" was implemented in IGCAR. Based on the request from AERB, a standalone web based payroll package was developed and implemented at AERB. In addition, a module was developed and implemented over ANUNET for automatically consolidating the monthly expenditure details received from various units of DAE by Principal Accounts Office at DAE for uploading into PFMS software for the Ministry of Finance.

DAE Budget Automation System (DAEBAS) was developed, tested and implemented by IGCAR for automation of budgeting process of DAE for consolidating the budget requirements (Revised Estimates for current financial year and Budget Estimates for ensuing financial year) for Capital and Revenue Budgets, received from various units of DAE. It has provision for generating consolidated statements, MIS reports and statutory formats for submission of

overall figures to Ministry of Finance (MoF). The module is also capable of allocating the funds to various units on receipt of budgetary ceilings from MoF.

Based on the request from GSO, Kalpakkam, gap analysis was carried out to identify the modification and addition to the existing ATOMS package of IGCAR to suit the requirements of GSO. Accordingly, the existing ATOMS package at IGCAR was customized and additional functionalities were incorporated. The package was implemented in GSO and upgraded to include more processes and features.

Various workflow based software applications have been developed and deployed on RRCAT Infonet (RRCAT information portal) which include e-Logbook for Indus beamlines, portal for personnel radiation dose monitoring, medical centre information management system, Digital Signature Certificates (DSC) enabled applications for CL/Sp.CL and leave applications, workflow based software for online stores requisition with DSC based approval for issue of common stock items from IRSU, workflow based work requisition and approval software for online requisition for jobs to be fabricated in workshops, software for recording 'Out Duty' details of employees with e-approval by Head of Divisions / Independent Sections integrated with attendance details of individual employees.

The data centre has been upgraded to accommodate 200 kVA of server load, distributed in 32 number of racks, with each rack of 42U size, capable of bearing 1200 Kgs of physical server loads. Very Early Smoke Detection Apparatus (VESDA) and Novec 1230 (FK-5-1-12 agent) gas based fire suppression systems have also been integrated in the data center. Video surveillance and biometric access control setup has also been integrated inside the data center.



*Layout of the commissioned Data Centre*

A new electronic messaging/ mailing setup with enhanced user email data storage has been commissioned for in-house usage by 2000 engineers / scientists / scholars / administrative staff working at RRCAT, Indore.

A web based monitoring system has been designed, developed and commissioned to visualize the state of electric fence surrounding the RRCAT campus. Thereby empowering security personnel to monitor perimeter level intrusions and take necessary action well in time. Photograph and signature capture and upload setup has been developed for ID card preparation of employees using advanced RISC machines (ARM).

As part of mobile-governance, a few employee-centric mobile phone based software applications viz IBA (Integrated Business Administration), TIME (Task and calendar management) and ONETEAM (Messaging solutions) were developed by NPCIL and are being widely used by employees. NPCIL also developed software for online Annual Performance Appraisal (APAR) and Human Resource Information System (CHARMS) for Atomic Energy Regulatory Board (AERB) and implemented them.





# CHAPTER

## TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES

7



*Indigenously developed plasma nitriding  
system for ISRO Inertial Systems Unit*



*Nano-titania production system installed at  
Institute for Plasma Research, Gandhinagar*



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

BARC has facilitated the transfer of several spin off technologies developed to the private domain for further commercial proliferation. During the year, 23 technologies were transferred to 41 parties, DTDDF (DAE Technology Display and Dissemination Facility) centres were inaugurated, 11 technologies advertised on BARC, 7 ATP (Akruthi Tech Pack) were established, One incubation of technology done with M/s. Godrej consumer product Ltd., Mumbai and 17 Awareness camps for DAE technologies were held.

Four technologies have been made available through Technology Transfer Cell, VECC/ DAE, for commercial production as import substitutes. They are 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. Three technologies were transferred to the commercial firms in exchange of the respective license fees.



*The RFID based embedded Issue/Return System for Library Management*



*The RFID based Hand Held Reader for Attendance Recording*



*Digital Pico-ammeter*



*Digital Nano-ammeter*



*Technology Transfer Ceremony at VECC*

The various technology transfers that have taken place at IPR are described below:

### Plasma based production of Nano-Powder

IPR has developed a thermal plasma-based



*Nano-titania production system installed at Institute for Plasma Research, Gandhinagar*

nano-powder production system. This is a single-step process, designed and fabricated indigenously. There is a single integrated system to produce as well as collect the nanomaterials. A special feature is the large production rate and low operational cost. The capital cost is less than a fifth of a comparable imported system. Furthermore, this is a single technology/process to produce varied nanomaterials. A patent application has been filed in May 2017. The technology has been transferred on non-exclusive basis to an Ahmedabad based company, M/s Vishal Engineers & Galvanizers Pvt. Ltd. (VEGPL). VEGPL plans to use this technology for production of zinc oxide nanoparticles and market them.

### **Plasma Nitriding system for Space applications**

From INSAT-2E onwards, all gears used in ISRO's satellites have been hardened for increased lifetime using Plasma Nitriding at IPR. Based on this long track record, ISRO had placed an order for a Plasma Nitriding system of 500 mm diameter & 500 mm height



*Indigenously developed plasma nitriding system for ISRO Inertial Systems Unit*

for in-house use. This system, along with documentation describing optimised process parameters and Standard Operating Procedures, has been delivered to ISRO Inertial Systems Unit, Thiruvananthapuram.

### **MoU between IPR and Health Dept., Gujarat Government**

An MoU was signed between IPR and the Health Dept., Govt. of Gujarat, to facilitate development of Artificial Intelligence (Deep Learning) software for health applications and Plasma Pyrolysis plant for biomedical waste disposal in hospitals. This was signed in the presence of MoS for Health & Family Welfare, Govt. of Gujarat.



*MoU signing between IPR and Health and Family Welfare Development, Govt. of Gujarat*

### **Artificial Intelligence software for automated detection of Pulmonary Tuberculosis**

Artificial Intelligence (AI) software has been developed in IPR for automated detection of Pulmonary Tuberculosis footprints in chest X-rays. It has been ported to hand-held devices like Mobile phones & Raspberry PI. The software performs fast and automated screening of chest X Rays to identify high-risk cases which can then be examined by experts. The prototype version has been demonstrated at various exhibitions and meetings. Training of the software on a larger dataset is now underway to improve accuracy.

### **Cryopumps for ISRO: MoU between Space Applications Centre and IPR**

An MoU was signed between IPR and SAC for collaboration in technology development. A short-term deliverable under the MoU is the supply of IPR-developed liquid nitrogen-cooled Sorption Cryopumps





**Signing of MoU between IPR and SAC-ISRO**

for sustaining ultrahigh vacuum in small and medium sized ThermoVac chambers that test ISRO's satellites under space-like conditions. This is an important indigenous substitute for expensive imported systems.

## COLLABORATIVE PROGRAMMES

BARC in collaboration with IIT Bombay has developed Parallel Model Checker (ParMC) Software for Hardware Description Language (HDL) designs that makes use of parallel computing systems in order to improve the scalability of model checking algorithms. Such software tools falls under technology denial regime. ParMC presently runs on the Anupam computer cluster in BARC. The software has been evaluated on a number of designs from DAE and on public-domain benchmark designs.

IPR has built up a variety of external linkages. These include projects/collaborations with agencies like NPCIL, BARC, NRB, ISRO Labs, DST, CSIR, DRDO Labs, Private companies, State Governments, MANTRA, Amrita University, M.S. University, TMC.

## SOCIETAL INITIATIVES

In Technology development for Industrial & Societal applications, IPR has initiated collaborative studies in several application areas of plasma techniques. In a project sanctioned by NPCIL, a plasma nitriding process will be developed to treat special steels of NPCIL to obtain three different specific case depths of hardened layers. In a project sanctioned to IIT-Gandhinagar (G) by DST, FCIPT in collaboration with IIT-G will work on development of indigenous technology to develop CZTS absorber based solar cells using industry friendly magnetron sputtering and RTP (Rapid Thermal Processing) Sulphurization process. In a project sanctioned to IIT-Kanpur by BRNS, FCIPT will develop

and supply 'a Plasma jet along with the necessary power-supply' to IIT-Kanpur. In a project sanctioned to Nirma University by BRNS, FCIPT in collaboration with Nirma University will explore non-equilibrium atmospheric pressure plasma for effective hand sterilization. In a research project sanctioned to IIT\_G, FCIPT will carry out synthesis and study of stable isotope nanoparticles (which will subsequently be integrated in body implants for monitoring the health of the implants). FCIPT will also be carrying out the up-scaling of this nanoparticle production. Required project equipment is being procured in the project "Development of a Plasma nitriding system for Hill agricultural tools & equipment" (project value:117 lakhs). Once it is done, the system will be assembled, tested, and installed in Nagaland.

In the existing 50 kg/hr Plasma pyrolysis system at FCIPT, experiments are being conducted for "Study on temperature distribution and electrode consumption at 80 kW of torch power at various operating parameters". A project has been sanctioned by M/s ABREF Chennai, in which feasibility studies on the interaction of thermal plasma with fly ash have been initiated in order to investigate the possible production of SiAlON. A new plasma torch and feeder mechanism to introduce the fine powder has been designed, installed and experiments are underway. A Dielectric Barrier Discharge (DBD) plasma system for food processing applications has been developed for Anand Agricultural University, Anand, Gujarat. The system is being tested and will be installed soon. In an on-going project, sanctioned by DST, bio-compatible coatings are being developed in collaboration with CGCRI-Kolkata. The work included deposition of Ti, TiN multilayer coatings on SS and Ti alloys and testing for biocompatibility of prototype implants. The project has been successfully completed. Several of these experiments have potential for conversion into viable technologies in future.

## 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 2017-18, four DAE-IPR cell meetings were held. DAE filed seventeen new patent applications which includes; one application under PCT (Patent Co-operation Treaty), ten in India, three in USA, two in Europe and one in Japan.

During this period, eight of the previously filed patents have been granted to the Department. These includes; seven in India and one in Europe. Following are the list of patents granted:

1. A Process for Producing Body Centered Cubic (B2) Nickel Aluminide (NiAl) Coating of Controlled Thickness on Nickel-base Alloy Surfaces – by IGCAR (in India). This invention is a process for aluminizing of nickel-base alloys by a protective coating of controlled thickness to achieve high hardness for high service temperature applications in nuclear, aircraft and gas turbine industries.
2. Development of a very high resistance to sensitization in austenitic stainless steel through a special heat treatment resulting in grain boundary microstructural modification – by IGCAR (in Europe). This invention is a process for achieving enhanced intergranular stress corrosion resistance of austenitic stainless steel by modifying the initial microstructure of the stainless steel through specific heat treatment without involving mechanical treatment. It has wide applications in stainless steel (manufacture and fabrication), chemical and powder industries.
3. A liquid based thin layer cyto-preparation for liquid based cytology – by TMC (in India). This invention is a thin mono-layer liquid based cyto-preparation for diagnostic cytopathology tests / investigation for a rapid, simple and cost-effective method, involving a unique and novel solution with applications in various medical and diagnostic investigations.
4. An improved process for production of high-grade Synthetic Rutile from Titaniferrous ores – by IREL (in India). This invention is an improved process for the production of high-grade synthetic rutile from titaniferrous ores, particularly Ilmenite ( $\text{FeTiO}_3$ ) containing  $\text{TiO}_2 < 50\%$ , by removing iron and other acid

soluble constituents including Uranium & Thorium. This invention helps overcome the shortfall of Rutile (naturally occurring  $\text{TiO}_2$ ) from Ilmenite. Rutile is widely used in the manufacture of refractory ceramic, as a pigment and for the production of titanium metal.

5. An optical source, its method of preparation and its application thereof – by TIFR (in India). The invention is a novel optical source having superior properties in terms of coherence and emission bandwidth without requiring sophisticated resonators. It has application in various fields including optics, lighting, communication and laser industry.

6. A single layer irradiated functional clay-polymer nanocomposite film and its method of preparation – BRNS Project by BARC & ICT, Mumbai (in India). The invention is a novel single layer irradiated functional clay-polymer nanocomposite film with several improved features, having wide applications in the packaging industry, particularly the food packaging industry.

7. An improved process for production of high pure submicron yttria stabilized zirconia powder from zircon – by IREL (in India). The invention is an improved process for production of highly pure submicron size yttria stabilized zirconia powder from zircon using solvent extraction process with impurities like iron, silica and titania below the objectionable levels. The product can be used as an electrolyte or electrode in solid oxide fuel cell applications.

8. A novel method of depositing corrosion resistant metal nitride hard coating with nano particle strengthened nickel-based composite coatings as interlayer on steel substrates – BRNS Project by IGCAR & CSIR (in India). The invention is a method of depositing hard, corrosion and wear resistant transition metal nitrides like  $\text{TiN}$ ,  $\text{ZrN}$ ,  $\text{CrN}$  coatings on work pieces and utility articles, particularly stainless steel, by magnetron sputtering.

During the same period, the following 3 patents were licensed to 4 companies in India.

- A method of making a supported dry asymmetric polyamide membrane for membrane filtration (BARC)

- A spiral wound dry polyamide element for membrane filtration and a method of making the same (BARC)
- Ultrafiltration Membrane water purification device (BARC)

Among the patents that were filed during the above mentioned period, the following patents were published.

1. Air Plasma Torch – by BARC (in India). The invention is a novel plasma torch which uses hafnium as the cathode and copper as the anode for the generation of large volume thermal plasma jet from atmospheric air at moderate power level. Simple design, low operational cost, use of air at a low flow rate, high efficiency, high temperature, extremely low cathodic erosion and ease of control are some of the key features of the technology. The invention could find application in medical waste treatment through plasma pyrolysis, destruction of hazardous waste, steel and metallurgical alloy industries, high temperature testing of heat shielding materials and other R & D applications.

2. A Coupling Device for joining Solid / Hollow Shafts – by BARC (in India). The invention is a new and innovative component called the KeyWing to join two pipes or shafts for rotational and torque transmission purposes. It finds application, especially for cables routed through pipes, as a substitute for flange / coupler joints as they are bulkier and occupy large radial space.

3. An improved Method of Manufacturing Actively Cooled Accelerator Grid with full penetration Weld Configuration – by IPR (in India). The invention is a specialized joining configuration and process which can weld through the thickness resulting in a full penetration Electron Beam Weld (EBW) of SS pipe to Copper plate using an Inconel intermediary with full integrity of the joint. The invention could find application in neutral beam source accelerator grid segments, space and defense applications with different combination of materials.

4. A Filter with Developed Sorbent Composite Material for removing Toxic Metal Contaminants for Aqueous Systems – by AMD (in India). The invention relates to a filter using Modified Powdered Activated

Carbon (MPAC-IV) granules loaded with ferrous ions capable of removing high concentration of arsenic, lead, cadmium and uranium at its natural pH, while retaining the essential minerals required for human body as per the Bureau of Indian Standards (BIS) 10500. The filter could be useful for removing toxic heavy metals from contaminated ground water, mine water, river water, etc., at its natural pH, and retaining the quality of treated water intact with respect to its natural pH and essential minerals.

During the year, 289 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.

As a part of Training School curriculum, IPR subject has been introduced at BARC Training School at AMD, Hyderabad, and at IGCAR Training School, Kalpakkam. Regular lectures on IPR are also delivered at the BARC Training School, Mumbai. A one day Intellectual Property Awareness program was conducted for scientists at TIFR and NISER, under the aegis of Administrative Training Institute at their respective institutes.





# CHAPTER INFRASTRUCTURE

8



*Cultural centre at Eastern Sector of Anushaktinagar*



*Inauguration of CISF Dormitory by  
Dr Arun Kumar Bhaduri, Director, IGCAR/GSO*

## 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 major works completed by DCSEM at Anushaktinagar were the Construction of 194 flats for CISF Quarters for (II-B & IV-D) along with PH services in western Sector at Anushaktinagar Mumbai, Construction of Cultural centre at Eastern Sector of Anushaktinagar and Building for Fission based  $^{99}\text{Mo}$  Production facility for BRIT adjacent to ISOMED in BARC at Trombay.



*CISF quarters at Anushaktinagar*



*Cultural centre at Eastern Sector of Anushaktinagar*

Various Works of DCSEM at Anushaktinagar, Mumbai under progress included the Restoration / Renovation of Old Houses more than 20 years old Phase-II; Up gradation of services under 12<sup>th</sup> plan;

Construction of 356 nos. residential quarters; Hostel for trainees of BARC/HBNI Phase- I&II; Construction of Extension of V.S.Bhavan; Construction of 312 flats of type V-E at Mandala, Anushaktinagar, Mumbai and Construction of Substation Building for 312 flats of type V-E including Civil, Electrical & PH works at Anushaktinagar, Mumbai.

Major construction works completed by DCSEM for other units/ Autonomous units of DAE included the Construction of First Research and Technical (FReT) Block for TIFR, Hyderabad and Construction of Office Complex (Phase-II) for AMD for exploration and Research at Southern Region, AMD complex, Nagarbhavi, Bangaluru.



*Construction of First Research and Technical (FReT) Block for TIFR, Hyderabad*



*Construction of Office Complex (Phase-II) for AMD Nagarbhavi, Bangaluru*

Major Works Under Progress included Construction of Facilities for Research in Experimental Nuclear Astrophysics (FRENA) laboratories for SINP, at Bidhannagar Kolkata; Construction of R&D Laboratory for AMD and Eastern Regional Regulatory Centre for AERB building at VECC Kolkata; Construction of 100 bedded hospital and Ancillary building for TMC at Vishakhapatnam, Andhra Pradesh (Retendered) and



Renovation of house internal finishes Phase-II in Mumbai.

Maintenance of residential flats (10169 nos.) including shops and Institutional buildings viz. DAE Secretariat, Dispensaries, AEES Schools, Community Centre, Shops, DAE Guest House etc. in Anushaktinagar, Mandala & City area including execution of upgradation works required for these buildings were carried out by DCSEM. It is also responsible for operation & maintenance and upgradation of electrical power distribution, water supply, sewer lines, sewage treatment plant, fire- fighting system, rain water harvesting system etc. for Anushaktinagar, Mumbai.

The Estate Management Group continued to look after the allotment & supervision of various public buildings like banks, post office, shopping centre, community centre, etc. within the residential colony. The DCSEM security continued to safeguard the DAE properties in Mumbai.

## PURCHASE & STORES

Directorate of Purchase & Stores (DPS) is one of the service organizations of Department of Atomic Energy. The directorate was set up in the year 1973 with a mandate for managing the material management requirements of various constituent units of the Department. The mandate includes procurement of right material, at right price and at right time for various programs of the department.

### Extension of e-tendering System

The e-tendering system being used by DAE units at Mumbai, Kalpakkam, Indore, Hyderabad and Kolkata was extended to DAE users of GCNEP Bahadurgarh, HWP Baroda, Tuticorin and Kota. Additional features have been incorporated in the e-tendering system for online release of purchase orders to the successful suppliers.

### Vendor Meet

During the year, DPS had arranged vendor meets at Kolkata, Baroda and Indore whereby feedback was obtained from vendors regarding their experience

on e-tendering and problems if any faced by them. In order to address the problems faced by the vendors a separate mail ID has been created and problems/grievances received on the mail are addressed and responded within the set timelines.

### Rate Contract for DAE Units

Rate Contract was concluded for procurement of some items to be operated by all the purchase units of DPS. There have been continued efforts in adding new features in the software thereby reducing lead time in procurement of goods.

### DAE User Meet

In order to acquaint users with the new software, user meet was arranged in BARC. In addition, regular user meetings were arranged for sorting out the procurement related issues. The issues as raised by the users in these meetings were addressed and monitored. Separate mail ID has been created for the users and issues raised are addressed within 48 hours. Video Conference connectivity was established with DPS Mumbai and HWP Tuticorin, Baroda and Kota

### Online Sale Tender

The e-tendering system was also used for sale of tenders at Central Stores Unit Mumbai. Users and vendors were trained for the new application. The participation in e-sale tenders was more than that against conventional mode.

### Increased Digital Usage

Offer received from vendors were transferred from DPS Central Purchase Unit Mumbai online to users of BARC for evaluation and recommendation. Indore Regional Purchase Unit has conducted RRCAT Purchase Committee meeting without distribution of agenda papers. Agenda papers were made available to all the committee members in soft format to be accessed directly from the system and even referring files when required were made available online.

### Uranium Fuel Import

Nuclear Trade has been opened up for civil

nuclear facilities. 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, Kazakhstan and Russia. Discussions were also held with prospective uranium suppliers from Canada, Australia, Japan and Kazakhstan for negotiation of new contracts.

## GENERAL SERVICES ORGANISATION

General Services Organization, Kalpakkam takes care of the common facilities such as Housing, Medical, Transport, Water Supply, Civil, Electrical, Telecommunication, Solid waste collection and disposal etc in the Atomic Energy Townships at Kalpakkam and Anupuram where employees of the DAE Units at Kalpakkam, viz – IGCAR, BARCF, MAPS and GSO reside. GSO provides infrastructural support to the Kendriya Vidyalayas, Atomic Energy Central Schools, Atomic Energy Higher Secondary School and accommodation for the CISF personnel. GSO 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 during the year 2017-18 include the following:

### Civil Work

In-house Architectural & Structural Engineering Design has been carried out for Phase -2 of the hospital at Anupuram, Integrated Radiation Monitoring Services building, Kindergarten School Building and the Security Isolation Scheme for Anupuram.

During this period 72 Nos. of Notice Inviting Tenders (NIT) were released and Work orders for 72 works has been issued at a total value of for Rs. 66.03 Crores. Major Work Orders issued include : Construction of 116 Numbers of Type II-B Residential Quarters in DAE Township at Kalpakkam for Rs. 22.64 Crores, Construction of 2 Nos. of 0.25 MG Capacity treated Water Sumps and pipe lines for Water Treatment Plant in DAE Township, Kalpakkam for Rs. 2.99 Crores,

Construction of Engineering Service Group Building (Civil Engineering lab, Mechanical, Electrical & Industrial Safety) in DAE Township at Anupuram for Rs. 3.49 Crores, Construction of Hospital (Phase-I) in DAE Township at Anupuram for Rs. 3.86 Crores, Widening of Bituminous road between NESCO and STP with RR Storm water drain in DAE Township, Anupuram for Rs. 2.43 Crores, Construction of Security isolation Compound wall and chain link fencing along both sides of the main road from Anupuram gate to Kunnathur gate at DAE Township, Anupuram for Rs. 1.99 Crores, Operating a Pharmacy for Supply of Medicines to CHSS Beneficiaries at Kalpakkam Township for Rs. 3.00 Crore.

Augmentation of the infrastructure at the Atomic Energy and Kendriya Vidyalaya (KV) Schools at the two townships was taken up on priority and construction works of Additional Class Rooms in AECS-III, Anupuram, KV1 and KV2 at Kalpakkam were completed. An additional Science Lab was constructed at AECS-II, Kalpakkam. Construction works of the



**Dormitory for CISF Personnel, Kalpakkam Township**



**Inauguration of CISF Dormitory by  
Dr Arun Kumar Bhaduri, Director, IGCAR/GSO**



**1.0 mt. Per day capacity (Nisargruna) bio-gas plant**

Dormitory for CISF Personnel, two wheeler & four wheeler parking sheds and provision of Lift facility at DAE Guest House completed. A Bio-Gas Plant of 1.0 M.T per day Capacity based on the Nisargruna technology, was successfully constructed and commissioned. Widening of Bituminous road between Anupuram Main gate (Gate - 1) and Neikuppi gate (Gate -2) in DAE Township, Anupuram, Sludge water treatment tank for Advanced Prototype STP at Efficiency plus tower blocks in DAE Township was completed.

### Electrical & Telecommunication

Augmentation of Electrical and Telecommunication Infrastructure was carried out. Major works carried out include Supply, installation, testing and commissioning of 50 kW Grid Interactive Roof Top Solar Photovoltaic Power Plant, Supply, installation, testing and commissioning of Energy Meter Distribution Board in DAE Township, Kalpakkam and Replacement of Conventional Street and Flood Light with energy Efficient LED Luminaries at DAE Township, Kalpakkam



**Interactive Roof Top Solar Photovoltaic Power Plant**



**LED Luminaries for Streets**

### Computer

A revamping of the Campus Backbone Network was successfully carried out to shift the central hub from the TONIC building to the GSO Annex Building. Face Recognition based biometric readers were introduced for attendance recording. The Estate Management Software was modified to implement the Seventh Pay Commission related modifications in quarters allotment. The year also witnessed the installation of the Work flow Management System to computerize the Accounts and Administrative Procedures, which considerably eased out the implementation of the Seventh Pay Commission recommendations with respect to salary and allowances.

### Mechanical

To meet the increased water demand during peak summer, provision was made to pump back potable water from 2MGD Desalination plant at IGCAR site through reverse pumping by using the existing new 3.0 MGD, dia 500 mm pipe line from Nandi circle



**Strain less Brake Drum Handler**



underground new sump at main gate to Raw Water sump at Kalpakkam. All works related to the reverse pumping system were completed. At the Autoshop, the Compressed Nitrogen shop floor pipeline layout was upgraded in-house. A new device called Strain Less Brake Drum Handler was fabricated to handle the heavy brake drum in a safe manner.

## Hospital

The medical needs of about 30,000 CHSS beneficiaries are handled effectively by the hospital at Kalpakkam and dispensary at Anupuram. In addition to the regular duties, the medical officers have undertaken the following case based analytical studies which give insight to the disease profiles of the population and throw light on specific health issues in the community. These studies include Clinical case study of efficacy of Nano Silver Dressing in healing of Diabetic Ulcers; Evaluation of cases of Bad Obstetric History (BOH); Short procedures using Supraglottic Airway Devices; Study and Management of Seroma Auricle towards achieving complete resolution; Evaluation of uterus and ovaries by USG Pelvis for female patients aged 40 years and above; Prevalence of angle closure glaucoma in our population males and females in our township; Measurement of corneal surface temperatures by infrared thermography in diabetic population and correlation with the degree of diabetic retinopathy; Study of fatty liver among diabetic patients; Comparative study of absolute eosinophil count among patients with asthma versus patients with asthma & allergic rhinitis; Study of S.Uric Acid levels in patients with Type II diabetes; Parental awareness regarding immunization schedule, optional and newer vaccines; A Study on prevalence of oral diseases among age group 21 - 40 years and Comorbidity among patients with psoriasis.

## Swachh Bharat Initiatives

On 2<sup>nd</sup> October 2017 a cleaning campaign was conducted at Anupuram Township. A team of about twenty five employees led by the Associate Director, ESG&MG participated in the campaign. The Swachhata Pledge was taken, followed by cleaning up of the area around NESCO building.



*Cleaning Activities at Anupuram Township*



# CHAPTER PUBLIC SECTOR UNDERTAKINGS (FINANCIAL PERFORMANCE)

9



*Tele ECG*





*Pramanik Smart Card Reader*

Financial performance data 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. is 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 expected profit for the year 2017-18 is about Rs. 2400 Cr. The profit (Total Comprehensive Income) for previous FY 2016-17 was Rs. 2491 Cr. NPCIL bonds continued to be rated as AAA (Highest Safety) by CRISIL and CARE.

## URANIUM CORPORATION OF INDIA LTD.

The performance of all major units of the company during the year 2016-17 remained quite satisfactory. The total income of the Company during the year 2016-17 was ₹ 1272.71 Crore as against ₹ 1025.53 Crore in the previous year. The Company has registered a Profit Before Tax of ₹ 209.84 Crore in the year 2016-17 as against ₹ 154.53 Crore in the previous year. Performance of the Company in terms of MoU signed with DAE is expected to be "Very Good" for the year 2016-17.

## INDIAN RARE EARTHS LTD.

During the period upto December 2017, the Sales Turnover achieved is ₹ 414.69 crore against ₹ 330.85 crore of the corresponding period of previous year. The projected sales turnover for 2017-18 is ₹ 514.64 crore against ₹ 412.02 crore of the Sales Turnover achieved in the year 2016-17.

## ELECTRONICS CORPORATION OF INDIA LIMITED.

The 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 huge growth in Strategic Electronics.

ECIL has made a conscious effort to develop a strong technological base in association with prestigious R&D institutions of DAE, DRDO, DoS and Academic Institutions like IITs. Though the initial thrust was on meeting Control & Instrumentation requirements of the Nuclear Power Program, ECIL has diversified into the design, development, manufacture, supply, installation, commissioning and maintenance of wide variety of electronic equipment for use in areas such as Atomic Energy, Defence, Security, Aerospace, IT, Telecom and e-Governance sectors.

ECIL's Electronic Voting Machines with their field proven simplicity, integrity and ruggedness have helped simplify the Electoral process and strengthened democracy, setting a benchmark around the world. The newly developed multi-post EVMs have been widely accepted for deployment in Local Body Elections by various State Governments.

ECIL has been continuously investing in upgrading existing products, developing new products and creating a world-class infrastructure to meet the ever changing requirement and catering for high rate of obsolescence with electronics.

## Performance

Against the MoU target of ₹1675 Crore each for production and Net Sales, the Company achieved a production of ₹ 818 Crore and a net sale of ₹ 689 Crore upto December 2017.

The sector-wise significant achievements during the year 2017-18 are as follows:

### Atomic Energy

- Passive Catalytic Recombiner Device (PCRD)

**Passive Catalytic Recombiner Device****Nuclear Instrumentation Package**

- Nuclear Instrumentation Package (NIP)
- Radiation Monitoring System
- Radiation Detection Equipment
- Control & Instrumentation and SCADA Systems

## Aerospace

- Secured Communication Network
- Rate Gyros
- Actuators

**Actuators****Gyros**

- Solid State Cockpit Voice Recorder (SSCVR)

## Defence

- M7 Multimode Digital Radios
- TR 2400 Radios
- TR 3060
- Cell Phone Jammers
- Vehicle Mounted Jammers
- Seeker
- Universal Electronic Fuzes
- Missile Test Bench Simulator



**M7 Multimode Digital Radio****TR 2400 Military Radio****Astra Missile & Launcher Checkout System**

- Checkout System for ASTRA Missile & Launcher

## Security

- CCTV

**CCTV Delhi Metro**

- Access Control System

## IT, e-Governance & OTHERS

- Electronic Voting Machines (EVM) and Voter Verifiable Paper Audit Trail (VVPATs)
- Smart Card Reader
- MAX-NG
- TELE-ECG
- Supervisory Control and Data Acquisition Systems for oil and gas pipelines
- Computerization of Sales Tax Operations in Maharashtra
- IT Education

**TELE ECG****Pramanik Smart Card Reader****Max NG exchange equipment**

## Research & Development

The in-house R&D Programmes are guided and supported by the Technology Development Council (TDC) leading to several new products and enhancements being introduced into the market.

### New Products Introduced

- Plastic Scintillator based Portal Monitoring System (PMS)
- Phasor Measurement Unit (PMU)
- RF Seeker for BrahMos Missile
- 0.45 M KU Band Airborne SATCOM Terminal
- 4.6 M Ship Borne Antenna System



**Phasor Measurement Unit**



**Antenna & Signal Distribution Units**



**LINUX Based MPROGICON 5200 PLC System**



**EC-POS**

- Linux based MPROGICON 5100 PLC system
- Situation Awareness Unit (SAU)
- Antenna & Signal Distribution Units (ADU & SDU) for V/UHF & HF
- EC-POS
- Checkout System for ASTRA Missile & Launcher

### Tie-ups and Agreements

- Entered in to an MoU with TATA Consultancy Services Ltd., towards synergizing strength and exploring new business prospects on mutually agreeable terms.
- MoU with C-DAC, Bengaluru for Transfer of Technology on IoT
- An MoU was signed with M/s TETRAEDR, a Belarusian Company for addressing the opportunities in the upgradation of the defence systems.
- An MoU was signed with ISTRAC, ISRO, Bengaluru for development of 18 M Antenna for development of Deep Space Network.
- An MoU was signed with RRCAT for ToT of HV DC and Pulsed Power Supplies to be used in "IMS Detector"

# CHAPTER OTHER ACTIVITIES

10



*Smt. Sumitra Mahajan, Speaker, Lok Sabha  
at the DAE pavilion*





*Vigilance Excellence Award-2017 conferred to Vigilance, NPCIL*

## 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.

With deployment of multiple safety systems and with inherent design features, the possibility of an accident in a nuclear facility or during transport of radioactive material which might lead to a radiation emergency in the public domain is unlikely. However, in order to handle any unforeseen situation, formal emergency response systems are in place and are tested regularly to ensure that there would be no radiation hazard to the public. All radiation facilities are regulated by an independent regulatory authority. However, in case, an unlikely event does occur and it

leads to a radiation emergency in the public domain, a response system is in place to tackle such situations, by mobilizing the expertise of the Department of Atomic Energy in the field of radiation measurement and protection and medical treatment of radiation injuries. The objective is to make these specialized technical supports available to public officials who would be handling various types of emergencies related to radiation / involving radioactive materials in the public domain. Also, CMG provides its expertise in the field of nuclear / radiological emergency management at various National and International levels.

The Crisis Management Group formally meets to review the crisis management plans, to discuss issues related to radiological incidence occurred, if any, in the country and provide necessary guidance on matters related to radiological safety in the public domain to avoid recurrence of such incidences.

The Emergency Response System of DAE is available to respond to requests from public officials in the event of any reported presence or suspected presence of radioactive material in public domain. For this purpose, guidelines have been circulated to Governments of all the States and Union Territories. A significant feature of the emergency response system of DAE is the availability of two Emergency Control Rooms (ECRs) located at two different places in Mumbai, which are backing-up one another. These control rooms, which are manned on round-the-clock basis, are equipped with diverse means of communication and are in constant 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 2017, India participated in all the five IAEA conducted International Convention Exercises, known as "ConvEx". This included ConvEX-3, which was a large scale international emergency exercise carried out assuming a severe accident scenario at a Nuclear Power Plant (NPP) site at Hungary; to test the full operation of the international Emergency Preparedness and Response (EPR) framework. As the Competent Authority, the Crisis Management Group

(CMG) coordinated India's satisfactory participation in this exercise. Similarly, as part of ConvEx-2B exercise, CMG successfully submitted "India's Offer of Assistance" for medical support and decontamination to the Kingdom of Bahrain, when a "Request for Assistance" was formally received through IAEA. Also, all the Convention requirements identified under the Early Notification and Assistance Conventions (ENAC) were satisfactorily met.

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 2017 were Communication Exercises- 408 Nos.; Fire Emergency Exercises – 77; Plant Emergency Exercises – 49; Site Emergency Exercises – 18 and Off-Site Emergency Exercises – 06.

CMG participated as observer and provided feedback for improvements when off-site emergency exercises were carried out at the nuclear power stations located at Kalpakkam, Kudankulam, Kaiga and Tarapur. Also, CMG ensured DAE's participation in a mock radiological emergency exercise at Chennai airport, conducted by the Ministry of Home Affairs (MHA).

## 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 2017, 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). India participated in the IAEA's International Conference on Nuclear Power in 30 October - 1st November 2017 in Abu Dhabi.

Cooperation at the multilateral level in peaceful uses of nuclear energy and advancement of nuclear science & technology was also promoted through active participation in the European Organisation for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER), and the Nuclear Energy Agency of OECD. DAE received delegation led by DG, OECD-NEA in November 2017 for a week-long visit. India became an Associate Member of CERN on January 16, 2017.

As part of India's continued engagement in civil nuclear cooperation with major partners, an Agreement between the Government of Republic of India and the Government of the People's Republic of Bangladesh on cooperation in the Peaceful Uses of Nuclear Energy was signed on 08.04.2017. Inter-Agency Agreements between GCNEP and Bangladesh Atomic Energy Commission (BAEC) on cooperation regarding nuclear power plants in Bangladesh and between AERB and Bangladesh Atomic Energy Regulatory Authority (BAERA) were also signed on 08.04.2017. As part of our on-going developmental partnership and capacity building programme with Bangladesh, specially designed training courses were organised by GCNEP and NPCIL for nuclear energy professionals from Bangladesh in the areas of civil nuclear science and technology.

The Agreement between the Government of the Republic of India and the Government of Japan for Cooperation in the Peaceful Uses of Nuclear Energy was signed on November 11, 2016 during the visit of Prime Minister to Japan and came into force on 20.07.2017. The Agreement would enable India to benefit from Japan's advancements in civil nuclear domain and its extensive supply chain, and would open up opportunities for collaboration between Indian and Japanese industries to advance India's civil nuclear programme through the construction of nuclear power plants, thereby meeting the country's clean energy



targets. The Agreement will also help foster cooperation in basic and applied research regarding peaceful uses of nuclear energy and nuclear safety. Overall, the Agreement underlines the strength of the Strategic and Global Partnership between India and Japan. In pursuance of the Agreement, a meeting of Joint Working Committee was held between both the sides on 03.08.2017 to work out modalities for taking cooperation further.

Further, as a part of our efforts to bolster international cooperation, a Joint Working Committee meeting was also held with Canada during 2-3 November 2017.

An Agreement between the Government of the Republic of India and the Government of the Socialist Republic of Vietnam on Cooperation in Peaceful Uses of Atomic Energy signed on 09.12.2016 entered into force with effect from 16.08.2017. The India-Vietnam IGA has provided a renewed framework for our civil nuclear cooperation with Vietnam.

India gifted Bhabhatron II and Imagin Simulator to Kyrgyzstan. The source has reached Bishkek in December 2017. The Kyrgyz team has undergone training in India and the machine would be made operational soon. India delivered 100 k curie source to Vietnam in January 2018 as per the contract reached in 2009.

Nuclear Controls and planning wing of DAE is responsible for coordinating all IAEA Safeguards related activities in Indian civil nuclear facilities. An 'Agreement between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities' (INFCIRC/754) was signed in Vienna on 2nd February 2009 and the Agreement entered into force on 11th May 2009. As on December 2017, India has notified 24 of its nuclear facilities under IAEA Safeguards. This includes 16 Nuclear Power Plants, latest being Kakrapar Nuclear Power Stations 3 & 4 which is under advanced stages of commissioning.

Director General (DG), IAEA, Yukiaya Amano visited India from 13-15 March 2017 at the invitation of Dr. Sekhar Basu, Chairman, AEC. He visited Kudankulam Nuclear Power Plant in Tamil Nadu where two 1000 MWe VVER reactors are in operation and



**Dr. Sekhar Basu Chairman of AEC with Yukiaya Amano, Director General (DG), IAEA**



**Yukiaya Amano Director General (DG), IAEA's visit to Kudankulam Nuclear Power Plant**

another twin unit is under construction. He interacted with senior officials of the plant management and visited some of the plant facilities. DG expressed satisfaction over the standard of safety systems maintained in the plant while addressing the local media during his visit.

During DG's meeting at DAE in Mumbai, Chairman of AEC, Dr. Basu indicated to further enhance cooperation with the IAEA and is ready to provide the facilities at the five schools under GCNEP. IAEA can use the facilities at GCNEP to train experts from the region and beyond in assisting its member states to build capacity in the area of nuclear safety and nuclear security. India can also provide access to other research facilities through IAEA for training and capacity building. India has gifted bilaterally Bhabhatron radiotherapy machines to several countries in Asia and Africa and would like IAEA to remain associated as India's partner in building human resources in these countries. India has established a national grid of more than 100 cancer care centres and India would be ready to extend this network with IAEA support to convert it to a regional network or beyond so that cancer care providers in other countries can also access the expertise available in India to the benefit of cancer patient.



**Director General, NEA's visit to BARC**

A delegation from NEA, OECD consisting of Director General, Deputy Director General and senior officials of NEA visited India during 20-22 November 2017. They visited TAPS units, AERB, BARC, CBS and NPCIL headquarters. NEA has technical cooperation with AERB and NPCIL.

Global Centre for Nuclear Energy Partnership (GCNEP), established at Bahadurgarh, Haryana is the sixth R&D unit under Department of Atomic Energy (DAE). Phase-I construction of the Centre has been completed and on-campus operation has started from April 2017. In the first phase of the project, School Building – 1 and Guest House Block A, has been constructed.



**GCNEP Guest House**

The school building has a total built – up area of 3450 sq m and houses Conference rooms, a multipurpose hall, lecture halls, tutorial rooms, besides eight laboratories and other amenities. The five schools that are operational 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).

The laboratories and facilities that have been setup at School Building include Access Control System Lab; CCTV & Video Analytics Lab; Model Emergency Response Centre and an IT Lab.

Other facilities such as Sensor Evaluation Test Bed, SARRT Lab, SANESS Lab & SNMCS Lab are being setup at GCNEP Campus. Few snapshots of various labs and facilities at GCNEP are shown below:



**Access Control System Lab**



**SNMCS Lab**



**CCTV and video analytics Lab**



**Model Emergency Response Centre**

GCNEP Guest House is located in the Township with a total built – up area of 2475 sq m and is having 27 suites equipped with required amenities.

GCNEP is engaged in conducting various training courses, seminars, workshop and technical





**GCNEP School Building – 1**



**Snapshots during GCNEP Programs**

meeting at campus since 2017. The various International and National on-campus programs that were conducted include National Training Course on "Nuclear Safety and security interface"; 5th Indo – US Joint Working Group (JWG) on GCNEP; Indo-US Technical Exchange Workshop on "Security by Design"; International Training Course on "Security of Radioactive Sources"; Training Course on "Industrial Applications of Radiation Technology and Radiotracers" for Tanzania; IAEA Workshop on "International Physical Protection Advisory Services (IPPAS)"; Training course on "Preparedness and Response to Nuclear Emergencies" for Bangladesh and IAEA Workshop on Safety, Security & Safeguards (SSS) Interface at Nuclear Installation. These programs have been well received and around 60 delegates from more than 10 countries participated in above programs beside around 100 participants from India. In addition to above, four off – campus programs namely Training cum RSO Certification Course on "Radiation Safety Aspects of

Nucleonic Gauges" (Venue: Mumbai, Maharashtra); National Training Course (NTC-5) on "Physical Protection of Nuclear Material and Nuclear Facilities" (Venue: NFC, Hyderabad, Telengana); Applications of Radioisotopes & Radiation Technology in Food Agriculture, Environment, Healthcare and Industry (Venue: Palampur, Himachal Pradesh) and NTC on Design & Evaluation of PPS for Nuclear Material & Nuclear Facilities (Venue: Mumbai, Maharashtra) were also conducted in 2017.

The activities for Construction of Phase II of the Centre have been initiated and the civil works are likely to start soon.

NPCIL is a member of international organizations such as World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and participates actively in various programmes of these organizations to enhance the safety and reliability of its nuclear power plants.

NPCIL is one of the founding members of WANO and is currently a member of two WANO regional centres located at Tokyo and Moscow. WANO was established in 1989 and its mission is to maximize the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices. All the nuclear power plants operating in the world are its members. NPCIL representatives are in the governing board of WANO Tokyo and Moscow centres. During the year, WANO Peer Review Follow-up review of RAPS-2 and WANO Corporate Peer Review Follow-up Reviews (CPR-FR) of NPCIL were carried out by a WANO team consisting of experts from various countries. WANO Peer Review Follow-up review of RAPS-3&4 was scheduled in February 2018. In the Follow-up Review, WANO team reviews the status of actions taken by the station / WANO member to address the Areas for Improvements (AFIs) identified in the Peer Review / CPR. In the CPR-FR of NPCIL, WANO team found the status of AFIs on track, thus endorsing actions taken by NPCIL to address the AFIs are appropriate and in the right direction to resolve the issues. These reviews provided NPCIL the opportunity to learn International best practices.



WANO organized seven 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. One more MSM is planned before the end of the Financial Year. So far, WANO has organized about 60 MSMs in India as per the request of NPCIL. Many persons from NPCIL participated in important meetings, seminars and workshops and gave presentations. A team from TAPS-1&2 is scheduled to visit Chinshan NPP in Taiwan under WANO's Benchmarking programme before the end of the Financial Year. Many 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 participated in some of the COG meetings held thru' audio and video conferences. In addition, COG representative visited NPCIL and discussed issues of mutual cooperation. Two experts participated in COG workshops held in Canada and Argentina, respectively. NPCIL participated in the information exchange programme of COG and had access to useful operating experience information related to PHWR plants.

Many officials from NPCIL participated in various meetings, workshops, seminars organized by IAEA. NPCIL continued to provide information for IAEA PRIS database.

## COMPUTER AND INFORMATION SYSTEMS DIVISION

CISD has successfully launched e-Office, a mission mode project under the National e-Governance Plan, in the Secretariat in March 2017. Within short span of 11 months, more than 11,000 new files and receipts have been created that have cumulatively clocked over 35,000 transactions. Employee leaves management has been made 100% paperless and digitisation of tour processing system is in the advanced stages of deployment. An e-Office helpdesk has been set up for in-field support and training; it resolves over 30



***eoffice.dae.gov.in, the DAE e-Office Suite hosted locally***



***darpan.dae.gov.in, the in-house developed single-window access portal***

troubleshooting instances daily. Digitisation facility with an industrial scanner has also been setup in-house for migration of paper-based files to e-Files. The facility is being used to digitise around 4,000 sheets per day. E-Office services shall soon be extended to the Branch Secretariat of the Department at New Delhi over AnuNet, the dedicated pan-India data network of DAE.

To strengthen the information ecosystem in the Secretariat, DARPAN, a web-portal providing single-window access to a number of e-services, has been developed and deployed in the Secretariat. It complements other digital resources including the DAE website, e-Office and the social media channels of the Department. Employee-centric digital services, which are not a part of e-Office, like Immoveable Property Returns, Attendance Management, and Salary Processing etc. are progressively being made interoperable with the e-Office data. Government digital

frameworks like Public Finance Management System (PFMS) have been successfully integrated with DARPAN. Digital integration has paved way for effective monitoring of newer functional mechanisms like implementation of flexi-timing in the Secretariat.

A fully functional Human Resources Module has been successfully deployed on the “Anusangrah” platform, the DAE-wide Integrated Management Information System launched earlier. The HR module provides a graphical interface to unit-level data which can be sliced and diced for reference and reports.

A web-based content repository has been deployed to collate the multimedia information related to events of the DAE Units and Institutions. This would help in generating reports and other electronic contents in a timely manner.

CISD has also upgraded the DBT (Direct Benefit Transfer) App, a web-based Management Information System, for the Units and Institutions of DAE to facilitate information exchange related to the schemes of the Department on the DBT portal.

CISD manages the Information Technology infrastructure in the DAE headquarters including the DAE website, e-Office Suite, other web-based services portals, servers and data networking. CISD is also engaged in developing the contents for the upcoming revamped website built over the new CMF framework of NIC.

## 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 CVOs discharges these responsibilities.

The functions of DAE Vigilance section at the secretariat during the year include the submission of 25 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). Processing of 12 new cases of Disciplinary cases of Group 'A' officers and retired Government servants. Eighteen complaints were downloaded from CVC portal and 3 complaints received through PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides, 3 complaints from CBI have also been processed. Twenty one cases have been closed with the approval of Competent Authority after necessary investigation and status uploaded onto the CVC portal. Thirty seven complaints have been received directly in the Department. After confirming the authenticity of the complainant, carried out necessary investigation and with the approval of Competent Authority 19 complaints were closed. Vigilance clearance were given for various purposes to 1,688 Group 'A' officers of Units, Aided Institutions and PSUs as well as staff in the Secretariat. Appointment of Vigilance Officer/ Chief Vigilance Officer of Constituent Units/ Aided Institutes and in the Department was done. Scrutiny of Annual Immovable Property Returns of DAE Secretariat. Co-ordination between CVC and Units for conducting of CTE (Chief Technical Examiner) examination.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2017" was observed in DAE during October 30th to November 04th, 2017 on the theme of "My Vision-Corruption Free India". The week commenced with administering integrity pledge by Chief Vigilance Officer and Joint Secretary (ER) to all officers and staff on 30/10/2016. During the week, various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were held in which officers and staff



**Vigilance Awareness Week 2017 observed in DAE Secretariat with the theme "My Vision-Corruption Free India"**

of DAE actively participated. Shri V.V. Laxminarayana, Additional Director General of Police, Mumbai delivered a talk on 04/11/2017. The key note address was delivered by Shri S. Mervin Alexander, Joint Secretary (A&A) and Chief Vigilance Officer, DAE. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 04.11.2017. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance awareness is one of the important parameter of good Corporate Governance. A number of initiatives were taken and innovative methods were adopted in spreading awareness and imparting knowledge to employees. Vigilance Seminars, Interactive Sessions at various sites and HQ are regularly organized by the NPCIL.

An initiative of organizing 'Outreach Programmes in vigilance awareness in Schools & Colleges' was taken by NPCIL as per directives of CVC in the months of October & November 2017. CVC assigned 'Greater Mumbai', 'Tirunelveli' & 'Kalpakkam' District to NPCIL for conducting these activities. A Workshop on 'Scrutiny of Audit Reports to detect possible Vigilance Angle' was held at HQ, Mumbai on November 3, 2017. Shri Guljari Lal, Director General-Audit (Central) & Shri Nilesh Patil, Dy. Director-Audit were the guest speakers.

A number of programmes viz. Seminars, Debate Competitions, Quiz competitions, Elocution Competition, Essay writing competition, Slogan writing competition, Short Film Competition, Poster Drawing, Street play & Speech competition etc. were held at NPCIL HQs and its sites.

'Chetna' – Annual edition of Vigilance Magazine was released by Shri U.C. Muktibodh, Director (Technical) in presence of Shri Anil Singhal, Ex- CTE & GM, NW Railways, CVO and Senior Management Officials of NPCIL at HQ on May 12, 2017. It contains a number of articles and poems on vigilance matters. A web based application 'Vigilance Reports Management System (VRMS)' was launched by CMD, NPCIL on July 21, 2017. It has been developed for Preparation / Submission and Approval of various reports pertaining



**Vigilance Excellence Award-2017  
conferred to Vigilance, NPCIL**

to Preventive / Surprise checks and complaint Investigation Report.

Vigilance Excellence Award 2017 was conferred to Vigilance, NPCIL by Central Vigilance Commission. CVO, NPCIL received the award from Honourable Vice President of India Shri Venkaiah Naidu during inaugural function of vigilance awareness week organized by CVC at Vigyan Bhavan, New Delhi on October 30, 2017. 'Corporate Vigilance Excellence Award 2016-17 Power Sector' was conferred to NPCIL by Institute of Public Enterprise, Hyderabad. The CVO along with General Manager (Vigilance) received the award from honourable Shri K.V Chowdary, Central Vigilance Commissioner, CVC in a function held at IPE premises in Osmania University at Hyderabad on March 4, 2017.

Eight Vigilance Officers of Headquarters and Units were imparted short duration training in reputed institutes to increase their capability and skills.

Vigilance Awareness Week was also observed at various constituent units of DAE such as BARC, IGACR etc. Competitions and awareness programmes were organised during the week.

## 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:





**(left to right)- Director (Admin & Cadre), CCA, Ex CE, HWB and IG (Security) shared the dias on the occasion of Hindi Day Celebration-2017**



**Meeting of Joint Hindi Advisory Committee (DAE-DOS) held on 26/09/2017 at Vigyan Bhavan, New Delhi**

The total strength of Hindi staff in DAE and its constituent Units, PSUs, and Aided Institutions is 127.

DAE have inspected 12 nos. of its Units/Public Sector Undertakings/Aided Institutes. The Parliamentary Committee on Official Language have inspected ECIL, New Delhi ECIL, Mumbai; IREL, Kochchi; IMSC, Chennai and ECIL, Kolkata.

A meeting of Joint Hindi Advisory Committee (DAE-DOS) was held on 26th September, 2017 in New Delhi.

Under the Official Language Rule 10(4) of OL Rules, 1976, 41 offices of the Department have been notified so far.

Thirty eight 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 Committees of the Parliament, and the Agreements and MOUs were prepared bilingually.

About 3052 officers and employees were imparted training in Hindi Noting and Drafting in Hindi Workshops (151 workshops were organized). About 323 officers and employees under the Incentive Scheme for doing original noting and drafting in Hindi, 29 Typists under the Incentive Scheme for Hindi Typing and 33 Stenographers under the Incentive Scheme for Hindi Stenography were awarded. About 248 officials, 02 Typists and 13 Stenographers were imparted training in Hindi, Hindi Typing and Hindi Stenography respectively & eligible candidates were given cash awards and other incentives for successfully passing Hindi, Hindi Typing and Hindi Stenography examinations.



**Shri Satish Iyer receiving memento from JS (R&D) on the occasion of the World Hindi Day -2018**

Quarterly meetings of Official Language Implementation Committees (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.

Hindi books worth Rs. 8,01,351/- were purchased. 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.

The Hindi Vigyan Sahitya Parishad, a voluntary organization of BARC continued to publish a popular Hindi quarterly bulletin "Vaigyanik" and conducting Scientific Seminars too. Pamphlets on various subjects related to DAE's activities were also prepared in bilingual form. A booklet on Swachh Bharat was prepared in Hindi.

Twenty three House Magazines and 12 Newsletters were brought out by various establishments of DAE.

NPCIL complies with the instructions/orders issued by Government of India from time to time on implementation of Rajbhasha "Hindi". Every year Hindi Workshops are conducted by NPCIL HQ as well as at its all sites. In this series 4 nos. of one day Hindi workshops were conducted in NPCIL HQ to apprise of provisions of OL policy to the employees and encourage them to do most of their official work in Hindi. One quiz competition 'ABC' was conducted as a part of Hindi Day Celebration.

A Rajbhasha Samman evam puruskar Vitran Samaroh was organized at HQ. 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 HQ participated enthusiastically in the competitions.

NPCIL was honoured with DAE Rajbhasha Shield consecutively for ninth year (2008-2016). NPCIL was honoured with the award for the year 2016-17 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 Rolling Shied in the category of large enterprise for the year 2016-17 by an NGO "Ashirwad" which works for promoting and propagating Rajbhasha Hindi in Mumbai. NPCIL has received prizes from this institution for 8 times in the past 10 years.

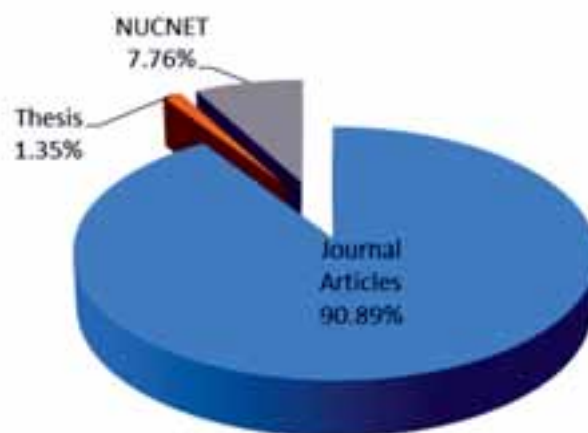
## SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

Scientific Information Resources of BARC is

continuously being upgraded / equipped with the state-of art facilities and technology infrastructure including 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 to provide seamless access to information to BARC scientists and engineers in their day-today R&D activities and also extends its facilities to other DAE institutions.

A total of 391 books and 130 e-books were procured to cater the needs of DAE Scientists. A total of 630 scientific and technical reports and 100 bound periodicals have been added to the collection. BARC currently subscribes to 1074 periodicals, 12 Standards and 13 Databases.

Nucnet has been hosted on Saraswati E-Sangrahay. This portal has been updated regularly for digital resources, reports, newsletter, Books/Reports on display. Digital institutional repository, under E-Sangrahay, holds more than 13700 articles, 1177 NUCNET news and 205 theses.



### Digital institutional repository holdings

BARC website is maintained and content management was regularly carried out. Anu Sangraha database contents are regularly updated. Special events, conferences, visit of delegates and scientific facilities developed by BARC and its units are captured, indexed and hosted on the intranet. National

Technology Day function was organized. A total of 8790 publications were published during 2013-2017 as per Scopus database. 31 BARC External and Internal Technical Reports, BARC Newsletter including the Founder's Day Special Issue and several other publications for various Divisions of BARC were carried out.

BARC is the nodal agency in India for all activities related to International Nuclear Information System (INIS) operated by International Atomic Energy Agency (IAEA) INIS. India has contributed 2981 bibliographic records to the database.

BARC's Foreign Languages Section provides translations of French, German, Russian, Spanish and Portuguese scientific and technical documents as well as interpretation services and language courses for all the units of DAE. Over 1256 pages of translated text were provided this year, 3 French language courses were held for scientists proceeding to ITER and interpretation services were provided for DRHR and visiting foreign scientists.

Library & information services such as Circulation, New Arrivals Services, News Clipping Services, Reference & Information Services, Reprography Services etc. were continued at the Scientific Information Resource Centre (SIRC) of DAE. New books, Periodicals & Journals and other reading materials were added to the resource collection. During the year, the online consortium of Elsevier E-Journals was renewed. Publication and printing of statutory document such as 'Annual Report' and internal publications such as 'Accounts at a Glance', 'DAE Diary', "DAE Essay Contest Announcement" etc. were continued. Publication and printing of various public awareness materials such as 'Nuclear India', 'Parmanu', 'DAE Perspective', etc. were also continued.

## PUBLIC AWARENESS

The Department of Atomic Energy (DAE) organized and participated in several events throughout the year to ease groundless unnecessary panic and addressed apprehensions harboured against Nuclear Energy. Across the nation there exists a void of any real understanding, on the part of general population, of

anything related to nuclear energy and technologies developed for better quality of life. To keep the public abreast with the latest developments and contributions of atomic energy towards societal welfare, DAE also participated in and organized events comprising exhibitions, seminars, workshops, essay and quiz contests in different parts of the country which were well received by the targeted audience.

Public Awareness Division, DAE initiated a massive awareness programme about atomic energy through Workshops for Journalists. 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. The workshop was held from March 02-06, 2017 at Mumbai. This DAE-Journalist Workshop, was the first in a series, which facilitated a forum for brainstorming and exchange of views regarding the Department's activities. Through collaboration with the National Union of Journalists (NUJ), we invited about 55 journalists from different parts of the country. The programme featured interaction with scientists, group discussions, briefing about various technologies along with visits to facilities like BARC, Trombay, BRIT, TMC & RMC and the TAPS 3 & 4, Waste Management Facility.



*Group Discussion of Journalists with Scientists*



*The Journalists at TAPS 3 & 4*

The Parliament standing committee on 'Science & Technology, Environment and Forests' had arranged an exhibition on "Science and Technology Innovations"





**Smt. Sumitra Mahajan, Speaker, Lok Sabha  
at the DAE pavilion**

at Parliament Annex Building, New Delhi during July 28 to August 12, 2017. The Department of Atomic Energy (DAE) participated in this event.

About 82 MPs from the Rajya Sabha and Lok Sabha, Shri Suresh Prabhu Hon'ble Railway Minister (then), Speaker of the Lok Sabha, Smt Sumitra Mahajan, Smt Renuka Chowdhury, and other dignitaries visited the DAE pavilion and had detailed interactions with the scientists.

The visitors lauded the department on its achievements and many of the MPs expressed a desire to establish facilities on food processing, sewage treatment, healthcare etc. in their respective constituencies.

21st June was declared as International Yoga Day by the United Nations at the initiative of our Hon'ble Prime Minister Narendra Modi. Yoga provides holistic fitness solution to mankind. DAE organized International Yoga Day on 21st June, 2017 in co-ordination with Atomic Energy Recreation Club at OYC Lawns of DAE premises. The programme was covered by Doordarshan, Mumbai, All India Radio, Mumbai, Press Information Bureau, Delhi and Sakal, Mumbai.

DAE participated in the Government Achievements & Science Expo 2017 at Pragati Maidan, New Delhi during July 14-16, 2017. The expo had wide participation from Government departments, ministries, PSEs and Pvt. Sector. More than 25 states of India and 100 departments of Central and State governments participated in the expo and it was very enlightening for the farmers, industrialists.



**Visitors during Government Achievements &  
Science Expo 2017 at Pragati Maidan, New Delhi**

DAE along with VECC participated in the Indian national Exhibition cum fair 2017 during August 17-20, 2017 at Gaira, Kolkatta. The theme of the exhibition was India Progressing towards a Great Nation- Science & Technology for National Development & Make in India.



**Students being briefed at Indian national  
Exhibition cum fair 2017, Gaira, Kolkatta**

Abhyantrik 2017 a Technical festival was held during October 06-07, 2017 at K.J. Somaiya College of Engineering, Somaiya Vidyavihar Campus. DAE participated in this festival and put up an exhibition. The



**Dr.R.Chidambaram, Principal Scientific Advisor to  
Govt. of India at the DAE pavilion during Abhyantrik 2017**

exhibition was visited by thousands of students from K.J.Somaiya as well as nearby colleges. Dr. R. Chidambaram.

Ministry of Science & Technology and Earth Sciences in association with Vijnana Bharati organised the Indian International Science Festival during 13-16 October 2017 at Science City, Chennai wherein a Mega Science Technology & Industry Expo was highlighted showcasing the achievements and success stories of Indian Scientific Organisation, R & D Labs and Indian Industry, with a focus on the flagship programmes undertaken during the last three years. There were also scientific conferences, student's programmes and many other activities. DAE participated in the IISF Expo 2017 along with BARC, RMC, IGCAR & RRCAT.



**Students at the DAE Pavilion during IISF 2018, Chennai**

DAE participated in the Gujarat Scientific Literacy Festival – A Science & Technology Workshop cum exposition on Multidimensional Technology & Innovation for empowerment of Weaker Section at Valsad during October 26-28, 2017. The exhibition was visited by a large number of people.

DAE participated in the two day Workshop organized by Graphic Era Hill University, during November 02-03, 2017. This workshop was attended by the students and faculty members of this university as well as nearby Schools, Colleges and Universities of Uttarakhand. The workshop highlighted the achievements of Department to propagate the use of atomic energy for production of power which is safe, economical and environmentally benign. Presentations

on the topics - Nuclear Power, Agriculture, Food, Healthcare, Industry and Technologies for better quality of life was made by the scientists of DAE.

Unmesh-Gyan Vigyaan Vichar Sangathan organized Parmanu Urja Jan Jagrati Abhiyaan at Jabalpur during November 15-17, 2017. DAE participated in this by setting up an exhibition and also supported it financially. Students from schools and colleges participated in the above programme in large numbers. The programme comprised an Exhibition, Lecture Series and interschool and college competitions. The theme of the Workshop was Science & Technology Communication and Popularization & Parmanu Urja Jan Jagriti Abhiyan.



**Students at DAE exhibition during Unmesh-Gyan Vigyaan Vichar Sangathan, Jabalpur**

DAE participated in the conference and exhibition at Nehru Centre, Worli, Mumbai during November 9-10, 2017. The event was co-organized by the Department of Atomic Energy (DAE) Government of India. The summit has been designed to showcase the opportunities, address challenges and evolve strategies, vision in order to propel sectorial development and charter the way forward. The exhibition was participated by academia, Senior Indian & International Government officials, thought leaders from the Corporate Sector. Country participation from France, Russia Korea and Canada.

This year, for the first time, as a diversification, a session on Radiation Processing of Food was organized on the 2nd Day of the event. Experts (speakers) from BRIT, BARC and some members from the private sector who have already set up such plants participated in the session. Entrepreneurs interested in setting up radiation processing plants attended the presentations.



The 55th National Metallurgists Day on the theme 71st Light Weighing for Defence, Aerospace and Transportation was held at Birla Institute of Technology and Science Pilani, Goa during November 11-14, 2017. DAE participated in this event by putting up exhibition. National Metallurgist Day – Annual Technical Meeting-2017 (NMD-ATM) had parallel sessions and symposia under different themes (Ferrous, Non-Ferrous, Materials Science & Engineering and Careers etc.). The exhibition was visited by over 1000 delegates as well as industries and experts from Goa.

Two days seminar was organised by National Association for Application of Radioisotopes & Radiation in Industry (NAARRI) on “Application of Radioisotopes and Radiation Technology in “Industries, Agriculture & Healthcare” at GKV University , Bangalore during Nov. 29-30, 2017



**Students at DAE pavilion during NAARRI exhibition at GKV University, Bangalore**

DAE participated in this by putting up exhibition and giving financial assistance. About 300-400 participants representing faculty members and research scholars from various universities, Agricultural research Institutions, Industrial houses, practicing doctors from leading hospital participated. The program involved invited talks by experts in the field from leading cancer hospitals, BARC, BRIT, AERB, DAE and other research institutions.

DAE participated in 13th Jatiya Sanhai Utsv-0-Bharat Mela 2017 organized by Bangiya Seva Samity during December 14-18, 2017. Distinguished dignitaries, Scientists, Government Officers, Industrialists and students from Schools and Colleges visited the exhibition. Officials from SINP & VECC, Kolkatta participated in the above event.

Indian Women Scientists Association had organized ‘Science Academies’ Refresher Course at IWSA Complex, Vashi during December 18-20, 2017. Teachers and Assistant Professors from various universities from different parts of the country participated. Students from nearby schools and colleges in Vashi, Navi Mumbai visited the exhibition. DAE participated in the event putting up exhibition and financial assistance.

DAE's participation in Sundarban Kristi Mela O Loko Sanskriti Utsab was organized by Kultali Milan Tirtha Society during December 20-29, 2017. DAE participated by putting up an exhibition and financial assistance. Academicians, Youths, Students, Scholars, Scientists, Government officials, dignitaries and general public visited the exhibition.

DAE organized Bhabha Day on November 15, 2017 at OYC Lawns. All the staff members along with their family were invited for the celebration. The programme started with a short film on the life and achievements of Dr. Bhabha. Thereafter a cultural programme was organized in which all the staff participated. All the unit Heads of DAE from Mumbai were invited. Distinguished Scientists, Outstanding Scientists, senior scientists with their family attended the event.

The 29th All India Essay Contest on Nuclear Science and Technology was held in October 2017. A total of 358 essays were received out of which the authors of 36 were selected for making an oral presentation at Mumbai. The selected participants visited various DAE facilities like BARC, RMC, ACTREC, BRIT and TAPS 3 & 4. Prizes, in cash were awarded on Founder's Day. The essays were received in Hindi, English, Tamil and Marathi languages.

NPCIL's public outreach includes regular interaction with the persons living nearby Indian Nuclear Power Plants (NPPs); visits of villagers, students, 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. Besides, NPCIL is



also in the process of setting up number of nuclear galleries at the science centers across the country to provide factual information in an interesting and interactive manner on nuclear power and other associated aspects.

Use of exhibitions, seminars, scientific meets, distribution of public awareness publications, advertisements in print and electronic media, screening of animated films in vernacular languages, enhanced interaction with press and media, e-public awareness campaigns etc. are also being adopted to enhance further outreach activities.

NPCIL has also been partnering with several expert agencies like National Council of Science Museums, other regional Science and Technology Centres, Public Relation agencies and Department of Science and Technology etc.

NPCIL has been reaching out to an average of around 3.3 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. Apart from that, lots of information about various aspects of nuclear energy is being shared through various social media platforms like Facebook, YouTube, Twitter, etc.

### **Publications**

Several Lakhs copies of various informative & educative public awareness publications on various aspects of nuclear power are being distributed to general public, students, teachers, eminent persons etc. on annual basis. These Public Awareness publications are being distributed in regional languages also in the states where NPPs are located.

### **Halls of Nuclear Power**

The permanent exhibitions on Nuclear Power “Halls of Nuclear Power” have been setup at science centers at Mumbai, Chennai and Delhi and witness lakhs of visitors yearly. Creation of similar galleries at other science centers across the country is also under process.

### **Miniature Nuclear Galleries**

In the smaller cities, miniature galleries are being planned in large numbers to further promote nuclear energy. These will be relatively small galleries covering area of around 300 sq. feet and will be established in prominent science centers, planetariums and in museums, comprising panels, banners, interactive models, screening of short films, publications etc.

### **Nuclear Power Plant Models**

The semi-dynamic NPP model is one of the best tools to inform general public about nuclear power plant operation and its safety features. The models of 220 MW PHWR units are fabricated and installed at various Science Centers viz. Dhenkanal Science Centre, Odisha; Kalimpong Science Centre, West Bengal; Regional Science Centre, Coimbatore & Tirunelveli Science Centre, Tamil Nadu; Regional Science Centre, Tirupati, Andhra Pradesh; Kurukshetra Panorama & Science Centre, Haryana and Pushpa Gujaral Science City, Chandigarh for public awareness.

### **Exhibitions**

NPCIL as a part of Public awareness activity reach out to the masses by organizing Exhibitions at various locations across the country to educate, inform and impart factual information related with nuclear power and radiation. Some of the significant exhibitions organized during the period include India International Trade Fair (IITF 2017) held at New Delhi, where nearly 4.5 lakhs visitors were benefitted; CSR Fair 2017 at New Delhi, 12th Biennial International Conference & Exposition 2017 at Jaipur, 6th International Conference on Advances in Energy Research (ICAER 2017) at Mumbai and “Achievements of Ministries of Science & Technology and Earth Sciences” in the Parliament Complex are some other important exhibitions where NPCIL participated. 2-week long exhibition was organized by RR site in Kota Dussera Mela. Over two lakhs visitors including VIPs and government officials and elected representatives were imparted awareness about nuclear power. NPCIL also participated in Energy Expo -2017 by Kakrapar Gujarat Site and in engineering college technical extravanza SHODH 2017 by JNPP.

## Awareness programmes in schools and colleges

NPCIL reached out to academics institutions in various parts of the country by the way of organizing lecture programmes, essay competitions, scientific quizzes, etc.

### Public Awareness Seminars

Organizing lecture series and participation in seminars as well as panel discussions on safety of nuclear power plants, radiation etc. are the ongoing PA activities. Total 124 lecture programs were organized.

### Campaign in Kendriya Vidyalayas

A long-term, sustained campaign has been initiated in Kendriya Vidyalayas all over India to sensitize students and teachers to the positive aspects of atomic power. Campaigns have been initiated and conducted in Maharashtra, Madhya Pradesh and other states covering over 40 Kendriya Vidyalayas. In addition, several under-privileged schools imparting education in Hindi and local languages were addressed by NPCIL.

### College Lecture Series

Over 60 lectures covering several thousand college students have been organized. These include seminars delivered at major scientific and technical events of various colleges.

### Doctors' Meets

3 Doctors' meets were organized in various medical institutions sensitizing around 110 medical doctors to the effects of radiation and epidemiological patterns of radiation-induced diseases such as cancer around nuclear plants to eliminate fear of radiation from the minds of the medical fraternity.

### Capacity-building for outreach

Around 90 resource-persons of NPCIL were trained during this period by the expert faculty in the various training programmes on media and public communication organized at NAPS, KKNPP and MAPS.

## Atom on Wheels (AoW)

Atom on Wheels Programme, a moving van with exhibits, is specially designed for the people living nearby upcoming nuclear power plants to allay prevailing apprehensions related to radiation and to develop the positives understanding on nuclear energy. Under this programme, around 500 villages of Maharashtra and Andhra Pradesh with approx. 2 Lakhs of people were covered during this fiscal year.

## Media / Public Relation (PR) Facilitation Programme

In order to increase the reach about the merits of nuclear energy to various sections of the society, nationwide campaign on media and PR facilitation has been launched. Under this programme many activities are organized in schools and colleges in 8 different states.

Variable Energy Cyclotron Centre (VECC), Kolkata, along with the Institute of Plasma Research (IPR) and Electronics Corporation of India Limited



*A model of superconducting cyclotron is being shown to students*



*Participants of VECC, DAE, Kolkata received the 1st prize*

(ECIL), represented the DAE pavilion at “Indian National Exhibition Cum Fair”, at Dinabandhu Andrews College Ground, Kolkata, during August 17-20, 2017, with the focal theme of the exhibition as “Science & Technology for National Development & Make in India”. The DAE pavilion has received the 1st prize among all the other pavilions at the above exhibition.

VECC, Kolkata has jointly participated along with the Technology Transfer and Collaboration Division of BARC, Mumbai in the “Sundarban Kristi mela –O-Loko Sanskriti Utsab” at Kultali, during December 20-29, 2017. The students and local people from the remote villages around Sundarban District visited the stall.

About 500 students from various schools and colleges have visited VECC since April, 2017 and more such visits have been planned during this year. The students have benefited greatly in interacting with the scientists at VECC and visiting the cyclotrons and various experimental laboratories at VECC.

Under the outreach programme, RRCAT participated in four national exhibitions. These include the “Pride of India” exhibition organized as part of 104th National Science Congress during January 3-7, 2017 at Sri Venkateswara University, Tirupati; Bhopal Vigyan Mela (BVM)-2017 held during March 3-6, 2017 at BHEL, Dussehra ground, Bhopal where the RRCAT Pavilion won the 2nd position amongst 120 exhibitors; “Mega Science and Technology Expo” organized as part of India International Science Festival 2017 during October 13 -17, 2017 at Anna University, Chennai; NUiCONE 2017 (exhibition on Green Technology and Innovations) at Nirma University, Gandhinagar by Institute of Plasma Research, Gandhinagar, organized during November 23-25, 2017.

RRCAT celebrated National Science Day on 25th and 26th February, 2017 by holding an open house for school students, teachers, family members of staff members and invitees from public. A number of scientific exhibits were set up at different laboratories to explain the scientific and technical activities of RRCAT and to demonstrate a few concepts in basic sciences. About 1400 students and teachers of 105 schools from Indore and nearby places visited the exhibits. A special feature this year was the participation of deaf and mute

students for which special arrangements were made using interpreters. A “Make in India Gallery” was set up to showcase recent important scientific achievements and in-house technology developments carried out at RRCAT.

Public Outreach programs were organized by the HWP sites in nearby schools/colleges, villagers, 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. HWB also participated in many International and National exhibitions by showcasing various non-nuclear applications of heavy water and d-labeled compounds synthesized by HWB.



**Awareness programme for students at SPIC Nagar Higher Secondary School, Thootukudi**

## SOCIAL WELFARE

### Corporate Social Responsibility, Sustainability and Rehabilitation & Resettlement

From the inception of nuclear power programme in the country, the units of NPCIL have been implementing social welfare activities for the benefit of local population living within sixteen (16) Km radius from plant site. With enactment of the Companies Act 2013, NPCIL has started structured programme as per the provisions under the Act.

Under CSR programme, NPCIL is taking up the activities in the identified thrust areas of education,





**Foundation stone by CMD, NPCIL for start of construction of school building under CSR at Eklingpura in Rajasthan**



**View of construction work of Govt. Boys Sr. Secondary School at Rawatbhata, Rajasthan site**

healthcare, infrastructure development, skill development and sustainable development and Swachh Bharat Mission.

Support to education is extended through implementation of projects such as construction of school buildings and class rooms, hostels, school boundary wall, toilets and urinals; augmenting school teachers, scholarships to students and development of Anganwadis. Educational items are provided to the school children for motivational purpose. Based on need, transport facility is provided for the school children and teachers.

Under healthcare category, primary health centres, mobile medical van services and medical camps are organized. Persons with disabilities were provided with special assistive device under project called 'ASAN' in association with Artificial Limbs Manufacturing Corporations of India Limited (ALIMCO). Towards this, assessment camps distribution camps were organized at stations and projects by ALIMCO.

Construction of roads, bridges and culverts, community halls, bus stop sheds, overhead tanks and

drinking water facility, R-O plants etc. are taken under infrastructure development.

Skill development programmes are implemented by imparting livelihood generating skills such as computer skills, tailoring, stitching and handcrafts etc. Sustainable development initiatives are taken through implementation of projects like installation of solar street lights and conservation of gangetic turtles, rain water harvesting, artificial reefs for augmenting fish production, solid waste management programme etc.



**Inspection of Vermi Compose pit at MAPS site by District Collector & Member of Parliament**



**Honey hive culture and honey extraction training at KGS site**

## Swachha Bharat Mission

The Department of Atomic Energy and its constituent units continued its activities for the "Swachha Bharat Mission". As a part of Swachh Bharath Mission at IGCAR, 900 Kg. of old records were weeded out and handed over to Stores for disposal and cleaning

of dump yards was also taken up. Swachh Bharat activities have been carried out at Headquarters and seven Regional Centers of AMD. AEES took lot of initiative and participated in the Swachhata campaign.

## 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 is providing 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 all children in the age group of six to fourteen years, under Right to Education Act. The same was implemented in AEES, in the year 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 teachers, 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.

### Opening of New AEC School

A new AEC School has been opened at Zirconium Complex, Pazhayakayal, Tuticorin, which started functioning from April 2017. The school currently runs classes from Pre- Preparatory to Illrd standard.

### Board (X and XIIth) Exam Results of AEES Students

About 2116 students appeared in the CBSE Board examination of Class X, in March, 2017. 28 out of 29 schools achieved more than 90% pass percentage, out of which 19 schools had a 100% result. The Quality Index and Excellence Index were at a rise this year when compared to the last year's results. The Quality Index rose from 7.95 to 8.1 this year. The overall Excellence Index stood at 95.7 as compared to 92.74 last year.

About 1587 students from 16 AEC Schools and 1 Junior College appeared for the Class XII examination in March, 2017. The pass percentage is 92.82% as compared to 92.29% last year and the overall Excellence Index stood at 68.87 as against 68.12 last year. The Quality Index also rose from 6.55 to 6.6 this year. The pass percentages of 9 Schools / Junior Colleges were above 90%, out of which AECS Mysore and AECS Kudankulam produced 100% result.

### Admission to Professional courses – 2016-17

Many students of AEES have secured admission to reputed professional colleges for Engineering, Medicine, etc. in the year 2016. In addition to the above, many students got admission to BE/ B.Tech courses through CET & AIEEE.

## Scholastic 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 is aimed at nurturing students towards excellence in Science and Mathematics at the high school level. Vigyan Pratibha initiative was formally launched on 31st July, 2017 at HBCSE. This programme is for the schools of Kendriya Vidyalaya Sangathan (KVS), Jawahar Navodaya Vidyalaya (JNV) and AEES. Initially, in the pilot phase, this programme has been launched in two schools of AEES, i.e. AECS-5, Mumbai and AECS-2, Tarapur along with some schools of KVS and JNV. Similar activities are being taken up at the Schools of Jaduguda Centre in collaboration with HBCSE and SINP, Kolkata.

### XVIII Junior Science & Mathematics Olympiad – 2017

Atomic Energy Education Society in collaboration with Homi Bhabha Centre for Science Education (HBCSE) has been conducting the Junior



**Validictory function of XVIII Junior Science & Mathematics Olympiad – 2017**



**XVIII Junior Science & Mathematics Olympiad-2017**

Science & Mathematics Olympiad orientation programme for the meritorious students of Class X of AEC Schools located all over India. This year, the programme was conducted by AECS-5, Mumbai and was held at AEJC, Mumbai from 9.10.2017 to 14.10.2017. There were 62 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 top 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 Gondhlekhar Memorial award.

## Co-Scholastic Achievements and Activities

### Achievements in Sports

The team of Atomic Energy Junior College, Mumbai won 1st position in Tennis Volleyball discipline of World Games, 2017 dated 15th to 18th June, 2017, organized by International Sports Council at Kathmandu. Miss Lakshita Mukati, class IX student of AECS, Indore was awarded with Gold Medal in CBSE National Taekwondo Championship (below 45 kg category) held at DPS, Kalinga. Miss K. Gayathri, class X student of AECS-1, Kalpakkam stood first in High Jump at CBSE National Level meet held at Allons Public School, Chhattisgarh.

### Republic Day Parade

Master Shivaksh Vyas, Class X student of AECS-3, Rawatbhata represented his NCC Directorate at the Annual NCC Republic Day Camp and the Prime Minister's Rally held at New Delhi from 1st January to 29th January 2017.

### 3rd International Yoga Day-2017

The 3rd International Yoga Day was celebrated with great enthusiasm in AEES, on June 21st, 2017. 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. A separate programme was arranged at the Central Office, AEES in the morning





**International Yoga Day, 2017 celebrated in AEES**

session where Chairman, Secretary and the administrative and academic staff of AEES participated. In the afternoon session a renowned yoga expert, Shri Ramkishan conducted an interactive session on Yoga and its benefits for the staff members of AEES, 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.

### **Achievement of students in Music**

The All India Inter - AECS Cultural (Music) Meet for Junior & Senior category of students was held in AECS-1, Hyderabad from 9.11.2017 to 11.11.2017. Students from all the AEC Schools and Junior Colleges from across the country participated in the competition which was held for various categories of events.

### **Achievement of students in Art**

The All India Inter - AECS Art competition (School level) was held in AEC Schools all over India on 21st November, 2017. The selected paintings will be displayed in the All India AEES Art Exhibition to be held on 26th January, 2018 at AEJC, Mumbai. AECS-3, Mumbai will coordinate the Art Exhibition.

### **Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition (JNNSMEE)**

Projects from AEC Schools are selected at AEES level and the selected exhibits are sent for selection to Jawaharlal Nehru National Science, Mathematics and Environmental exhibition organized by NCERT. Master. Tarang Srivas, Class X student of

AECS-2, Rawatbhata got selected for No. 1 position at All India Inter AECS Level, selected amongst best 30 Projects at JNSSE at Bhopal and selected for the Rashtriya Kishore Vaigyanik Sammelan to be held at Osmania University from January 4-6, 2018.

### **Workshops, Seminars and Orientation Programmes**

In-service training programmes were organized for Post Graduate Teachers, Trained Graduate Teachers & Primary Teachers of AEC Schools. For the first time in the history of AEES, such programmes were held in collaboration with KV's Zonal Institute of Education and Training (ZIET). More than 200 teachers attended the In-Service programmes in May-June 2017.

### **Installation of CCTV Surveillance System in AEC schools**

AEES has taken up a sub-project for the installation of CCTV Surveillance System in all 30 AEC Schools/Junior Colleges managed by AEES, as an intense need for such Surveillance System was felt for the safety, security and discipline related problems faced in the Schools/ Junior Colleges. The installation process is in full swing.

## **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 during the year 2017-18 is outlined as follows.

The XXXIII rd Annual DAE Sports and Cultural Meet is being conducted in eleven different sports and cultural events (Athletics, Badminton, Cricket, Cultural (Poetry/Drama), Table- Tennis, Swimming, Football, Lawn Tennis, Bridge, Chess and Kabaddi) at various units of DAE at various locations in the country.

The Football Meet 2017-18 was hosted from 24th to 28th December, 2017 by UCIL, at Jaduguda. All the eight teams namely Ajanta, Dwarka, Ellora, Golconda, Konark, Nagarjuna, Rameshwaram and Pushkar participated in the meet. Konark team won the championship by beating Ajanta team in the finals. Final score was 2:1.



**Konark team with the Championship Trophy**



**Kabaddi: Winning Team AJANTA  
with CE, NFC & CMD, ECIL**

Kabaddi Meet, 2017-18 was hosted from 4th December to 8th December, 2017 by NFC, Hyderabad at Atomic Energy Central School II (AECS-II), DAE Colony. Ajanta team won the Championship by beating Rameshwaram team in the finals.

The Athletics Meet 2017-18 was hosted from 27th to 29th December, 2017 by IGCAR, at Kalpakkam,

All eight teams participated in the meet. Overall championship was won by team Ajanta.

DAE S&CC organized summer coaching camps for DAE school children for four weeks jointly with AEES at various DAE Schools located at different units of DAE. More than 2700 students participated in preliminaries camp and 1500 students participated in the main camp.

Employees of DAE participated in various Marathon in Mumbai and suburbs including Standard Chartered Mumbai Marathon-2017, ICT Marathon, Kharghar Half Marathon, Mumbai Customs Half Marathon, Ladakh Marathon etc. and were proved to be the great source of inspiration for many youngsters.



**DAE Participants at various Marathons**

DAE Sports & Cultural Council & BARC Staff Club joined hands and conducted Anushakti Monsoon Marathon 2017 (AMM 2017), on Sunday 27/08/2017 in twelve different categories for 2.5 Km and 10.5 Km distances. 186 DAE participants and 115 non-DAE guest participants took part in the event.



**Glimpses of AMM 2017**





DAE S&CC in coordination with BARC Staff Club and under the aegis of Bridge Federation of India (BFI) successfully organised the Inter-State National Bridge Championships-2017 (ISNBC-2017) along with Sub-Junior and Junior Bridge national Championships during 31st August 2017 to 3rd Sept 2017 at New Community Centre, Anushaktinagar, Mumbai. The tournament was conducted with international standard Bridgemate Scoring, computerized Dealt boards, BBO Vu-graph and Daily Bulletins for the first time in Anushaktinagar.

DAE S&CC in association with BARC Staff Club successfully organised the All India Inter Institutional Kabaddi Tournament-2017 (AIIKT-2017) under the aegis of Amateur Kabaddi Federation of India (AKFI), Maharashtra State Kabaddi Association (MSKA) and Mumbai Upanagar Kabaddi Association (MUKA) during May 08-10, 2017 at PTAA Facility, Anushaktinagar, Mumbai.

DAE S&CC has been sending DAE teams for participation in National Table Tennis & Ball Badminton championships.

Under its Health and Fitness Activities, 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.

Two days Fitness Mela -2017 was organised by BARC Staff Club – Health & Fitness Section (Yoga Circle)

in association with Anushaktinagar Residents Welfare Association (ARWA). More than 300 staff members / family members participated in the programmes beside volunteers, Yoga teachers, trainers & experts.

Team “Girisanchar” of DAE S&CC arranged various Nature & Adventure related activities throughout the year. These includes Himalayan Trekking expeditions, Monsoon treks, Nature & Adventure Camp for school children, Cyclothon & Cycling Expedition, Walkathon, Know Your Trees Walk for school Children etc.

DAE Cultural Centre (DCC) has initiated various activities like Dance, Drama, Music, Literature, Traditional Art, Films etc in the first year of its functioning. 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.) been started from Oct 2016 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.

New Community Centre under DAE S &CC has organized SPLASH-2017 sports and cultural meet in Anushaktinagar from 1st to 10th December 2017. Current or Ex-DAE Employees, their dependent family members, regular trainees of various DAE units in Mumbai/Navi Mumbai and existing members of NCC participated in Spalsh-2017 meet. The fun filled sports extravaganza of SPLASH 2017 is a huge tournament having around 14 events comprising of Badminton, Table Tennis, Lawn Tennis, Carrom, Snooker, Chess, Swimming, bridge, cricket, musical events, dance competition, fitness. The response for SPLASH-2017 was overwhelming and all the events were conducted and completed successfully.

## 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.



RTI applications received generally pertain to the Selection Process for the OCES/DGFS programmes of the BARC Training Schools. Information provided include: (i) GATE cut-off scores in the previous recruitment cycle (ii) Online cut-off marks in the previous recruitment cycle (iii) Question Papers for the previous year's Online Exam etc. The other set of queries come from applicants who appeared for Selection Interview but were not finally selected. In this case, the applicants seek to know (i) Marks awarded to them in Selection Interview and (ii) Cut-off Interview Marks for final Selection to OCES/DGFS. During the year 2017, 78 RTI applications were received and replied to.

At IGCAR, the provisions contained in Section 4 of RTI Act 2005, were fully complied with and information relating to suo moto disclosure was updated regularly and uploaded in the website. 106 applications were received, 9 applications were transferred to other PIOs. Information was provided to the applicants within the prescribed time limit. 7 appeals were received and disposed of within the prescribed time limit.

A total of 242 RTI applications and 29 appeals for first appellate authority were received at AMD and they were replied. 4 CIC hearings on second appeal were attended and orders passed by CIC.

The number of RTI applications received at RRCAT were 171 and out of which 156 were disposed of during the calendar year.

During the period upto December 2017 129 RTI queries were received at IREL and 119 RTI queries were replied and reply to balance 10 RTI applications will be sent within prescribed period as per RTI Act.

During the Financial Year 2017-18 till December 2017, total 500 nos. of RTI applications and 130 Nos. of Appeals were received at NPCIL under the RTI Act 2005 and were disposed off. Department of Personnel and Training (DoPT) RTI online portal is used effectively in NPCIL. The online RTI applications and Appeals so received are being disposed online through portal.

SINP received 25 RTI applications out of which 24 applications were replied and out of 4 appeal received all of them were replied.

## AWARDS & PRIZES

Several awards in areas of safety and performance, Vigilance, Public Awareness (PA) activities, Corporate Social Responsibility (CSR) and Official Language (OL) were bagged by various units of NPCIL and Headquarters.

TAPS-1&2 received various awards such as NSCI Safety Award (Bronze Medal) from Honorable minister of State Shri Bandaru Dattatreya (Independent Charge), labour & Employment, Govt. of India, at Vigyan Bhavan, New Delhi for the assessment period of three years 2012-2014; National Safety Council (Maharashtra Chapter) award of a plaque for "Factories Working over One Million Man-ours" under Scheme - I – Lowest Accident Frequency Rate for the year 2015 at West End Hotel, Mumbai on 17.09.2016; AERB Industrial Safety Award in the category of Winner from Chairman, AERB for the year 2015 at Gandhinagar and National Safety Council has announced a Bronze Award for TAPS-1&2 for the Year 2016.



**NSCI safety award 2016  
Shreshtha Suraksha Puraskar for TAPS-1&2**

TAPS-3&4 bagged "Shreshtha Suraksha Puraskar" (Silver trophy and Certificate) for the assessment period 2013-15 in Group-C (Power Generation - Thermal/ Hydel/ Nuclear power plants), for effective implementation of Occupational Safety and Health (OSH) management systems and procedures and achieving outstanding performance in OSH and certificate of excellence from National Safety Council - Maharashtra Chapter, for achieving zero accident frequency rate consecutively for three years 2013, 2014 & 2015.

MAPS-1&2 received AERB Industrial Safety Award for the year 2016 under the category of production units among the DAE establishments; Shreshtha Suraksha Puraskar (Silver Trophy) for the year 2016 under the Power sector category from National Safety Council of India, Mumbai; Gold Safety Award for the year 2016 under the Power Nuclear Sector category from Greentech Foundations, New Delhi and Second Prize (TOLIC Rajbhasha Shield) among the Public Sector Under taking for the best performance in the progressive use of Official Language during the year 2016-17.

KAPS-1&2 received Golden jubilee memorial trust award for environment conservation and pollution control for the year-2015-16 from the Southern Gujarat Chamber of Commerce & Industry (SGCCI), Surat; Shreshtha Suraksha Puraskar (certificate & trophy) 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-2013 to 2015 and it won "National Safety Award" for the performance year-2015 based on accident free year and lowest average frequency rate in the Category-I&II.



**KAPS-1&2 won "National Safety Award" for the performance year-2015 based on accident free year and lowest average frequency rate in the Category-I&II**

KAPP-3&4 received 'Prashansa Patra' from National Safety Council for year 2016.

KGS-1&2 was awarded with National safety award and adjudged Runner-up in the category of

"Accident Free Period" for the performance year 2015, by Directorate General Factory Advice Services and Labour Institute (DGFASLI). It bagged "Unnatha Suraksha Puraskara 2017" for the performance year 2015 & 2016 from National Safety Council, Karnataka Chapter and it was also awarded with "Prashansa Patra" for the year 2017 (for the previous three performance years) from National Safety Council, Mumbai.

KGS-3&4 bagged the prestigious National Safety Award "Sarva Shreshtha Suraksha Puraskar" (Golden trophy) from National Safety Council of India for the second time in a row for the year 2016 & 2017; Safety Award "Unnatha Suraksha Puraskara" from the National Safety Council, Karnataka Chapter for the performance year 2015 & 2016 and Runner Up award for the year 2015 in the category of "Lowest Frequency Rate from DGFASLI (Directorate General Factory Advice Service & Labour Institutes", Govt. of India, Ministry of Labour and Employment). Three employees of KGS-3&4 received prizes in cartoon competition on Safety Themes in 34th DAE safety & OH Professional Meet held at KKNP Site.

KK-1&2 "Green award" from TNPCB for the year 2015 received from Honorable Chief Minister, Tamilnadu and AERB fire safety award for the year 2016 during 34th DAE Safety & Occupational health professionals meet held at KKNPP.



**NPCIL stall was awarded Silver Medal for Excellence in Display category in the India International Trade Fair (IITF) – 2017 at New Delhi**

In Public Awareness, NPCIL stall was awarded Silver Medal for Excellence in Display category in the India International Trade Fair (IITF) 2017 at New Delhi. The "Atom on Wheels" won third prize under Best Public Awareness Programme in the 39th Public Relations Society of India (PRSI), National Awards 2017, held at Visakhapatnam. The "Atom on Wheels" also won the "Pratishtha Award" under Best Public Awareness

Programme in the INDICOM 2017, summit held at Mumbai.

AMD officers were conferred with National Geoscience Award by Ministry of Mines; Homi Bhabha Science & Technology Award-2016 & Group Achievement Award-2016 by DAE; Life Time Achievement Award & Dr. G.R. Udas – Dr. K.K. Dwivedy Medal by Indian Society of Applied Geochemists (ISAG).

ECIL won many awards such as SCOPE Award for Excellent & Outstanding Contribution to the Public Sector management Institutional Category III (Other Profit Making PSEs) 2014-15 on 11th April 2017; Significant Contributions to Digital Initiatives - Swayam Prabha Program on 10th July 17; SCOPE Commendation for the Best Corporate Communication Campaign for the year 2017 on 7th December 2017; The IEI Industry Excellence Award in recognition of the contributions ECIL has made to the country in achieving self-reliance in nuclear and strategic electronics and setting up bench marks in corporate governance and Social Responsibility activities and Renewal of Recognition as In-House R&D unit upto March 31st 2021 by Department of Scientific and Industrial Research (DSIR). ECIL has been appraised at maturity level 5 on Capability Maturity Model Integration (CMMI) – DEV, V1.3. "Rajbhasha Shield" for the year 2016-17 in Big Organizations category for excellent implementation of Official Language.

Smt. Kankana Chandra, PRT, AECS-2, Mumbai was awarded the National Award for teachers on Teachers' Day, i.e. on 5th September, 2017. She received the award at the hands of Shri Venkaiah Naidu, Honourable Vice President of India.



**National Award to Smt. Kankana Chandra,  
PRT, AECS-2, Mumbai**



# CHAPTER

## IMPLEMENTATION OF PERSONS WITH DISABILITIES (EQUAL OPPORTUNITIES, PROTECTION OF RIGHTS & FULL PARTICIPATION) ACT, 1995

11

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 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 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               | VH  | HH  | OH  | VH                        | HH  | OH  | Total | VH                      | HH   | OH   | 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 | 8365                | 1   | 2   | 43  | 0                         | 1   | 4   | 101   | 0                       | 1    | 2    | NIL  | NIL                       | NIL  | 30    | 0    | 0                       | 1    |  |  |
| Group B | 9192                | 5   | 8   | 68  | 1                         | 3   | 2   | 28    | 0                       | 3    | 3    | NIL  | NIL                       | NIL  | 122   | 0    | 0                       | 4    |  |  |
| Group C | 10715               | 19  | 41  | 133 | 3                         | 7   | 18  | 396   | 3                       | 5    | 17   | 0    | 1                         | 0    | 41    | 0    | 0                       | 0    |  |  |
| TOTAL   | 28272               | 25  | 51  | 244 | 4                         | 11  | 24  | 525   | 3                       | 9    | 22   | 0    | 1                         | 0    | 193   | 0    | 0                       | 5    |  |  |

**Note 1 :** (i) VH stands for Visually Handicapped (persons suffering from blindness or low visions)

(ii) HH stands for Hearing Handicapped (persons suffering from hearing impairment)

(iii) OH stands for Orthopaedically Handicapped (persons suffering from locomotor disability or cerebral palsy)

(iv) There is no reservation for persons with disabilities in case of promotion to Group A and B posts. However, persons with disabilities can be promoted to such posts, provided the concerned post is identified suitable for persons with disabilities.

**Note 2 :** Column No. 9 and 16 show the sum total appointments made in the Department by way of Direct Recruitment and Promotion

**ANNUAL STATEMENT SHOWING THE REPRESENTATION OF PERSONS WITH DISABILITIES AS 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 IN RESPECT OF AIDED INSTITUTIONS**

| Group   | Number of Employees |     |     |     | Direct Recruitment        |     |     |       |                         |      |      |      | By Promotion              |      |       |      |                         |      |  |  |
|---------|---------------------|-----|-----|-----|---------------------------|-----|-----|-------|-------------------------|------|------|------|---------------------------|------|-------|------|-------------------------|------|--|--|
|         |                     |     |     |     | No. of vacancies reserved |     |     |       | No. of appointment made |      |      |      | No. of vacancies reserved |      |       |      | No. of appointment made |      |  |  |
|         | Total               | VH  | HH  | OH  | VH                        | HH  | OH  | Total | VH                      | HH   | OH   | 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 | 1358                | 3   | 2   | 9   | 4                         | 5   | 4   | 14    | 2                       | 2    | 6    | NIL  | NIL                       | NIL  | 3     | 0    | 0                       | 0    |  |  |
| Group B | 2536                | 6   | 4   | 19  | 2                         | 8   | 3   | 9     | 0                       | 4    | 5    | NIL  | NIL                       | NIL  | 4     | 0    | 0                       | 0    |  |  |
| Group C | 2266                | 2   | 13  | 33  | 3                         | 0   | 0   | 2     | 0                       | 0    | 2    | 0    | 0                         | 0    | 0     | 0    | 0                       | 0    |  |  |
| TOTAL   | 6160                | 11  | 19  | 61  | 9                         | 13  | 7   | 25    | 2                       | 6    | 13   | 0    | 0                         | 0    | 7     | 0    | 0                       | 0    |  |  |

**Note 1 :** (i) VH stands for Visually Handicapped (persons suffering from blindness or low visions)

(ii) HH stands for Hearing Handicapped (persons suffering from hearing impairment)

(iii) OH stands for Orthopaedically Handicapped (persons suffering from locomotor disability or cerebral palsy)

(iv) There is no reservation for persons with disabilities in case of promotion to Group A and B posts. However, persons with disabilities can be promoted to such posts, provided the concerned post is identified suitable for persons with disabilities.

**Note 2 :** Column No. 9 and 16 show the sum total appointments made in the Department by way of Direct Recruitment and Promotion



**ANNUAL STATEMENT SHOWING THE REPRESENTATION OF PERSONS WITH DISABILITIES AS 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 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               | VH  | HH  | OH  | VH                        | HH  | OH  | Total | VH                      | HH   | OH   | 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 | 7193                | 10  | 6   | 59  | 2                         | 6   | 3   | 217   | 0                       | 2    | 11   | NIL  | NIL                       | NIL  | 0     | 0    | 0                       | 0    |
| Group B | 5456                | 9   | 9   | 64  | 0                         | 7   | 1   | 52    | 0                       | 0    | 1    | NIL  | NIL                       | NIL  | 0     | 0    | 0                       | 0    |
| Group C | 4916                | 16  | 11  | 53  | 8                         | 19  | 6   | 225   | 1                       | 6    | 5    | 0    | 0                         | 0    | 0     | 3    | 0                       | 1    |
| TOTAL   | 17565               | 35  | 26  | 176 | 10                        | 32  | 10  | 494   | 1                       | 8    | 17   | 0    | 0                         | 0    | 0     | 3    | 0                       | 1    |

**Note 1 :** (i) VH stands for Visually Handicapped (persons suffering from blindness or low visions)

(ii) HH stands for Hearing Handicapped (persons suffering from hearing impairment)

(iii) OH stands for Orthopaedically Handicapped (persons suffering from locomotor disability or cerebral palsy)

(iv) There is no reservation for persons with disabilities in case of promotion to Group A and B posts. However, persons with disabilities can be promoted to such posts, provided the concerned post is identified suitable for persons with disabilities.

**Note 2 :** Column No. 9 and 16 show the sum total appointments made in the Department by way of Direct Recruitment and Promotion

# CHAPTER CITIZEN CHARTER

12







## 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.

## II) 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) WHOM TO CONTACT

- I. Public Grievance and complaints  
**Shri S. Mervin Alexander**, Joint Secretary (A&A) &  
 Public Grievance Officer,  
 Department of Atomic Energy,  
 Anushakti Bhavan, C.S.M. marg,  
 Mumbai – 400 001.  
 Tel. No. 022-22022816  
 Email I.D. jsaa@dae.gov.in
- II. Vigilance Complaints  
**Shri S. Mervin Alexander**, Joint Secretary (A&A) &  
 Chief Vigilance Officer,  
 Department of Atomic Energy,  
 Anushakti Bhavan, C.S.M. Marg,  
 Mumbai – 400 001.  
 Tel. No. 022-22022816  
 Email I.D. jsaa@dae.gov.in
- III. 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 SPHERES 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 S. Mervin Alexander**, Joint Secretary (A&A) &  
Chief Vigilance Officer,  
Department of Atomic Energy,  
Anushakti Bhavan, C.S.M. Marg,  
Mumbai – 400 001.  
Tel. No.022-22022816  
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.



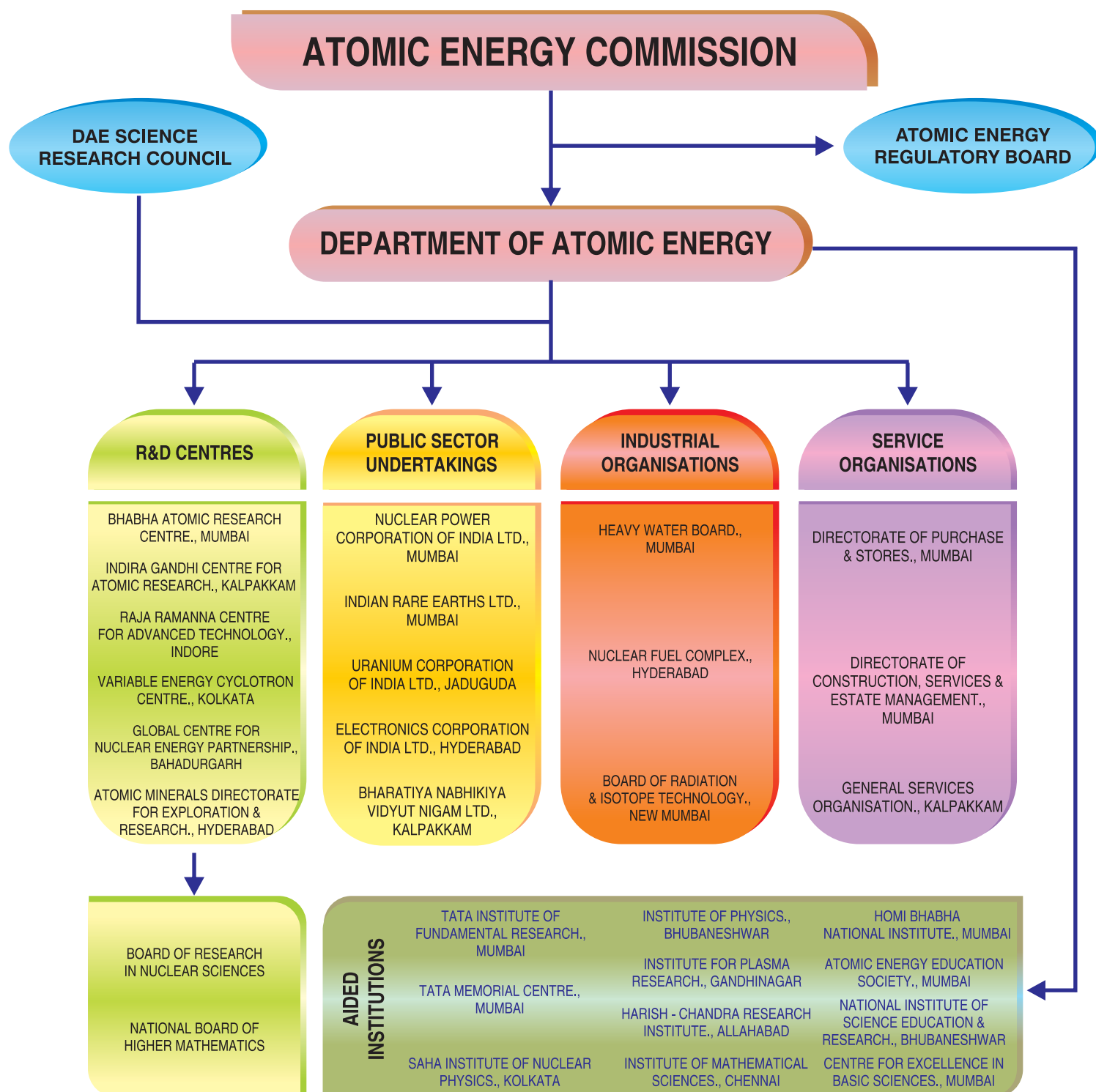
# ANNEX-I

## 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 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. 17 of 2017 Chapter II: Compliance Audit-Union Government, Scientific and Environmental Ministries/Departments**

### **Para No. 2.1 - A voidable expenditure on purchase of medicines without tendering process**

Medicines worth ₹ 29.52 crore were purchased during 2012-16 without following the process of open tendering. Consequently, Bhabha Atomic Research Centre could not avail of higher discounts as received in purchases made through tendering process, resulting in avoidable extra expenditure to the extent of ₹ 2.36 crore.

#### **Action Taken:**

A comprehensive review was done of the system and the time gap between raising of indent to delivery of medicines have been considerably reduced to 3-4 months as against earlier lead time of 6-8 months. The clauses in the rate contract have been made more stringent with regard to delivery period and liquidated damages for delayed supplies, thereby discouraging unscrupulous bidders. The result of the review measures taken will take some time to be effective.

### **Para: 2.2 - Management of Human Resources in Autonomous Bodies of Department of Atomic Energy**

Autonomous Bodies under administrative control of Department of Atomic Energy did not follow Government rules and regulations in matters relating to creation of posts, appointments, promotions, revision of pay and allowances, entitlements and grant of extension of service. This resulted in irregular expenditure amounting to ₹ 74.59 crore in seven test checked Autonomous Bodies.

#### **Action Taken:**

A Committee constituted for the purpose of formulating uniform bye-laws/guidelines for the AIs has completed its deliberations and in advanced stage of finalizing its report. Once the recommendations of the Committee are finalized, there will be uniformity in bye-laws of all the Units.

### **Para: 2.3 - Blocking up of funds due to non-installation of equipment**

Saha Institute of Nuclear Physics, Kolkata and Tata Memorial Centre, Mumbai failed to ensure readiness of site due to which the equipments procured at a cost of ₹ 1.98 crore and ₹ 1.08 crore respectively could not be installed.

#### **Action Taken:**

SINP Authorities are ensuring improved internal control mechanisms for preventing such recurrences. Accordingly, the procurements are as far as possible presently processed only subsequent to the positioning of the required infrastructure and safety systems.

### **Para: 2.4 - Irregular construction of residential flats and diversion of grant funds**

National Centre for Biological Sciences, Bengaluru, a centre of the Tata Institute of Fundamental Research, constructed residential flats without obtaining approval of component authority and diverted ₹ 18.33 crore from Extra Mural Grants for funding the construction.

**Action Taken:**

Following steps are taken for keeping control over the activities of NCBS.

- a) Implementation of TIFR Mumbai software "TIIS" at NCBS so that funds movement, if required can be tracked from Mumbai also.
- b) Increased the frequency of Audit from yearly to half yearly,
- c) Involvement of Financial Advisor in all procurements of NCBS above Rs.25 Lakh, instead of ₹ 1 Cr. previously.

## Report No.38 of 2017 Performance Audit on Kudankulam Nuclear Power Project

### Financial Management

#### Para: 2.1

The scheduled date of completion was postponed from 30 October 2007 to 3 December 2011 for Unit I and 30 October 2008 to 31 December 2012 for Unit II, inter alia due to delayed completion of different activities, of which many were attributable to the M/s Atomstroyexport (ASE), a company responsible for undertaking the Russians scope of work. However, there was no revision of schedule of repayment of the Russian credit. This resulted in start of repayment of Russian credit, before revenue generation, causing an additional interest burden on NPCIL to the tune of ₹ 449.42 crore.

**Action Taken:** ATN Under submission

#### Para: 2.2

NPCIL had to resort to external borrowings at a higher interest rate due to non-provisioning for erection reserve supply contracts while availing Russian credit, which was available at a cheaper rate. This resulted in additional interest cost amounting to ₹ 76.02 crore.

**Action Taken:** ATN Under submission

#### Para: 2.3

NPCIL availed term loan of ₹ 1,000 crore from HDFC Bank Limited in violation of CVC's guidelines on tendering.

**Action Taken:** ATN Under submission

### Tariff and Revenue Generation

#### Para: 3.1

NPCIL, while fixing tariff for power, did not consider two components, i.e., 'interest on foreign debt' and 'interest on domestic borrowings', though these were actually incurred and paid. This resulted in short realization of revenue to the tune of ₹ 90.63 crore during pre-commercialization period.

**Action Taken:** ATN Under submission



**Para: 3.2**

NPCIL did not include a component of 1.5 paisa per KWh in tariff towards self Insurance Fund of Hot Zone Assets of Atomic Power Plants in respect of electricity generated during pre-commercialization period and sold to State Electricity Board and had to forego revenue to the tune of ₹ 7.04 crore.

**Action Taken:** ATN Under submission

**Para 3.4**

Unit I of KKNPP was shut down from 24 June 2015 to 31 January 2016 for 222 days as against the planned period of 60 days. This was due to decision of NPCIL to shut down the plant and execute the refuelling work on its own without evaluating its technical competency. The extended shutdown resulted in revenue loss of ₹ 947.99 crore to NPCIL.

**Action Taken:** ATN Under submission

**Project Implementation****Paras 4.1.1 and 4.1.2**

Unit I and Unit II of KKNPP started commercial operation after a delay of 86 months and 101 months respectively. The delays were primarily due to shifting of work from Russian scope to Indian scope; in execution of work and in submission of working documents/supply of equipment/materials by ASE; delays due to design changes; erection delays and additional works. The delay in completion have also resulted in cost overruns. NPCIL did not initiate any claim for recovery of additional expenses of ₹ 264.79 crore which were caused due to delayed completion of works by ASE.

**Action Taken:** ATN Under submission

**Russian Scope of Work****Paras 4.2.1**

As against the original value of USD 29 million (₹ 131.66 crore), NPCIL incurred an amount of USD 50.91 million (₹ 231.13 crore) for supply of same equipment in a rearranged contract leading to extra expenditure of ₹ 99.47 crore.

**Action Taken:** ATN Under submission

**Paras 4.2.3**

No claim was raised by NPCIL, on ASE, for turbine of Unit I which was damaged due to manufacturing defects and ₹ 12.76 crore was incurred on repairs and replacement of turbine rotors. It also resulted in non-generation of electricity and consequently loss of revenue amounting to ₹ 53.73 crore.

**Action Taken:** ATN Under submission

**Paras 4.2.4**

NPCIL neither assessed the extra payment/loss due to non-supply/defective supply of materials by ASE nor did it initiate any action for recovery/adjustments for the same.

**Action Taken:** ATN Under submission

**Para 4.2.5 (a)**

NPCIL did not raise/pursue claims for liquidated damages worth ₹ 463.08 crore from ASE even though during the same time, it was borrowing funds and paying interest to discharge debt obligations including from ASE.

**Action Taken:** ATN Under submission

**Indian Scope of Work****(Para 4.3.1)**

The work of erection and commissioning of Nuclear Steam Supply System and Turbo Generator was shifted from the Russian scope to the Indian scope for achieving the stated purpose of optimization of man power cost by way of reduction in man-months of Russian specialist for supervision at the site. This was done without any cost-benefit analysis, which not only resulted in delays in completion of the project but also ended up in NPCIL incurring an extra expenditure of ₹ 706.87 crore for the work.

**Action Taken:** ATN Under submission

**(Para 4.3.2 (a), (b) and (c))**

NPCIL incurred an extra amount of ₹ 8.37 crore towards shipment charges calculated on the basis of improper assumption. NPCIL compensated a sea route transporter by reimbursing wharfage charges and additional handling charges amounting to ₹ 7.08 crore, which was unjustified as the terms of contract provided for such charges to be incurred by transporter himself. NPCIL failed to provide the minimum stipulated inducement quantity to the transporter for shipment and incurred an avoidable amount of ₹ 11.72 crore towards dead freight.

**Action Taken:** ATN Under submission

**(Para 4.4.1 and 4.4.2)**

NPCIL did not ensure reasonability of the rates of third party supplies worth USD 191 million (₹ 899.95 crore), made by ASE, for the plant. Further, an amount of USD 19 million (₹ 92.04 crore) towards 10 per cent interest free advance was paid by NPCIL to ASE for the third country supplies without ascertaining the existence of similar provisions in the sub-contracts entered by ASE with third country suppliers.

**Action Taken:** ATN Under submission

**(Para 4.6)**

NPCIL, on 31 December 2014, declared commercial operation of the Unit I of KKNPP which was six months before receiving the license from AERB for regular operation of the plant.

**Action Taken:** ATN Under submission

## ANNEX-III

## REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 IN RESPECT OF **CONSTITUENT UNITS**

| Groups  | Representation of ST/ST/OBC<br>(as on 01.01.2018) |      |      |      | Number of appointments made during the calendar year 2017 |     |     |              |       |      |               |       |      |      |
|---------|---|------|------|------|---|-----|-----|--------------|-------|------|---------------|-------|------|------|
|         |   |      |      |      | By Direct Recruitment                                     |     |     | By Promotion |       |      | By Deputation |       |      |      |
|         | Total<br>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 | 8365  | 587  | 154  | 874  | 194   | 1   | 1   | 22           | 302   | 29   | 5             | 1     | 0    | 0    |
| Group B | 9192  | 1689 | 798  | 2282 | 59  | 10  | 1   | 17           | 191   | 25   | 13            | 10    | 0    | 1    |
| Group C | 10715   | 2197 | 989  | 3430 | 536   | 73  | 58  | 281          | 90    | 29   | 9             | 1     | 1    | 0    |
| TOTAL   | 28272   | 4473 | 1941 | 6586 | 789   | 84  | 60  | 320          | 583   | 83   | 27            | 12    | 1    | 1    |



**ANNUAL STATEMENT SHOWING THE REPRESENTATION OF SCs, STs AND OBCs AS ON 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 IN RESPECT OF AIDED INSTITUTIONS**

| Groups       | Representation of ST/ST/OBC<br>(as on 01.01.2018) |             |            |             | Number of appointments made during the calendar year 2017 |           |           |           |              |          |          |          |
|--------------|---|-------------|------------|-------------|---|-----------|-----------|-----------|--------------|----------|----------|----------|
|              | Total<br>Emp                                      | SC          | ST         | OBC         | By Direct Recruitment                                     |           |           |           | By Promotion |          |          |          |
|              |   |             |            |             | Total   | SC        | ST        | OBC       | Total        | SC       | ST       | Total    |
| (1)          | (2)   | (3)         | (4)        | (5)         | (6)   | (7)       | (8)       | (9)       | (10)         | (11)     | (12)     | (13)     |
| Group A      | 1358  | 82          | 8          | 109         | 54  | 2         | 0         | 3         | 11           | 0        | 1        | 0        |
| Group B      | 2536  | 419         | 116        | 512         | 199   | 20        | 14        | 58        | 14           | 4        | 2        | 0        |
| Group C      | 2266  | 743         | 155        | 487         | 50  | 1         | 9         | 15        | 1            | 0        | 0        | 0        |
| <b>TOTAL</b> | <b>6160</b>                                       | <b>1244</b> | <b>279</b> | <b>1108</b> | <b>303</b>  | <b>23</b> | <b>23</b> | <b>76</b> | <b>26</b>    | <b>4</b> | <b>3</b> | <b>0</b> |

**ANNUAL STATEMENT SHOWING THE REPRESENTATION OF SCs, STs AND OBCs AS ON 01.01.2018 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2017 IN RESPECT OF PUBLIC SECTOR UNDERTAKINGS**

| Groups  | Representation of ST/ST/OBC<br>(as on 01.01.2018) |      |      |      | Number of appointments made during the calendar year 2017 |     |     |     |              |      |      |       |               |      |
|---------|---|------|------|------|---|-----|-----|-----|--------------|------|------|-------|---------------|------|
|         |   |      |      |      | By Direct Recruitment                                     |     |     |     | By Promotion |      |      |       | By Deputation |      |
|         | Total<br>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 | 7193  | 829  | 269  | 1237 | 224   | 26  | 30  | 73  | 1149         | 141  | 40   | 2     | 1             | 0    |
| Group B | 5456  | 910  | 452  | 1451 | 58  | 9   | 2   | 29  | 823          | 136  | 89   | 0     | 0             | 0    |
| Group C | 4916  | 912  | 673  | 1247 | 294   | 50  | 31  | 133 | 479          | 102  | 61   | 3     | 0             | 0    |
| TOTAL   | 17565   | 2651 | 1394 | 3935 | 576   | 85  | 63  | 235 | 2451         | 379  | 190  | 5     | 1             | 0    |

|         |   |          |  |
|---------|---|----------|--|
| AAS     | Alarm Annunciation System                                       | CAIR     | Centre for Artificial Intelligence and Robotics                |
| ACS     | Anti Compton Shields  | CARDS    | Cobalt Adjustor Rods Dismantling Tools                         |
| ACTREC  | Advanced Centre for Treatment, Research and Education in Cancer | CARS     | Contract for Acquisition of Research Services                  |
| ADU     | Aammonium Di-Uranate  | CBI      | Central Bureau of Investigation                                |
| AECS    | Atomic Energy Cetnral School                                    | CBS      | Centre for Excellence in Basic Sciences                        |
| AEES    | Atomic Energy Educational Society                               | CBS      | Computer Based System  |
| AERB    | Atomic Energy Regulatory Board                                  | CBM      | Compressed Baryonic Matter                                     |
| AEWACS  | Airborn Early Warning and Control System                        | CCE      | Centre for Cancer Epidemiology                                 |
| AGMS    | Annulus Gas Monitoring System                                   | CEMS     | Continuous Emission Monitoring System                          |
| AHWR    | Advanced Heavy Water Reactor                                    | CERN     | European Organisation for Nuclear Research                     |
| AHX     | Air Heat Exchanger  | CFD      | Computational Fluid Dynamics                                   |
| AICRIP  | All India Coordinated Rice Improvement Programme                | CFFP     | Ceramic Fuel Fabrication Plant                                 |
| ALARA   | As Low as Reasonably Achievable                                 | CFVS     | Containment Filtered Venting System                            |
| ALICE   | A Large Ion Collider Experiment                                 | CGGC     | Chhotanagpur Granite Gneissic Complex                          |
| ALIMCOI | Artificial Limbs Manufacturing Corporation of India             | CHF      | Critical Heat Flux   |
| AMD     | Atomic Minerals Directorate for Exploration & Research          | CHHS     | Contributory Health Service Scheme                             |
| AoW     | Atom on Wheels  | CIP      | Cold Isostatic Pressing  |
| APAR    | Annual Performance Appraisal Report                             | CLIC     | Compact Linear Collider  |
| APC     | Astroparticle Physics & Cosmology                               | CLOE     | Corrosion Loop Experiments                                     |
| APMO    | Asian Pacific Mathematics Olympiad                              | CMG      | Crisis Management Group  |
| APUS    | Automatic Pellet Unloading System                               | CMMS     | Computerized Maintenance Management System                     |
| ARDC    | Asymmetric Rotating Disc Column                                 | CMR      | Custom Made Sources  |
| ASDF    | Actinide Separation Demonstration Facility                      | CNT      | Carbon Nanotubes   |
| ASE     | Atomstroyexport   | CoARs    | Cobalt Absorber Rods   |
| ASGS    | Absolute Segmented Gamma Scanning                               | COBOT    | Cobalt Bundle Opening Tools                                    |
| ASM     | Advanced Servo Manipulator                                      | COG      | Candu Owner's Group  |
| ASWTF   | Alpha Solid Waste Treatment Facility                            | CORAL    | Compact Reprocessing facility for Advanced fuels of Lead cells |
| ATI     | Administrative Training Institute                               | CPP      | Captive Power Plant  |
| ATM     | Advanced Training in Mathematics                                | CPU      | Central Processing Unit  |
| ATOMS   | Automated Workflow Management System                            | CRC      | Clinical Research Centre                                       |
| ATRA    | All Trans Retinoic Acid   | CRD      | Control Rod Drive  |
| ATTF    | AHWR Thermal Hydraulic Test Facility                            | CRS      | Clinical Research Secretariat                                  |
| AVT     | Advanced Varietal Trial   | CRU      | Common Readout Boards  |
| AWTSF   | Alpha Waste Transit Storage Facility                            | CRZ      | Coastal Regulation Zone  |
| BAEC    | Bangladesh Atomic Energy Commission                             | CSDU     | Crude Sodium Diuranate   |
| BAERA   | Bangladesh Atomic Energy Regulatory Authority                   | CSP      | Core Sub assembly Plant  |
| BARC    | Bhabha Atomic Research Centre                                   | CSR      | Corporate Social Responsibility                                |
| BBCI    | Dr. B. Barooah Cancer Institute                                 | CSRDM    | Control & Safety Rod Drive Mechanism                           |
| BCA     | Body Composition Analyzer                                       | CSTS     | Calandria Side Tube Sheet                                      |
| BCD     | Bleed Condenser   | CTS      | Cobalt Teletherapy Sources                                     |
| BET     | Bacterial Endotoxin Test  | CVC      | Central Vigilance Commission                                   |
| BFP     | Boiler Feed Pump  | CVO      | Chief Vigilance Officer  |
| BHAVINI | Bhartiya Nabhikiya Vidyut Nigam Limited                         | DAE      | Department of Atomic Energy                                    |
| BIS     | Bureau of Indian Standards                                      | DAEBAS   | DAE Budget Automation System                                   |
| BMPR    | Batch Manufacturing Production Records                          | DAE S&CC | DAE Sports and Cultural Council                                |
| BNCT    | Boron Neutron Capture Therapy                                   | DBD      | Dielectric Barrier Discharge                                   |
| BoG     | Board of Governors  | DCSEM    | Directorate of Construction Services & Estate Management       |
| BOH     | Bad Obstetric History   | DDCS     | Digital Distributed Control System                             |
| BRIT    | Board of Radiation & Isotope Technology                         | DESY     | Deutsches Elektronen Synchrotron                               |
| BRNS    | Board of Research in Nuclear Sciences                           | DGBM     | Design Basis Ground Motion                                     |
| BSA     | Beam Shaping Assembly   | DGFS     | DAE Graduate Fellowship Scheme                                 |
| BWR     | Boiling Water Reactor   | DHM      | Digital Holographic Microscope                                 |



|         |   |       |  |
|---------|---|-------|--|
| DLX     | Double Layer Experiment   | FPGA  | Field Programmable Gate Array  |
| DMRL    | Defence Metallurgical Research Laboratory                         | FPS   | Fabry-Perot spectrometer   |
| DoPT    | Department of Personnel and Training                              | FRENA | Facilities for Research in Experimental Nuclear Astrophysics               |
| DPS     | Directorate of Purchase & Stores                                  | FReT  | First Research and Technical   |
| DPSS    | Diode Pumped Solid State  | FRET  | Fluorescence Resonance Energy Transfer                                     |
| DPR     | Detailed Project Report   | FRFCF | Fast Reactor Fuel Cycle Facility   |
| DPTMS   | Discharge Pit Trolley Movement System                             | FRIDM | Fuelling machine operated Remote pressure tube Inside Diameter Measurement |
| DRDO    | Defence Research Development Organisation                         | FRS   | Floor Response Spectra   |
| DRT     | Dimensional Radiation Therapy                                     | GCIC  | Gamma Compensated boron lined Ionisation Chamber                           |
| DRX     | Dynamic Recrystallization   | GCNEP | Global Centre for Nuclear Energy Partnership                               |
| DSP     | Digital Signal Processing   | GeM   | Government e-Marketplace   |
| DTD     | Directorate of Technology Development                             | GFA   | General Framework Agreement  |
| DTDDF   | DAE Technology Display and Dissemination Facility                 | GHAVP | Gorakhpur Anu Vidyut Pariyojana  |
| EBSD    | Electron Backscatter Diffraction                                  | GIXAS | Grazing Incidence X-ray Absorption Spectroscopy                            |
| EBW     | Electron Beam Welding   | GMP   | Good Manufacturing Practices   |
| ECAA    | Extra-Cellular Acidity Analyser                                   | GMRT  | Giant Metrewave Radio Telescope  |
| ECHM    | Electro Chemical Hydrogen Meters                                  | GPM   | Gaussian Plume Model   |
| ECIL    | Electronic Corporation of India Limited                           | GPS   | Gigahertz Peaked Spectrum  |
| ECR     | Emergency Control Room  | GRG   | Giant Radio Galaxy   |
| ECR     | Electron Cyclotron Resonance                                      | GST   | Goods and Services Tax   |
| EED     | Electro-Electrodialysis   | GUI   | Graphics User Interface  |
| EEG     | Electro Echo Gram   | HAL   | Hindustan Aeronautics Limited  |
| EFFP    | Enriched Fuel Fabrication Plant                                   | HAN   | Hydroxyl Amine Nitrate   |
| EGFR    | Epidermal Growth Factor Receptor                                  | HAP   | Hydroxy Apatite  |
| EGMO    | European Girls' Mathematics Olympiad                              | HBCSE | Homi Bhabha Centre for Science Education                                   |
| EMCCR   | En-masse Coolant Channels Replacement                             | HBGS  | Hybrid Biofilm Granular Sludge   |
| EMFR    | En-masse Feeders Replacement                                      | HBNI  | Homi Bhabha National Institute   |
| EOS     | Equation of State   | HDD   | Hard Disk Drive  |
| EPIG    | External Pipe Inspection Gauge                                    | HDL   | Hardware Description Language  |
| EPR     | Emergency Preparedness and Response                               | HEBT  | High Energy Beam Transport   |
| EPR     | Electron Paramagnetic Resonance                                   | HER   | Hydrogen Evolution Reaction  |
| EPZ     | Emergency Planning Zones  | HFM   | Hollow Fibre Membrane  |
| EQAS    | External Quality Assessment Schemes                               | HOMFS | Higher Order Modes Frequency Shifter                                       |
| ERM     | Environmental Radiation Monitor                                   | HPU   | Health Physics Unit  |
| ERM-AVP | Environmental Radiation Monitor with Autonomous Vertical Profiler | HREE  | Heavy Rare Earth Elements  |
| ESCIA   | End Shield Calandria Integral Assembly                            | HRTF  | Hydrogen Recombiner Test Facility  |
| ESL     | Environmental Survey Laboratory                                   | HSPCB | Haryana State Pollution Control Board                                      |
| EVM     | Electronic Voting Machine   | HWB   | Heavy Water Board  |
| EXAFS   | Extended X-Ray Absorption Fine Structure                          | HWP   | Heavy Water Plant  |
| FAIC    | Free Air Ionization Chamber                                       | IAEA  | International Atomic Energy Agency   |
| FAME    | Fatty Acid Methyl Esters  | IARC  | International Agency for Research on Cancer                                |
| FBTR    | Fast Breeder Test Reactor   | IAS   | Isotope Application Services   |
| FBR     | Fast Breeder Reactor  | IBA   | Integrated Business Administration   |
| FDNPP   | Fukushima Daiichi Nuclear Power Plant                             | ICTS  | International Centre for Theoretical Sciences                              |
| FHA     | Fire Hazard Analysis  | IDCOL | Industrial Development Corporation of Odisha Limited                       |
| FIB     | Focused Ion Beam  | IDCT  | Induced Draught Cooling Tower  |
| FIBPM   | Flange Integrated Beam Position Monitor                           | IFTM  | Inclined Fuel Transfer Machine   |
| FMISO   | Fluoromisonidazole  | IGA   | Inter-Governmental Agreement   |
| FMP     | Fission Molybdenum Project  | IGKV  | Indira Gandhi Krishi Vishwa Vidyalaya                                      |
| FMR     | Ferromagnetic Resonance   | IGM   | India Government Mint  |
| FMTF    | Fuelling Machine Test Facility                                    | IHX   | Intermediate Heat Exchangers   |
| FPC     | First Pour of Concrete  | IITF  | India International Trade Fair   |

|         |   |        |   |
|---------|---|--------|---|
| ILRT    | Integrated Leak Rate Test   | MAA    | Macro Albumin Aggregates  |
| IMO     | International Mathematics Olympiad  | MACE   | Major Atmospheric Cerenkov Experiment Telescope                               |
| IMSc    | Institute of Mathematical Science   | MAPCDS | Minor Actinide Product Conversion Demonstration System                        |
| INGA    | Indian National Gamma Array   | MAPS   | Madras Atomic Power Station   |
| INIS    | International Nuclear Information System                                  | MBE    | Magnetic Barkhausen Emission  |
| INMO    | Indian National Mathematics Olympiad                                      | MBE    | Molecular Beam Epitaxy  |
| INPRO   | Innovative Nuclear Reactors and Fuel Cycles                               | MCF    | Medical Cyclotron Facility  |
| IOP     | Institute of Physics  | MDA    | Minimum Detectable Activity   |
| IPPAS   | International Physical Protection Advisory Services                       | MEAL   | Mobile Environmental Assessment Laboratory                                    |
| IPR     | Intellectual Property Rights  | MHA    | Ministry of Home Affairs  |
| IPR     | Institute for Plasma Research   | MJPJAY | Mahatma Jyotiba Phule Jeevandayee Aarogya Yojana                              |
| IPHWR   | Indian Pressurized Heavy Water Reactor                                    | MoEFCC | Ministry of Environment, Forest and Climate Change                            |
| IREL    | Indian Rare Earths Limited  | MoF    | Ministry of Finance   |
| IRM     | Intermediate Range Monitor  | MOS    | Multi-object Infrared Spectrometer  |
| IRMA    | Immunoradiometric Assay   | MOT    | Magneto Optical Trap  |
| IRSIS   | Infrared Spectroscopic Imaging Survey                                     | MoU    | Memorandum of Understanding   |
| ISAG    | Indian Society of Applied Geochemists                                     | MOV    | Motor Operated Valve  |
| ISI     | In-service Inspection   | MPAC   | Modified Powdered Activated Carbon  |
| ISM     | Induction Skull Melting   | MQW    | Multiple Quantum Well   |
| ISNS    | Indian Spallation Neutron Source  | MRAL   | Mobile Radiological Assessment Laboratory                                     |
| ISRO    | Indian Space Research Organisation  | MREE   | Medium Rare Earth Elements  |
| ITER    | International Thermonuclear Experimental Reactor                          | MRL    | Maximum Residue Level   |
| ITFT    | Integrated Thermal Hydraulic Test Facility                                | MRTDDF | Magnesium Recycling Technology Development and Demonstration Facility         |
| ITS     | Integrated Test Station   | MSBR   | Molten Salt Breeder Reactors  |
| JHR     | Jules Horowitz Reactor  | MSLB   | Main Steam Line Break   |
| JNNSMEE | Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition | MSLD   | Mass Spectrometer Leak Detector   |
| JNPP    | Jaitapur Nuclear Power Project  | NAARRI | National Association for Application of Radioisotopes & Radiation in Industry |
| JNV     | Jawahar Navodaya Vidyalaya  | NABL   | National Accreditation Board for Testing and Calibration Laboratories         |
| JVA     | Joint Venture Agreement   | NAPS   | Narora Atomic Power Station   |
| JWG     | Joint Working Group   | NBHM   | National Board of Higher Mathematics  |
| KAMINI  | KAlpakkam MINi Reactor  | NCG    | National Cancer Grid  |
| KAPP    | Kakrapar Atomic Power Project   | NCN    | Non Compound Nucleus  |
| KAPS    | Kakrapar Atomic Power Station   | NDCT   | Natural Draught Cooling Tower   |
| KARP    | KAlpakkam Reprocessing Plant  | NDRF   | National Disaster Response Force  |
| KGS     | Kaiga Generating Station  | NDT    | Non Destructive Testing   |
| KKNPP   | Kudankulam Nuclear Power Plant  | NEA    | Nuclear Energy Agency   |
| KVS     | Kendriya Vidyalaya Sangathan  | NFNBR  | National Facility for Neutron Beam Research                                   |
| KWO     | Kitchen Waste Oil   | NEFTF  | New Extrusion & Fuel Tube Facility  |
| LEHIPA  | Low Energy High Intensity Proton Accelerator                              | NET    | Neuro Endocrine Tumors  |
| LFGNM   | Lead-Free Gulmarg Neutron Monitors  | NGLF   | Naso-Gastric Liquid Feed  |
| LHC     | Large Hadron Collider   | NICAM  | Non-hydrostatic Icosahedral Atmospheric Model                                 |
| LHR     | Linear Heat Rating  | NICB   | Nuclear Island Connected Building   |
| LLAT    | Left Lateral  | NIP    | Nuclear Instrumentation Package   |
| LLCB    | Lead-Lithium Cooled Ceramic Breeder                                       | NISER  | National Institute of Science Education & Research                            |
| LLNL    | Lawrence Livermore National Laboratory                                    | NIT    | Notice Inviting Tender  |
| LLRT    | Local Leak Rate Test  | NMD    | National Metallurgist Day   |
| LMCE    | Long Manufacturing Cycle Equipment  | NODRS  | National Occupational Dose Registry System                                    |
| LOCA    | Loss of Coolant Accident  | NPCIL  | Nuclear Power Corporation of India Limited                                    |
| LREE    | Lighter Rare Earth Elements   | NPP    | Nuclear Power Plants  |
| LSPR    | Localized Surface Plasmon Resonance                                       | NRB    | Nuclear Recycle Board   |
| LVDT    | Linear Variable Differential Transformer                                  |        |   |
| LWR     | Light Water Reactor   |        |   |

|        |   |        |  |
|--------|---|--------|--|
| NSDF   | Near Surface Disposal Facility                | RCR    | Regional Centre for Radiopharmaceuticals                           |
| NTTF   | NPCIL Thermal Hydraulic Test Facility         | REE    | Rare Earths Elements   |
| NSAID  | Non-Steroidal Anti-inflammatory Drugs         | REPM   | Rare Earth Permanent Magnet  |
| NUFAP  | Natural Uranium Fuel Assembly Plant           | REPS   | Reliable Electrical Power Supply                                   |
| NUJ    | National Union of Journalists                 | RFEC   | Remote Field Eddy Current  |
| NUOFP  | Natural Uranium Oxide Fabrication Plant       | RFID   | Radio Frequency Identification                                     |
| NUP    | National Uranium Project                      | RFO    | Refuelling Outage  |
| OCAL   | Orientation Course on Accelerators and Lasers | RFQ    | Radio Frequency Quadrupole   |
| OER    | Oxygen Evolution Reaction                     | RGJAY  | Rajiv Gandhi Jeevandayee Aarogya Yojana                            |
| OLIC   | Official Language Implementation Committees   | RHVPS  | Regulated High Voltage Power Supply                                |
| ORR    | Oxygen Reduction Reaction                     | RIA    | Radioimmunoassay   |
| OSH    | Occupational Safety and Health                | RIB    | Radioactive Ion Beam   |
| PACVD  | Plasma Assisted Chemical Vapour Deposition    | RIH    | Reactor Inlet Header   |
| PCP    | Primary Coolant Pump                          | RLAT   | Right Lateral  |
| PCPTF  | Primary Coolant Pump Test Facility            | RMC    | Radiation Medicine Centre  |
| PCRD   | Passive Catalytic Recombiner Devices          | RMO    | Regional Mathematics Olympiad                                      |
| PCT    | Patent Co-operation Treaty                    | RMRE   | Rare Metal and Rare Earth  |
| PDDC   | Pulsed Disc and Doughnut Column               | ROFDTs | Raman Optical Fibre Distributed Temperature Sensor                 |
| PDHRS  | Passive Decay Heat Removal System             | RPC    | Radiopharmaceutical Committee                                      |
| PDT    | Photodynamic Treatment                        | RPhP   | Radiopharmaceuticals Production                                    |
| PEF    | Pre-Equilibrium Fission                       | RPP    | Radiation Processing Plant   |
| PET    | Positron Emitting Tomography                  | RPV    | Reactor Pressure Vessel  |
| PFBR   | Prototype Fast Breeder Reactor                | RRCAT  | Raja Ramanna Centre for Advanced Technology                        |
| PFMS   | Public Finance Management System              | RTE    | Ready-to-Eat   |
| PHT    | Primary Heat Transport                        | RTI    | Right to Information   |
| PHWR   | Pressurised Heavy Water Reactors              | RUP    | Reprocessed Uranium Oxide Plant                                    |
| PIDS   | Periphery Intrusion Detection System          | RWB    | Rad Waste Building   |
| PIE    | Post Irradiation Examination                  | SAB    | Service Auxiliary Building   |
| PIGE   | Particle Induced Gamma-ray Emission           | SAG    | Severe Accident Guideline  |
| PIU    | Poison Injection Unit                         | SANESS | School of Advanced Nuclear Energy System Studies                   |
| PLC    | Programmable Logic Controller                 | SARRT  | School on Applications of Radioisotopes and Radiation Technologies |
| PLF    | Plant Load Factor                             | SAU    | Situation Awareness Unit   |
| PLIS   | Performance Linked Incentive Scheme           | SAXS   | Small Angle X-ray Scattering                                       |
| PMD    | Photon Multiplicity Detector                  | SBD    | Singridungri-Banadungri  |
| PMS    | Portal Monitoring System                      | SBF    | Stuffed Baked Food   |
| PMT    | Photo Multiplier Tube                         | SBN    | Strontium Barium Niobate   |
| PMU    | Phasor Measurement Unit                       | SBO    | Station Blackout   |
| POST   | Power On Self Test                            | SDU    | Sodium Di Uranate  |
| PPMS   | Physical Properties Measurement System        | SED    | Spectral Energy Distribution                                       |
| PREFRE | Power Reactor Fuel Reprocessing               | SEEP   | Societal Enrichment and Education Programme                        |
| PRL    | Preformed Ring Liner                          | SERS   | Surface Enhanced Raman Spectroscopy                                |
| PRSI   | Public Relations Society of India             | SGDHR  | Safety Grade Decay Heat Removal                                    |
| PSA    | Probabilistic Safety Assessment               | SGPEM  | Shoreline Gaussian Plume Exposure Model                            |
| PSPC   | Pulsed Sieve Plate Column                     | SGS    | Segmented Gamma Scanner  |
| PTA    | Per Terphthallic Acid                         | SIMS   | Secondary Ion Mass Spectrometer                                    |
| PTC    | Patent Co-operation Treaty                    | SINP   | Saha Institute of Nuclear Physics                                  |
| QCD    | Quantum Chromo Dynamics                       | SIP    | Sputter Ion Pump   |
| QGP    | Quark Gluon Plasma                            | SIRC   | Scientific Information Resource Centre                             |
| QIC    | Quantum Information and Computation           | SMPS   | Switch Mode Power Supply   |
| RAL    | Radioanalytical Laboratory                    | SNDHM  | Startup Neutron Detector Handling Mechanism                        |
| RAPP   | Rajasthan Atomic Power Project                | SNM    | Special Nuclear Materials  |
| RAPS   | Rajasthan Atomic Power Station                | SNMCS  | School of Nuclear Material Characterization Studies                |
| RCB    | Reactor Containment Building                  |        |  |



|           |  |       |   |
|-----------|--|-------|---|
| SNSS      | School of Nuclear Security Studies                     | VFD   | Variable Frequency Drive                    |
| SORS      | Spatially-offset Raman Spectroscopy                    | VTB   | Virtual Tumor Board                         |
| SPP       | Solvent Production Plant                               | VVPAT | Voter Verifiable Paper Audit Trail Printers |
| SPRINTARS | Spectral Radiation-Transport Model for Aerosol Species | WANO  | World Association of Nuclear Operators      |
| SRC       | Safety Review Committee                                | WBMC  | Whole Body Monitoring Console               |
| SRDM      | Shut-off Rod Drive Mechanism                           | WHO   | World Health Organization                   |
| SRM       | Source Range Monitor                                   | WSN   | Wireless Sensor Network                     |
| SRSS      | School of Radiological Safety Studies                  | WTP   | Water Treatment Plant                       |
| SSCVR     | Solid State Cockpit Voice Recorder                     | XPS   | X-ray Photoelectron spectroscopy            |
| SSF       | Structural Steel Floor                                 | XRD   | X-Ray Diffraction                           |
| SSNS      | Single Sphere Neutron Spectrometer                     | YMV   | Yellow Mosaic Virus                         |
| SSTM      | Spent Subassembly Transfer Machine                     | ZIET  | Zonal Institute of Education and Training   |
| SSTP      | Stainless Steel Tube Plant                             | ZOP   | Zirconium Oxide Plant                       |
| STC       | Sodium Technology Complex                              | ZSP   | Zirconium Sponge Plant                      |
| STM       | Scanning Tunnelling Microscope                         | ZSR   | Zirconium Scrub Raffinate                   |
| SUT       | Start-Up Transformer                                   |       |   |
| SWRO      | Sea Water Reverse Osmosis                              |       |   |
| SXP       | Solvent Extraction Plant                               |       |   |
| TACTIC    | TeV Atmospheric Cerenkov Telescope with Imaging Camera |       |   |
| TAPS      | Tarapur Atomic Power Station                           |       |   |
| TBM       | Test Blanket Module                                    |       |   |
| TBP       | Tributyl Phosphate                                     |       |   |
| TCDM      | Trombay Chhattisgarh Dubraj Mutant                     |       |   |
| TCF       | Technical Cooperation Fund                             |       |   |
| TDC       | Technology Development Council                         |       |   |
| TDCR      | Triple to Double Coincidence Ratio                     |       |   |
| TDPAC     | Time Differential Perturbed Angular Correlation        |       |   |
| TDU       | Technology Demonstration Unit                          |       |   |
| TEM       | Transmission Electron Microscope                       |       |   |
| TES       | Tritium Extraction System                              |       |   |
| TFS       | Tritium Filled Self-luminous Sources                   |       |   |
| TIFR      | Tata Institute of Fundamental Research                 |       |   |
| TIMS      | Thermal Ionization Mass Spectrometer                   |       |   |
| TLD       | Thermo Luminescence Dosimeters                         |       |   |
| TMC       | Tata Memorial Centre                                   |       |   |
| TMH       | Tata Memorial Hospital                                 |       |   |
| TMIS      | Training Management Information System                 |       |   |
| TNMB      | Tamil Nadu Maritime Board                              |       |   |
| TNPCB     | Tamil Nadu Pollution Control Board                     |       |   |
| TOF       | Time of Flight   |       |   |
| TOR       | Terms of Reference                                     |       |   |
| TPDM      | Technical Programme Discussion Meetings                |       |   |
| TPS       | Treatment Planning Software                            |       |   |
| TSH       | Training School Hostel                                 |       |   |
| TSMTG     | Top Seeded Melt Texture Growth                         |       |   |
| TSO       | Trainee Scientific Officer                             |       |   |
| UAS       | University of Agricultural Sciences                    |       |   |
| UCIL      | Uranium Corporation of India Limited                   |       |   |
| UNRC      | Uranyl Nitrate Raffinate Cake                          |       |   |
| UOP       | Uranium Oxide Plant                                    |       |   |
| VDI       | Virtual Desktop Infrastructure                         |       |   |
| VECC      | Variable Energy Cyclotron Centre                       |       |   |
| VEGPL     | Vishal Engineers & Galvanizers Pvt. Ltd.               |       |   |



