Government of India
Department of Atomic Energy

ANNUAL REPORT
2015-16



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सत्यमेव जयते

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Front cover: Overall View of Prototype Fast Breeder Reactor (PFBR)

CONTENTS

	EXECUTIVE SUMMARY	I- XXXVII
Chapter-1 :	Nuclear Power Programme-Stage-I	1-48
Chapter-2 :	Nuclear Power Programme-Stage-II	49-69
Chapter-3 :	Nuclear Power Programme-Stage-III	71-82
Chapter-4 :	Advanced Technologies and Radiation Technologies and their Applications	83-137
Chapter-5 :	Basic Research	139-181
Chapter-6 :	Research Education Linkages	183-193
Chapter-7 :	Technology Transfer and Collaborative Programmes	195-198
Chapter-8 :	Infrastructure	199-205
Chapter-9 :	Public Sector Undertakings	207-211
Chapter-10 :	Other Activities	213-240
Chapter-11 :	Implementation of Persons with Disabilities (Equal Opportunities, Protection of Rights & Full Participation) Act, 1995	241-244
Chapter-12 :	Citizen's Charter	245-249
Annex-I :	The Organisation	I
Annex-II :	Replies to Audit Observations	V
Annex-III :	Representation of SCs, STs and OBCs	VII

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 2015-16, 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 & LIGHT WATER REACTORS

The Nuclear Power Corporation of India Ltd. (NPCIL) is a dividend paying company with AAA credit rating by CRISIL and CARE and is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. At present, it operates 20 nuclear power reactors (excluding RAPS-1, which is under extended shutdown and belongs to DAE) with installed capacity of 5680 MWe. The second unit of Kudankulam Nuclear Power Project (KKNPP-2) in Tamilnadu is under commissioning. First pair of indigenously designed 700 MWe Pressurised 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.

Power Generation

During the calendar year 2015, NPCIL recorded highest ever generation of 38364 Million Units (MUs) which was about 3% higher than the generation of 37146 MUs in the last calendar year 2014 (including 2984 MUs infirm power from KKNPP- 1).

During the financial year 2015-16, NPCIL has registered generation of 27813 MUs till December 31, 2015.

During the financial year 2015-16, the overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 74% and 77% respectively till December 31, 2015.

During the year 2015, RAPS-4 (412 days), KGS-1 (481 days), KGS-4 (419 days) and NAPS-2 (518 days) achieved continuous run for more than a year. So far, this feat has been achieved 20 times by various reactors operated by NPCIL.

Projects under Commissioning

Kudankulam Nuclear Power Project (KKNPP) Unit-2 (1000 Mwe)

The unit is under commissioning. Important commissioning milestone “Hot Run of Nuclear Steam Supply System” has been completed. Subsequent to Reactor Pressure Vessel (RPV) top head opening and removal of dummy fuel assemblies, Pre-service Inspection (PSI) of Reactor Pressure Vessel (RPV)



KKNPP-1&2 Plant view

and primary circuit is in advanced stage of completion. Preparation for next commissioning milestone i.e. Initial Fuel Loading (IFL) is in progress. Generator Transformer has been charged. Commissioning of condenser cooling water pumps has been completed. Commissioning of other systems like sea water systems, reactor auxiliary systems, Diesel Generator (DG) systems etc. are in advanced stage. The physical progress of the unit is 98.69% as on December 2015. The reactor criticality followed by connection to grid is expected in first quarter of 2016-17.

Projects under construction

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

In Unit-3, civil construction and finishing works of all major buildings are nearing completion. Inner Containment Wall (ICW) concreting is completed and ring beam construction is in progress. Major critical path activities such as erection, alignment and welding of End Shields & Calandria, Calandria Tubes rolling, charging of Startup Transformers (SUTs) etc. have been completed and primary coolant channels installation is in progress (25% completed as on December 2015). Erection of Pressuriser, Steam Generators (3 out of 4 nos) and Generator Stator etc. have been completed. In Unit-4, ICW concreting is completed and ring beam construction is in progress. A major critical path activity, "Erection and Welding of End Shields & Calandria" is completed and preparatory work for Calandria Tubes rolling is in progress.



KAPP-3&4 Plant view

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

Civil and Mechanical works in various fronts are in progress. In Unit-7, ICW of Reactor Building (RB) has been constructed up to ring beam bottom. A major critical path activity, "Erection, alignment & welding of End Shields & Calandria" has been completed.

In Unit-8, ICW up to 111.7M EL has been constructed and a major milestone "Construction of Calandria Vault" has been completed. Both the End Shields are received at site, subsequently ball filling has been completed and preparation for lowering them in calandria vault is in progress.



RAPP-7&8 Plant view

Sanctioned Projects

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

Government administrative approval and financial sanction of the project exists. Environmental clearance and CRZ clearance from MoEF are obtained. Atomic Energy Regulatory Board (AERB)

Siting consent and Excavation consent have been obtained. General Framework Agreement (GFA) for setting up of KKNPP Units-3&4 has been signed with M/s. Atomstroyexport (ASE) and is made effective. Manufacturing of equipment/components under contract "supply of Long Manufacturing Cycle Equipment & First Priority Equipment (LMCE & FPE)" is started in Russian Federation (RF). Draft contract for supply of balance plant equipments is submitted by ASE, discussions/negotiations related to same are under progress. Technical Assignment for KKNPP Units-3&4 has been finalized and signed. About 91% work of First Priority Design Works (FPDW) contract is completed. Administrative approval has been obtained for tendering of main plant civil works, construction of hydro technical structures, engineering, procurement, construction and commissioning of common services mechanical systems. Excavation consent from AERB has been obtained.

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

Land acquisition for the plant is completed. Government administrative approval and financial sanction of the project exists. Environmental clearance from Ministry of Environment, Forests and Climate Change (MoEFCC) has been obtained for project site. Haryana State Pollution Control Board has granted consent to establish GHAVP. Siting consent from AERB is received. Site Geotechnical studies are in advanced stage of completion. Boundary wall construction is in progress and site mobilization by contractor for Site Management Building is in progress. Tendering action has been initiated for long delivery equipments. However, conditional offers related to Civil Liability for Nuclear Damage (CLND) act clauses by various bidders need to be resolved for further progress and the same is in progress. Site preparation activities like ground improvement, construction power, water supply and infrastructure development, etc. are being taken up progressively.

New Project / Sites

In respect of Jaitapur Nuclear Power Project (JNPP), land is acquired and site office is established. Environmental clearance is obtained from MoEFCC and Siting clearance is under review by AERB. Pre Engineering Agreement (PEA) for the Engineering Services is signed between NPCIL and AREVA and contract has commenced. The techno-commercial discussions with AREVA/ALSTOM are in progress. Public Awareness activities are ongoing.

Land acquisition, environmental studies, public outreach activities, various site studies to the extent possible etc. are under various stages at new sites namely Chutka and Bhimpur, Madhya Pradesh, Mahi Banswara in Rajasthan, Mithi Virdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga Unit-5&6 in Karnataka and Haripur in West Bengal.

Land is already available for Kaiga-5&6. Section-11 notification has been issued for land acquisition by respective State Govt. authorities for Chutka site in Madhya Pradesh and Mahi Banswara site in Rajasthan. In respect of Chutka, Rehabilitation & Resettlement package is announced and part amount has been remitted to Govt. of Madhya Pradesh towards land acquisition. In respect of Kovvada and MithiVirdi, land acquisition process as per the new RFCTLARR (The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement) Act, 2013 is in progress.

Quality Assurance

Quality Assurance (QA)/ surveillance activities are being carried out by NPCIL for projects and stations. Pre-Service/In-Service Inspections of KKNPP-1&2, TAPS-1&2, TAPS-3&4, KAPS-1&2, NAPS-1&2, RAPS-5&6, RAPS-3&4 and KGS 3&4 have been completed successfully. Corporate QA audits of projects i.e. KAPP-3&4 and RAPP-7&8 have been completed in a planned way. Corporate reviews of operating stations have been conducted based on the World Association of Nuclear Operators (WANO) guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO. Various Directorates at NPCIL HQ are ISO: 9001 certified. Surveillance/Re-certification audits of all these Directorates by the certifying body have been completed successfully.

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 constitutes 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

The Heavy Water Board has contributed successfully to the first stage of Nuclear Power Programme by producing Heavy Water for all Pressurised Heavy Water Reactors in a cost effective manner enabling the department to provide nuclear power at an affordable cost to common man. Presently, Heavy Water Board is not only self-sufficient in meeting the domestic demand of heavy water, but is also geared up to supply heavy water for the future PHWRs and AHWRs as per the envisioned nuclear power programme of DAE. Over a period of time, HWB has emerged as the largest global producer and a trusted 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.

Performance of the Board during the period was excellent with respect to production, specific energy consumption, on stream factor and plant safety. As per the Annual Action Plan for the year 2015-16, HWPs at Manuguru, Kota, Hazira & Thal have carried out the Annual Turn Around jobs during the period. However, the overall specific energy consumption including the non-productive consumption during the planned shutdown period could be brought down less than the targeted figure due to continual and meticulous review of the process parameters to ensure optimum levels of plant operation. Further, the plants could achieve nearly continuous run with an on-stream factor close to 1, excluding the planned shutdown periods. Consequently, during the period Board could surpass the production target by more than 12% and also achieved 113.7% of overall capacity utilization.

The Heavy Water Board achieved more than 112% of targeted production for the financial year 2015-16 and the specific energy consumption was 28.6 GJ/Kg.

India's position as a trusted supplier of high quality heavy water in the international arena, was further strengthened by bagging one more export order for supply of 15,000kg. Heavy water worth 5.16 Million USD from M/s Linde Electronics & Specialty Gases, USA for non-nuclear applications. After obtaining necessary approvals, HWB has sent quotations to three more existing customers in USA and France for export of 25,000 kg heavy water. The net financial inflow realized from these export orders will reduce the pool price of heavy water marginally.

Recently, HWB has also received request for supply of 20,000 Kg heavy water for making deuterated drugs by a leading Pharmaceutical Research and Development company in USA. Board has also received an enquiry from US Department of Energy Science for supply of heavy water for Neutron Spallation Studies.

Diversification Activities

HWB has made major progress on its extended mandate in the field of development, demonstration and deployment of technologies for in-core and out of core material inputs for Indian Nuclear Power Programme, required at the Front-end as well as Back-end of nuclear fuel cycle mainly centering around three broad areas such as solvents for front and back end hydrometallurgical operations of nuclear fuel cycle; demonstrating solvent extraction technology for extraction of various rare materials and producing stable isotopes like ^{10}B for Fast Breeder Reactors and ^{18}O for societal applications.

Solvent Technology

In the area of solvents, both the industrial facilities at HWP, Baroda and Talcher for production of TBP (Tributyl Phosphate) and D2EHPA have performed very well enabling HWB to meet the entire requirement of NFC, NRB and all other units of DAE.

Developmental efforts have already been put in place at HWP, Tuticorin in the Versatile Solvent Synthesis Pilot Plant (VSSP) in campaign mode for special and futuristic solvents like D2EHPA-II, TiAP, DHOA and TAPO for collection of data for industrial level production of these solvents. Small quantities were supplied to BARC/NFC/IGCAR for taking up R&D work. HWB has initiated setting up of Solvent Production Plant (SPP) for industrial scale production of these solvents with an objective to achieve self-reliance. HWB is also planning to take up synthesis of some special solvents viz. DGA, Calixarene etc. based on collaborative efforts with DAE units as requested by them.

HWB has successfully demonstrated the solvent extraction technology in industrial prototype scale at its Technology Demonstration Plant for various nuclear hydrometallurgical operations. Process optimization and development of more efficient equipment are the current thrust areas.

Boron Enrichment

In consonance with the material input required for second stage of NPP based on FBRs, HWB, with its decades of experience of handling isotope separation process, took up development, demonstration and deployment of indigenous technologies for production of enriched Boron. Boron Enrichment Exchange Distillation (BEXD) plant at HWP Talcher and Boron Enrichment Plant (BEP) based on Ion Chromatography at HWP, Manuguru are operating very well. HWB has now acquired comprehensive capability in this area achieving enrichment levels beyond 95% in multiple chemical forms. To support the second stage of NPP, HWB has successfully delivered the entire quantity of enriched Boron for the 1st core of PFBR. India has thus found a place in the handful of countries possessing such capability.

Sodium Metal

Sodium is another important input for FBRs, used as coolant in the reactor. Networking with the Indian R&D organizations, HWB has developed indigenous and safer closed electrolytic cell technology for production of nuclear grade Sodium. Successively larger size cells are tested with the ultimate intent of an industrial scale set up.



Sodium Cell at HWP, Baroda

Mineral Exploration and Mining

Atomic Minerals Directorate for Exploration and Research (AMD) continued the accelerated pace of exploration activities during the year by integrated, multi-disciplinary methodology and judicious utilisation of manpower with a focussed approach on augmentation of uranium, thorium and rare metals. This resulted in the augmentation of additional uranium oxide (U_3O_8) reserve of over 15,775 tonnes in the areas of Andhra Pradesh, Meghalaya, Rajasthan and Jharkhand. The country's uranium reserve has been updated to 2,29,936 tonnes of Uranium Oxide (U_3O_8) as of 31st December 2015.

Significant uranium anomalies were located in Uttar Pradesh, Uttarakhand, Tamil Nadu, Chhattisgarh, Madhya Pradesh, Odisha and Arunachal Pradesh. About 1,90,585m reconnoitory, exploratory and evaluation drilling was carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of mineralization in the new promising areas. Significant mineralized intercepts/bands have been identified in boreholes drilled at Andhra Pradesh, Jharkhand, Meghalaya,

Karnataka and Chhattisgarh. Potential/significant blocks have also been identified at Haryana, Rajasthan, Jharkhand, Meghalaya and Chhattisgarh.

Geochemical surveys (4,040 sq km) have been carried out in different parts of the country for delineating the target for detailed investigations. Ground geophysical surveys (about 560 sq km) have delineated conducting zones in Haryana and high chargeability zones in Karnataka and Jharkhand. Airborne survey and remote sensing survey has also been carried out over 42,559 line km in parts of Rajasthan and Karnataka.

Rare Metal and Rare Earth (RMRE) investigations resulted in location of significant concentrations of RMRE along Chhattisgarh, Tamil Nadu and Karnataka.

Beach Sand and Offshore Investigations (BSOI) resulted in establishing potential heavy mineral zones mainly along the east coast. Significant zones of Total Heavy Mineral (THM) concentration have been located at Andhra Pradesh, Odisha and Tamil Nadu. Sonic drilling was initiated in beach sand investigations to evaluate deeper horizons.

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. A new mine and a processing plant are also under construction at Tummalapalle, Andhra Pradesh. The Indian Rare Earths 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 overall performance of UCIL during the year was satisfying. The Tummalapalle Uranium Project at Andhra Pradesh is readying for commissioning in 2015-16. The mine has achieved the desired ore production capacity and adequate ore has been stockpiled. During the year, “Incidental production” has gone up by 35.67% with respect to previous year.

UCIL has started augmentation of the mining operations at Bhatin mine. The Banduhurang mine is continuously improving its performance. A new project of installation of gyratory crusher at Banduhurang open cast mine is being taken up to improve capacity utilization.

Mining lease of Mohuldih mine has been granted by State Govt.

Construction of a new Uranium Peroxide facility at existing Turamdih Uranium processing plant has been completed.

UCIL has proposed to construct uranium recovery plants for recovery of uranium from copper tailings of M/s Hindustan Copper Ltd's operations at Mosabani.

UCIL has also proposed seven projects, grouped under Debottlenecking of Singhbhum and Tummalapalle operations to remove hindrances in smooth and sustained operations in its facilities at Singhbhum and Tummalapalle with high capacity utilization level.

The major achievement of IREL was the commercial production of the 10,000 tpa monazite processing plant at OSCOM, Odisha which commenced on 1st January 2015 after obtaining clearance from AERB.

Project report prepared by IREL for setting up of the technology demonstration plant for producing nano titanium and zirconium oxy-chloride has been vetted by the consultant. Draft EIA/ EMP report prepared by the environment consultant has been submitted to OSPCB seeking suitable date for public hearing.

Licensing Agreement for Transfer of Technology has been signed with Defence Metallurgical & Research Laboratory (DMRL), Hyderabad for transfer of rare earth based magnet making technology to IREL. Agreement for transfer of process for preparation of Sm-Co magnetic alloy powder technology has been signed with Bhabha Atomic Research Centre (BARC), Mumbai. Based on the above technologies available, IREL is contemplating to set up a rare earth based permanent magnet plant. For this, preparation of detailed project report is under way.

During the year, two patents covering a process for production of pure Zirconium oxide from Zircon and a process for the production of thorium phosphate from thorium oxalate and recovery of oxalic acid have been filed.

Upgradation of Metal Reduction Technology & Effluent handling facility was commissioned at BARC for purification of natural U concentrates & recycles to produce nuclear pure Ammonium Di-Uranate (ADU).

An improved precipitation technique for recovery of U with improved particle size and settling rate of precipitate was developed and demonstrated at Tumallapalle mill based on enhancing the concentration of leach liquor from 1 g/l U_3O_8 to 2.5 g/l by dissolving Sodium Di-Uranate (SDU) followed by its precipitation in two stages using NaOH solution as precipitating reagent.



Experimental set up for the precipitation of Sodium Di-Uranate from leach liquor of Tummalapalle uranium ore

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, PHWR fuel tubes, Niobium metal and SS tubes & job orders was achieved during the period.

Production of 202 nos. of pressure tubes for 700 MWe PHWRs through new route of two stage radial forging and single pilgering of billets were completed, thus meeting the complete requirement of forth coming KAPP - 3 & 4 and RAPP - 7 & 8.

Production of the final set of UNS 8800 U-bend Steam Generator tubes for 700 MWe PHWRs was completed.

NFC launched 19 new projects during the XII plan and 3 new projects during MTA. These projects were launched to meet the fuel and zircaloy requirements of forthcoming 700 MWe PHWRs and 300 MWe AHWR, in addition to augmentation and modernisation of the present production facilities, in line with the demand from M/s NPCIL.

In addition to the above, setting up of 300 tpy of VVER Fuel Fabrication Facility along with a Zircaloy Fabrication Facility of 75 tpy capacity for producing fuel tubes and other components to meet the requirements of 12 x 1000 MWe VVERs and setting up of a Stainless Steel Tube plant of 400 tpy capacity to cater to the requirements of 2 nos. of 500 MWe FBRs was proposed at Kurnool in Andhra Pradesh.

Various activities are in progress for the 5 continuing projects including the green field project, NFC-Kota at Rajasthan and for establishing Niobium Thermit Production Facility (NTPF) to meet the Niobium requirement of VSSC (Dept. of Space) indigenously.

Production of nuclear grade U metal to support DHRUVA operation close to 100 MWt continued. Multiple Alpha Counting System (MACS) has been indigenously designed and developed by BARC.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

All the fuel reprocessing plants are operating at their design capacity. Warm commissioning of Power Reactor Fuel Reprocessing Plant-3A commenced. Power Reactor Thoria Reprocessing Facility (PRTRF) was hot commissioned to recover ^{233}U from irradiated Th. Demonstration of reprocessing of irradiated thoria bundle and quantitative separation/recovery of ^{233}U is an important milestone in the 3 stage nuclear power program.

Advanced Vitrification System, Tarapur completed vitrification of radioactive liquid waste in Joule melter. Centralized Waste Management



In-cell piping at PREFRE- 3A, Kalpakkam

Facility, Kalpakkam continued to provide uninterrupted radioactive waste management services & filter testing services to various units of DAE at Kalpakkam. Plutonium Plant, Trombay continued processing of the spent fuel from Dhruva to fissile and fertile material. An innovative method to partition the radio-elements from inactive salt constituents using indigenously developed solvents was employed for the management of radioactive waste.

R&D SUPPORT TO POWER SECTOR

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

The fuel utilization in Indian Pressurised Water Reactor equilibrium configuration was enhanced to get a discharge burn-up of 45 GWd/T with a profiled fuel assembly of average ^{235}U content of 4.22%. Numerical models were developed and validated for deflagration, flame acceleration and detonation using experimental data to understand different physical and chemical processes during hydrogen combustion. Fitness-for-Service and assessment of remaining life of hemispherical bottom head of second stage hot tower of HWP, Kota was carried out by finite element analyses and limit load calculations. The design of the Reactor Outlet Header of TAPS - 3 & 4 was modified using spherical bearings at both the ends. A fixture was developed and used for forming radial hydride in Zr-2.5Nb alloy in pressure tube sections for the first time. About 250g of sintered UO_2 microspheres of 2.00 and 2.15 O/M ratios were fabricated as a part of ceramic fuel development program for advanced reactors. A novel method for the accurate determination of Mo extracted from U based fuels, by pyrohydrolysis, using ion chromatography was developed. A new hot cell facility to evaluate the performance of irradiated nuclear fuels and structural components was commissioned in BARC. Post irradiation examination of two mixed-oxide bundles of 220 MWe PHWR was carried out. BARC developed, manufactured and tested an electrochemical filter for 220 MWe PHWR for removal of suspended nano-particles.



Electrochemical Filter

Fuel pins and burnable poison rods were fabricated and sent to Kalpakkam for making fuel assemblies for compact light water reactor after the non-destructive evaluation. Ultrasonic inspection methodology using focused longitudinal wave transducers was standardized on a mock-up block of dissimilar weld metal joints containing reference defects. An electrodeposition technique was developed for preparing enriched UO_2 coated substrates of different shapes and sizes. They are used in making electrodes of fission based neutron detectors for measuring neutron flux in reactors.

HEALTH SAFETY & ENVIRONMENT

NPCIL has recorded about 430 reactor years of safe operation of reactors by the end of December 2015. 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 ALARA (As Low as Reasonably Achievable) 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 all 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.

An online Thoron monitoring network was installed and made operational at PRTRF at Trombay to monitor the thoron gas concentration at various locations in the facility. Internal exposure assessment of occupational workers from various facilities of BARC at Mumbai and Tarapur was carried out by whole body/lung counting and bio-assay (urine/fecal) sample analysis. Radiological protection and environmental surveillance services were provided to front-end facilities like fuel fabrication plants, back-end facilities like fuel reprocessing plants and waste management facilities, RMP Mysore, PRP and particle accelerators. Environmental surveillance around NPP sites and BARC was carried out for radiological impact assessment of general public. Personnel monitoring services to ensure radiation safety of the workers and the installations for external radiation were provided to about 30,000 radiation workers in DAE. Personnel monitoring of non-DAE radiation workers were provided through laboratories accredited by BARC.

All the plants of Heavy Water Board are certified for ISO Quality Management system, Environmental Management System and OSHA System. The overall safety standards of Heavy water Plants were far better than similar chemical industries in the country.

NUCLEAR POWER PROGRAMME: STAGE 2

FAST BREEDER REACTORS

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

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

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.

Prototype Fast Breeder Reactor

PFBR is a pool type reactor using mixed oxide of uranium and plutonium as fuel. The coolant



Overall view of PFBR

used is liquid sodium. The project is located 500m south of the existing Madras Atomic Power Station.

At BHAVINI, the major systems of PFBR were identified and primary focus was given to these systems. Commissioning activities have been finalized in three stages: Preheating of Main Vessel, Sodium filling in Main Vessel and fuel loading towards approach to criticality. Presently, PFBR is in first stage of the commissioning programme which involves sodium filling and engineering experiments with pumps and heat exchangers. Reactor operation team consisting of six crews has been formed for covering round the clock shifts.

All the components & hardware required for fabrication of various sub-assemblies were completed and final assembly fabrication work was completed for most of the sub-assemblies at NFC. Balance quantity of 18 nos. of fuel sub-assemblies, 8 nos. of diluent sub-assemblies and 3 nos. of source sub-assemblies are under final stage of completion to meet the commissioning schedule of PFBR.

A committee consisting of external experts was constituted to conduct preliminary site walkthrough before first approach to criticality and the recommendations made by the committee are being addressed. System-wise balance activities to be completed for the entire project along with time schedule are identified and submitted to the expert committee. The gaps in various mechanical, electrical and instrumentation systems have been identified and taken up on priority. The major activity that governs the project schedule is installation and commissioning of field cabling and associated interface software for transmitting the signals from local control center to main control room. This was successfully accomplished in an accelerated phase involving both ECIL and IGCAR.

The project has achieved an overall physical progress of 97.64% at the end of January-2016.

Fast Breeder Test Reactor

During 2015-16, Fast Breeder Test Reactor (FBTR), the flagship of the IGCAR, continued to play an important role in testing the fuel, structural materials and special neutron detectors for FBR programmes. On 29th December 2015, the reactor power was raised to 26.1 MWt for the first time with turbo generator generating a power of 5 MWe. Currently the 24th irradiation campaign has been started. About 122 number of thoria subassemblies were loaded in the reactor towards production of Uranium-233. Recommendations of SARCOP including post Fukushima and seismic retrofits were implemented.

FBR Fuels

The U-Pu mixed carbide fuel pins for FBTR at Kalpakkam and fuel pins for the full core of PFBR were supplied by BARC. Electro refining of U-Pu-Zr alloy in molten LiKCl-$PuCl_3$ electrolyte was demonstrated at IGCAR. Direct reduction of 100 gram batches of uranium dioxide to uranium metal by the new molten salt electro-deoxidation process was demonstrated with a conversion efficiency of more than 98%.

Fast Reactor Fuel Reprocessing

Towards reprocessing programme, the operation of CORAL (Compact Reprocessing facility for Advanced fuels in Lead cells) facility provided immense experience in the domain of remote handling & maintenance and in achieving product purity in addition to reprocessing the FBTR fuel. In the Fast Reactor Fuel Cycle Facility, civil construction of various buildings is progressing well.

FBR Related Technologies

Towards R&D related activities for the fast reactors and associated fuel cycle, various experimental facilities such as commissioning of a 100 tonne shake table, research facility for irradiation studies in sodium at high temperature, an innovative out of pile test loop and rupture and ballooning in tubes facility were completed.

Future FBRs

A 5/8th scale 90° sector model simulating the hot pool of future FBRs was commissioned for conducting hydraulic studies in water. A new facility was commissioned to study the flow induced vibration characteristics of a cluster of subassemblies of the core of FBR.

Health, Safety & Environment

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD (Thermo Luminescence Dosimeters) personnel monitoring services, covering about 2500 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 800 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for over 150 occupational workers were also carried out.

Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated.

Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Online nuclear emergency response decision support system and module for the off-site emergency exercise with weather prediction system were developed.

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

The Advanced Heavy Water Reactor (AHWR) equilibrium core cluster having (Th, Pu-U) MOX fuel was re-optimized for better performance. A Passive Auto Depressurization System was developed for fast de-pressurisation of main heat transport system to initiate timely injection of cooling water to ensure safety and integrity of the core. A mock-up facility was developed and installed in BARC to demonstrate all aspects of automatic and remote fabrication of (Th-^{233}U)O_2 fuel.

Other Thorium Reactor Systems

The refueling and removal of molten salt fuel from the 850 MWe Indian Molten Salt Breeder Reactor was computed for various burn-ups. A high temperature heat pipe was fabricated with sodium as the working fluid and tested. A process was developed to prepare high purity beryllium oxide and fabrication of rectangular shape high density sintered beryllia ceramic by vacuum hot pressing. A vitrification process was developed for safe disposal of solid waste generated during extraction of Be from its ore by immobilizing the Be value present in waste mud. Boron alloy composites (TiCr)B_2+$MoSi_2$ and B_4C+ZrO_2 for control rods of P-4 facility and shut-off rods of project B-3 were prepared. A carbon vapour deposition spray coating facility using induction heating to coat the internal and external surfaces of CHTR fuel tube with pyrolytic carbon and silicon carbide was commissioned.



Unfinished sintered beryllia blocks and multi-cavity die for production of beryllia stack

KAlpakkam MINI (KAMINI) Reactor

KAMINI reactor was operated successfully for neutron radiography of various pyro devices for Department of Space. High temperature fission chambers required for neutron flux measurement of PFBR were successfully tested.

Research Reactors

Dhruva operated at rated power of 100 MWt at a high safety level and availability factor. A number of researchers from across the country utilized the neutron beam facility of the UGC-DAE Consortium for Scientific Research. Commissioning of an air cooled adjuster rod with a drive mechanism enabled production of high specific activity ^{60}Co in Dhruva for cancer treatment. Triplicated Trombay Programmable Logic Control (TPLC) based Reactor Trip Logic System (RTLS) was commissioned as a part of the Dhruva Control & Instrumentation up-gradation. Construction of 2 MWt Apsara Reactor is in progress. Operation of Heavy Water Upgrading Plant to improve Isotopic Purity of downgraded heavy water from Dhruva continued.



TPLC-32 based RTLS in Dhruva

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 facility for processing of multi-cell 1.3 GHz Superconducting Radio Frequency (SCRF) cavities has been set up at RRCAT. Using this facility a nine-cell 1.3 GHz SCRF cavity has been fabricated and electro-polished to remove an average of 50 micron material. A semi-automatic cavity tuning machine has been designed and developed indigenously for the RF resonating frequency and field flatness correction of a multi-cell 1.3 GHz SCRF cavity. A centrifugal barrel polishing machine has been indigenously designed and developed for polishing of the internal surface of multi-cell SCRF cavities.

An innovative laser welding technique for fabrication of SCRF cavities has been developed indigenously. This technique is being used now to fabricate a single-cell 650 MHz SCRF cavity which is much larger in size. Helium liquefaction using a completely indigenous system has now been upgraded with a larger refrigeration capacity expansion engine and state-of-the-art brazed aluminium plate fin heat exchangers. A horizontal test cryostat has been designed for testing two 650 MHz "dressed" SCRF cavities at 2K in a single testing cycle.

A bell-shaped tuneable oxygen-free copper Radio Frequency (RF) cavity and high power input coupler operating at 505.8 MHz for Indus-2 has been indigenously designed, fabricated and tested. All four RF stations of Indus-2 have been now upgraded with Field Programmable Gate Array (FPGA) based digital Low Level Radio Frequency (LLRF) control



A nine-cell 1.3 GHz SCRF cavity on semi-automatic tuning machine

system. All the different types of magnets required in the Indus synchrotron sources have been developed in-house. A 10 MeV electron linac suitable for operation under industrial conditions has been developed with mostly indigenous design and component manufacturing. Development of an Infra-Red Free Electron Laser (IR-FEL) designed to lase in a wavelength range of 15 – 50 μm using a 15 – 25 MeV electron beam has been completed. An indigenously built hydrocarbon-free ultraclean cold walled controlled atmosphere brazing furnace has been installed to facilitate brazing of dissimilar metal transition joints and copper-to-copper joints for accelerator components. Components for the Indian Spallation Neutron Source (ISNS) programme has been developed at RRCAT.

The 10 MeV Injector Cryo-module (ICM) of the superconducting Electron Linac has been assembled and its first beam test were conducted successfully at TRIUMF, CANADA. The second ICM, which is meant for VECC has been fabricated and is being assembled at TRIUMF. The testing is scheduled at TRIUMF in early 2016. Apart from ICM, the Injector comprises a 300 kV electron gun and low energy beam transport (LEBT) line which are being indigenously developed by Indian industry. A test area has been set-up at VECC for initial tests of 100 keV electron gun for the Advanced National facility for Unstable & Rare Isotope Beams (ANURIB) Facility. The physics and RF design of high current rod type RFQ accelerating 5mA protons to 1 MeV has been completed, which will be used as injector for the ANURIB 50 MeV proton driver. Similarly physics design and layout of the ANURIB phase-1 building that will house the driver linacs, target modules, ion-sources and separators, low energy experimental facility, services etc. has been frozen.



The Injector Cryo-module during testing at TRIUMF

Using ion–beams from existing Radioactive Ion Beam (RIB) facility a fast and large area nano dot formation of magnetic materials in minimum processing steps is one of the big efforts, which is underway apart from developing an experimental set-up, a new R&D programme on Graphene layer formation by carbon ion implantation has been initiated. Carbon ion implantation at low energy has also been used for the investigation of possible ferromagnetic ordering in wide gap ZnO.

A 3 axis computerized magnetic field measurement facility using Hall probe has been indigenously developed at VECC to measure the magnetic field upto 3 Tesla with accuracy of ± 1% in a volume of 1.5 m x 1.3 m x 0.15 m with an overall accuracy of better than 0.2 mm over the entire volume. The facility will be able to measure the absolute magnetic field of different types of magnets and validate its design. The control logic and software have been developed for automatic operation of the magnetic field measurement facility.

On successful completion of the design of single-cell 650 MHz, β=0.61, Superconducting RF (SRF) linac cavity, fabrication of prototype aluminium cavity and also single-cell niobium cavity was completed.

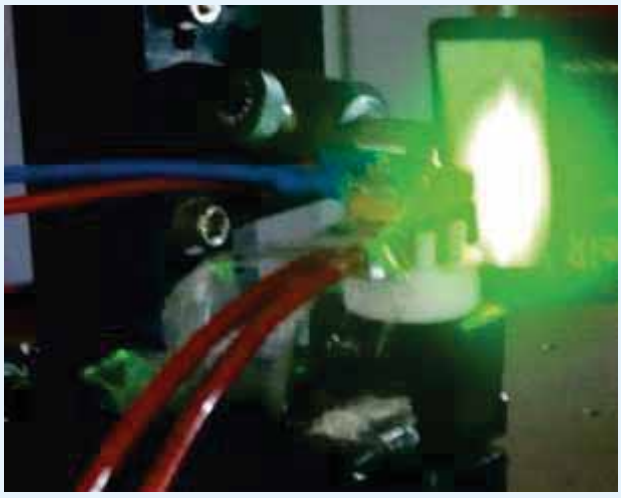
A system to test the performance of 1.3 GHz superconducting RF cavity cryo-module is developed by BARC under Indian Institution and Fermi Lab Collaboration.

Laser Technology Development and Applications

A fiber coupled pulsed Nd:YAG laser providing pulses of 20 kW peak power has been developed at RRCAT for laser welding of up to 4 mm thick niobium SCRF cavities. A pulsed Nd:YAG laser for remote dismantling of irradiated fuel subassemblies of the Prototype Fast Breeder Reactor (PFBR) has been developed. An Yb-doped Continuous Wave (CW) fiber laser of 400 W output power has been developed using a single oscillator. A

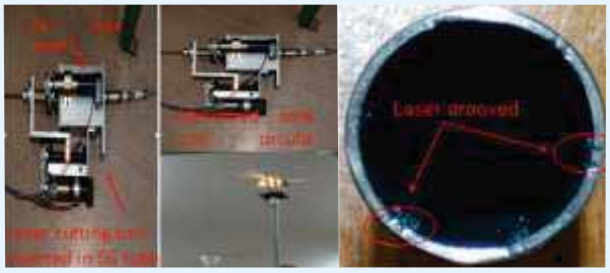
diode side-pumped continuous wave (CW) Nd:YAG laser of output power 1 kW operating at 1060 nm wavelength has also been developed. An Er-doped fiber laser emitting at the eye-safe wavelength of 1600 nm which uses a large mode-area Er-doped fiber pumped by a 975 nm diode laser and having a CW output power of 25 W has been developed.

A user-friendly engineered version of diode-pumped solid-state green laser operating at 532nm has been developed. A wide-aperture XeCl excimer laser providing 120 mJ output power at 308 nm wavelength has been developed. Testing and quality control parameters and procedures have been evolved for the Nd-doped phosphate laser glass indigenously developed in collaboration with CGCRI, Kolkata. A large beam diameter (250 mm) Fizeau interferometer has been developed for surface quality testing of polished large laser amplifier discs. Photonic devices based on GaAs and InP semiconductors have been fabricated. These include laser diode arrays operating at 980nm with 23.5 W peak power under pulsed operation and 3 W CW power, GaAs based radiation hard (100 kGy for gamma rays) quadrant detectors operating in the wavelength range of 200-900 nm and a novel gold/semiconductor hybrid detector that can simultaneously measure the degree of circular polarization and intensity of a laser beam.



The diode array laser and its output on a fluorescent screen

The Technologies developed at RRCAT for various applications included the Development of laser cutting tool and technique for axial and circular cutting of Steam Generator (SG) tubes for Kaiga



Laser cutting mock up, fixture for laser cutting of Steam Generator (SG) tube and laser grooved sample of SG tube

Generating Station-4 reactor; Water-jet assisted underwater laser cutting of damaged and flared fuel assemblies of Dhruva reactor; SG tube cutting at Kudankulam nuclear power plant; In-situ laser cutting of Q-16 coolant channel from KAPS-2 reactor; Novel thin foil target for quasi-mono-energetic ion acceleration; Collimated MeV fast electron beam at grazing incidence laser - solid interaction; Oblique laser peening technique for tubular SS304L to improve stress corrosion cracking resistance; Cone-shell Raman spectroscopy for depth-sensitive measurements in layered tissue; Raman optical tweezers for cell cycle analysis; Laser additive manufacturing of nuclear components; Prototype nuclear fuel pellet inspection system; Development of Fiber Bragg Grating (FBG) based distributed temperature sensor and Two-color femtosecond optical Kerr gate.

A three-electrode APPJ was fabricated and tested for its use in actinide decontamination. Process laser system was designed and installed with three dye laser chains in Master Oscillator Power Amplifier configuration in BARC.

Electronics & Instrumentation

The Electronics Corporation of India Limited (ECIL) continued to remain engaged in the design, development, manufacture, supply, installation and commissioning of electronic equipment for the Atomic Energy, Defence, Aerospace, Security, Information Technology and e-Governance sectors. Some of the new products introduced during the year were Uranium Analyser; Solid State Digital Video Recorder System; Radar Target Echo Simulator; High Power Solid State Switches; TDM Signal Analyser and De-multiplexer and Linux based ECSCADA Server Software.



Compact high voltage power supply



Peripheral Pulse Analyzer

The technology of Quadrupole Mass Spectrometer (QMS) was transferred to M/S ECIL by BARC for the development of QMS based Hydrogen and Steam Concentration Measurement System (HSCMS) for NPCIL. Compact +/- 5 kV, 2 mA high voltage modules operating with 24 V dc supply was developed for precision analytical instruments. An improved and compact SMPS based power supply was developed for sputter ion pumps (140 litres/sec) and the technical knowhow was transferred to a private company. A universal vacuum gauge based on a combination of Pirani and hot cathode ionization gauge was developed for pressure measurement from atmosphere to 10^{-10} Torr. A battery based miniature neutron generator using penning ion source providing $5x10^{6}$ n/s for applications in oil logging, uranium mining etc. has been developed. Continuing the collaborative development of Active Radar Seeker with ECIL, the seeker was set up on the shore to track ships at sea in range and angle.

Robotics

A robot based frameless stereotactic system is developed at BARC for performing neurosurgery



A 6D-PKM based robot developed for frameless stereotactic neurosurgery

which has accuracy and patient comfort level comparable to frame based system. It automates the frameless stereotaxy using a high precision robot (Parallel Mechanism based Robot). A 4 DOF (Degrees of Freedom) Surgical Coordinate Measuring Mechanism (SCMM), a 6 DOF Parallel Kinematic Mechanism (6D-PKM) based robot and the visualization display to aid the surgeon during neurosurgery are the major components of the system.

Cryogenics

A cryogenic system consisting of cryogen distribution lines for liquid helium and liquid nitrogen, sub-atmospheric vacuum jacketed lines for helium, warm helium lines between the helium buffer tanks and compressors, and a 500 watt helium liquefier is being set-up for the superconducting electron and heavy-ion linacs at VECC. The design of the cryogenic system has been finalized.

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 Dhruva research reactor at Trombay, accelerator at Kolkata and the various nuclear power plants of NPCIL. During the report period, a wide variety of

radioisotopes for medical, industrial and research applications were produced and supplied by BARC. The Board of Radiation and Isotope Technology (BRIT) produced and supplied a wide range of radioisotope products, and radiation technology equipment for medical and industrial uses. BRIT's plants for radiation sterilization of medical products and radiation processing of spices and allied products continued to offer services to medical and agro-industry. Radiation technology based tools and techniques benefitted variety of industries and social sector.

Agriculture

Trombay Groundnut (TG) varieties TG 79 and TG 80 entered for evaluation in Indian Council of Agricultural Research trials all over the country. 340 quintals of breeder seed of TG varieties were produced in BARC, Gauribidanur & from contract farming and distributed to seed agencies in various states. Seed multiplication of black gram varieties TAU-1, TAU-2, TPU-4, TU94-2 and TU-40 was done. Protocol for the preparation of biomass for the uptake of U and suitable color reagent for its detection was established.

A gel-free protocol has been developed for rapid assessment of single band DNA markers and to expedite selection of desired traits in wheat plants. 148 new indigenous and exotic germplasm lines of sorghum were evaluated for their synchronous flowering, seed set and potential to be used in the hybrid development. A purely organic, seed dressing biofungicide formulation of an improved Trichoderma virens mutant strain was developed.

FoodTechnology

The potential of using irradiated onion scales as a source of natural food additive was evaluated. Methods were standardized for the preparation of ready to eat (RTE), shelf stable mutton masala using gamma radiation. A procedure was standardized for ready to bake chapattis by radiation processing at 1 kGy dose and heating at 800°C for 15 minutes in water bath. Silver nanoparticles synthesized using mint extract were found to be bactericidal against E. coli, S. aureus, B. cereus and P. aeruginosa. Copper nanoparticles were incorporated in PVA films to develop active antimicrobial films. Improvement and modification of litchi preservation technology was effected by replacing hydrochloric acid treatment with tartaric acid doing away with the ascorbic acid treatment making the process more cost effective. The effect of allylisothiocyanate (AITC) in combination with low temperature (10 °C) storage on post harvest quality of minimally processed shredded cabbage was investigated. Technology for preparation of radiation processed guar gum as a dietary fiber is ready for transfer to the prospective entrepreneurs.

Nuclear Medicine and Healthcare

More than 12,000 patients were benefitted from nuclear medicine diagnosis and therapy for various ailments such as thyroid, heart, etc. The Scintigraphy and PET-CT Section performed nearly 12,000 diagnostic scans. Facility for indigenous sourcing of expensive and clinically relevant peptides such as DOTA-TATE, HYNIC-TOC, cyclic-RGD, etc., using solid phase peptide synthesis has been developed. A two-vial kit for the preparation of ^{188}ReN-DEDTC/lipiodol (DEDTC–diethyl dithiocarbamates) for inoperable liver cancer as a cost-effective alternative to imported ^{90}Y-based products was developed. The Medical Cyclotron Facility was extensively used for the production of ^{18}F and its conversion to ^{18}F-Radiopharmaceuticals was carried out and supplied to 11 nuclear medicine centers. More than 50,000 analyses for TSH, T4, fT4, Thyroglobulin and anti microsomal antibodies were carried out using in-house developed kits. 142 Ci of $^{99m}TcO_4^-$ was extracted from ^{99}Mo and various ^{99m}Tc-radiopharmaceuticals were prepared for diagnostic studies. ^{68}Ga- DOTA-peptides were prepared and supplied for diagnostic scans. 50 Ci of ^{177}Lu-DOTATATE was prepared for neuroendocrine tumour therapy. Around 4 kCi activity of radioisotopes ^{131}I, ^{99}Mo, ^{153}Sm, ^{177}Lu, ^{32}P, etc. were chemically processed. Laboratory reference sources, custom-made sources, ^{125}I brachytherapy seeds and TRODAT-1 and HYNICTOC freeze dried kits were supplied to BRIT.

More than 20,000 consignments of ready to use Radiopharmaceuticals of Sodium Iodide (Na^{131}I) in the form of both solution and capsules for diagnosis and therapy of thyroid disorders, ^{131}I–meta Iodo Benzyl Guanidine (mIBG) for neuroendocrine

tumor detection & therapy, ^{32}P, ^{153}Sm and ^{177}Lu for bone pain palliation were supplied to various nuclear medicine centres & hospitals all over India in the form of ready-to-use injectables.

Total number of therapeutic treatments based on supplies are estimated to be more than 20,000. This major product included doses of $Na^{131}I$ for treatment of thyroid cancer & hyperthyroidism.

More than 75,000 cold kits for the formulation of ^{99m}Tc- Radiopharmaceuticals (15 products; BRIT Code-TCK) were supplied to nuclear medicine centres.



TCK Cold Kits Production Facility

Approx 71.5 Ci of Sodium Molybdate ($Na^{99}MoO_4$) solution in 342 consignments, for solvent extraction generator has been supplied upto December 2015. A total of ^{377}Ci of ^{99}Mo (1069 Consignments) in the form of sodium molybdate has been supplied as ^{99}Mo-^{99m}Tc generators (both Gel and Coltech) to various nuclear medicine centres.

Medical Cyclotron Facility (MCF), Parel, continued the supply of Positron Emitting Tomography (PET) radiopharmaceuticals such as ^{18}F-FDG, ^{18}F-NaF and ^{18}F-FMISO to various hospitals in and around Mumbai. Approx 15,000 patients were benefited.

Approx 3,000 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits to carry at about 5,00,000 in-vitro investigations, were supplied to various hospitals, research centres and immunoassay laboratories throughout India.

Approximately 2,45,544 In-vivo diagnostic investigations are estimated to have been carried with varied diagnostic Radiopharmaceuticals, the major are ^{99m}Tc based cold kits and ^{99}Mo- ^{99m}Tc generator systems.

Around 600 radiopharmaceuticals samples were analysed and certified by Quality Control section before being despatched to nuclear medicine centres.

Biodistribution studies (6 batches) were performed for Macro Albumin Aggregates (MAA) for lung scan. Similarly these studies were also performed for newly launched kits such as ^{177}Lu-EDTMP and ^{99m}Tc-TRODAT.

Labelled compounds Programme of BRIT continued the synthesis and supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products and various types of Tritium-Filled Self luminous sources (TFS). Since April 2015, approximately 7500 TFS sources of various sizes and shapes were supplied to defence establishments.

For societal applications of radio-technology, VECC has collaborated with BRIT, Kolkata to install and evaluate the TCM-AUTOSOLEX generator for preparation and use of [^{99m}Tc] pert echnetate in hospital. Irradiation of Enriched ^{100}Mo for ^{99m}Tc production in VEC cyclotron and determination of radionuclidic purity of the cyclotron produced ^{99m}Tc, as part of the IAEA Coordinate Research Project (CRP) on direct production of ^{99m}Tc in cyclotron, production feasibility of ^{89}Zr from ^{nat}Y and subsequent radiochemical separation of ^{89}Zr from the target matrix, evaluation of $^{68}Ge/^{68}Ga$ generator and synthesis of cross linked Chitosan for preparation of ^{99}Mo-^{99m}Tc Generator have also been performed.

Alternative Applications of Heavy Water

Realizing the potential requirements of Oxygen-18 (^{18}O) having application in nuclear medicine and bio-chemical research, HWB has successfully accomplished technology development for enrichment of ^{18}O at HWP, Tuticorin. The industrial scale facility for ^{18}O production plant has been commissioned at HWP, Manuguru. All columns have been successfully operated with DM water. Nuclear grade heavy water was charged and is under enrichment in coupled condition since July 2015.

Considering the immense potential of application of Deuterium and heavy water in life sciences, pharmaceuticals and technology areas, HWB has put in place an action plan to facilitate and nurture R&D activities in this area. Many Indian companies and government institutions like Indian Council of Agricultural Research (ICAR), Indian Veterinary Research Institute (IVRI), Institute of Plasma Research (IPR), Tata Institute of Fundamental Research (TIFR) etc., have shown their interest in this area and HWB has supplied small quantities of heavy water to support their R&D jobs.

As part of developmental activities on non-nuclear uses of Heavy Water, methods for synthesizing deuterated NMR solvents have been developed at HWP, Baroda in laboratory scale. Process optimization has also been done to minimize the consumption of Heavy Water used for synthesizing these molecules. As part of MoU signed between HWB & BRIT, BRIT has already started marketing these solvents to various reputed research institutes in the country.

Cancer Diagnostics & Treatment Services

During the period, TMC acquired around 140 equipments. Installation of major equipments like Surface Plasmon Resonance System, refrigerated shaker Incubators, Tabletop Centrifuges, Inverted Microscope, Thermal Cycler, Water Purification System, Micro plate Reader, Gel Documentation System, Real Time PCR Machine etc. has been done. Household survey was continued for screening of eligible women for breast, uterine, cervix and oral cavity cancers. Construction work has commenced for the establishment of Cancer hospital in Andhra Pradesh. For the Cancer Hospital in Chandigarh, work order has been issued. Clinical Research Secretariat (CRS) and Department of Atomic Energy Clinical Trials unit (DAE-CTC) has continued to play a key role in facilitating research in the field of oncology at the Hospital. The number of patients referred to and registered at ACTREC has increased over the years. A new state-of-the-art linear accelerator (Varian True Beam) was installed and commissioned for clinical use towards the year-end. The indigenously developed Multi Leaf Collimator (MLC) system installed on the Bhabhatron-II telecobalt unit received regulatory approval for clinical use. About 2000 major surgical procedures were performed in ACTREC. The achievement of Clinical Pharmacology lab involved in drug development included the encouraging preclinical findings of chlorophyllin as a radio protective agent and its technology transfer to an industry partner.

Industrial Applications of Radioisotopes & Radiation

Eleven Cobalt Teletherapy Sources (CTS) containing 98,300 Ci of ^{60}Co were supplied to different cancer hospitals till December 2015.

Sixty six Irradiator sources in seven consignments with total activity of 10, 66,498 Ci were supplied to various radiation processing plants within the country and also exported.

More than 850 ^{192}Ir & ^{60}Co Radiography sources containing 37,460 Ci of activity was supplied to NDT users. Reference and Custom Made Sources (CMR) of ^{46}Sc and ^{137}Cs in 975 consignments containing 5.67 Ci of radioactivity were also supplied to various organizations.

Ahmedabad Municipal Corporation and BARC signed MoU to set up a first of its kind Sewage Sludge Hygienisation Plant to treat sewage sludge at Ahmedabad using Radiation Technology as a part of the Clean India initiative (Swachcha and Swastha Bharat). The treated sludge will be inoculated with useful bacteria to convert into manure.

Radiation Processing

About 5116 Cubic meters of healthcare products were processed using radiation for terminal sterilization at ISOMED, BRIT upto December 2015.

Gamma Radiation Indicator Buttons were developed indigenously as an import substitute (Made in India) for qualitative indication of low and medium range gamma radiation dose delivery to the products.

About 2933 Tons of spices and other products like nutraceuticals and colour pigments were processed during the report period.

NABL accreditation for dosimeter calibration laboratory of Radiation Processing Plant (RPP), Vashi was obtained during the period.

MoU for setting up of Radiation Processing Plants was signed each with M/s Avantee Mega Food Park Pvt. Ltd. at Indore, M/s Electro Magnetic Industries at Sinnaur, Vadodra, Gujarat, M/s. Maharashtra State Agricultural Marketing Board, Vashi, Navi Mumbai.

M/s Aligned Industries Pvt. Ltd. commissioned Radiation Processing Plant for processing of food and medical products at Dharuhera, Haryana.

Four more Radiation Processing Plants under MoU with BRIT have been commissioned in the reported period. Total operational RPP's under MoU with BRIT are 14.

Radiation Technology based Equipment & Services

About 81 Radiography Cameras, ROLI-2 and ROLI-3, were supplied by BRIT to various NDT users within India. One Blood Irradiator containing 800 Ci of ^{60}Co was supplied to Ruby Hospital, Pune. First ^{137}Cs based Blood Irradiator was manufactured during the period.



First ^{137}Cs based Blood Irradiator

During the year, six units of 'Bhabhatron' have been commissioned at BARC, taking the total number of operating units to 36. One unit at ACTREC has been integrated with multi-leaf collimator, which is aimed at superior conformity. Six units of Radiotherapy Simulator 'Imagin' have been installed taking the total number of operating units of 'Imagin' to 10. One unit of 'Bhabhatron' and 'Imagin' were gifted to Mongolia during the honorable Prime Minister's visit. Postal Dosimetry Audit Phantom and Methods for intensity modulated radiotherapy was developed.

Water Purification, Water Desalination & Isotope Hydrology

A 250 m^3/hr capacity ultra-filtration plant was commissioned at BARC for conventional pre-treatment of SWRO (Sea Water Reverse Osmosis) process.



Ultra-filtration plant

A simple and low cost method based on an innovative chemical agent was developed for removal of fluoride from contaminated water. BARC has designed a solar photo-bioreactor capable of treating domestic waste water and simultaneously generating biomass for biofuel generation.

Isotope hydrological investigation was carried out in Goa to investigate the impact of iron ore mining to groundwater and surface water quality in downstream of the mine pits. Isotope techniques in aquifer mapping at a model project site in Patna district of Bihar state was carried out to understand recharge mechanism

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

Extraordinary fast fluid transport through carbon nanotubes was established at BARC using two phase thermodynamic method.

At SINP, a challenging integrable defect problem is solved with an innovative application of space-time duality, hidden in integrable systems. A novel class of exactly solvable spin Calogero models, associated with the D_N root system has been constructed by using the polarized spin reversal operators.

A new invariant, the Hilbert-Kunz density function was developed at TIFR. A structure theorem for saturated subgroup schemes of GL(V) was proved. An efficient numerical algorithm for the inversion of an integral transform arising in ultrasound imaging was developed. A method to determine the lower order perturbation of the polyharmonic operator from partial boundary data was analyzed. In a breakthrough discovery, it was shown that a simple power control policy can achieve finite delays and non-zero capacity in a large wireless network, where previously only infinite delays and zero capacity was known.

At HRI, new results have been obtained in the area of zero-sum problems with weights. A conjecture of Zagier regarding the asymptotic behavior of the inverse Mellin transform of the symmetric square L-function associated with the Ramanujan tau function has been generalized. All finite groups whose non-linear irreducible characters of the same degree are Galois conjugates have been classified. An optimal Hardy-Sobolev inequality has been proven for the twisted Laplacian.

The Institute of Mathematical Sciences (IMSc) remained involved in joint projects with national and international institutes for many projects on Mathematics.

Physics

At BARC, Neutron induced cross-sections for fusion technology application were determined for the first time for ^{55}Fe radio-nuclei by surrogate ratio method. TeV Atmospheric Cerenkov Telescope with Imaging Camera at Mt. Abu, Rajasthan continued to study extragalactic very high energy gamma-ray sources having low red shift, flaring history and hard gamma-ray emission spectra. The setting up of the Major Atmospheric Cerenkov Experiment Telescope at Hanle in Ladakh is in progress. A Collimator housing assembly and its supporting platform designed for neutron radiography was installed in VSSC, Trivandraum under a MoU between BARC and VSSC.



Collimator & Moderator Housing for Neutron Radiography

In astronomy at TIFR, ASTROSAT, India's first astronomy satellite was launched and placed into orbit. Three of the payloads were designed and



Astrosat before integration with PSLV

fabricated at TIFR. All instruments on board are functioning according to specifications. At the National Centre for Radio Astrophysics, a giant radio galaxy was discovered by the Giant Metrewave Radio telescope, and good progress was made on the upgrade of the GMRT.

In the area of experimental physics at TIFR significant advances were made in the fields of condensed matter, materials science, nuclear and atomic physics. Advances were made in the research of superconducting circuits, and in semiconductor research, synthesis of single crystals and the study of their properties was conducted. TIFR continued to participate in experiments at CERN. Also, simulation experiments were successfully carried out with the ICAL detector, a critical component of the India Based Neutrino Project.

Significant advances were made at SINP in the research activities in various areas of Condensed Matter Physics, Surface Physics, Nuclear Physics, Applied Nuclear Physics, Theoretical Physics and Astrophysical Sciences and Plasma Physics.

At VECC, a Total Abosorption Gamma Spectroscopy (TAGS) setup using BaF_2 detectors was designed and tested for accurate beta-decay feeding measurements, which has application in the reactor decay heat calculations. A method has been developed to calculate microscopically mass and charge distributions of spontaneous fission yields.

The main research activities in the Institute of Physics (IOP) during the year 2015–16 were focused on theoretical and experimental areas of Condensed Matter, High Energy, Nuclear, Atomic and Accelerator based physics and other related subjects.

In HRI, significant contributions have been made in materials like silicene, germanene and a class called Weyl semi metals which all exhibit topological effects in one form or another. Progress has been made by HRI in quantifying quantum coherence, in handling quantum uncertainties and in the study of monogamy of quantum correlations and quantum information transmission networks. The dark matter issue has also been approached from the neutrino angle. The astrophysics group have come up with an intriguing prescription for detecting the spin of a black hole from the accretion spectrum. HRI has remained focused on several directions of research in string theory.

NISER continued to carry out research in the areas of Cosmology and Galaxy formation, Black holes and String theory, Particle Physics and Quark-gluon Plasma, Hadron Spectroscopy, Statistical Mechanics and Soft matter, Quantum Optics and Non-linear dynamics, Magnetism and Superconductivity and several other areas of Condensed Matter Physics.

Synchrotrons and their Applications

The Raja Ramanna Centre for Advanced Technology (RRCAT) has set up Synchrotron Radiation Sources Indus-1&2 for carrying out advanced basic research.

During the year, both the synchrotron radiation sources, Indus-1 and Indus-2, were operated round-the-clock. Indus-2 was operated at beam current up to 200 mA and 2.5 GeV energy while Indus-1 was operated at 100 mA current and 450 MeV energy. The Indus-2 storage ring is operating with a highly stable electron beam. The improved performance of the Indus synchrotron radiation sources is reflected in a substantial increase in the number of users. The user experiments have doubled from 190 in 2013 to 390 in 2015. The availability of 13 beamlines in Indus-2 for user experiments was about 4370 hours.

Two planar undulators U1 and U2, one for Atomic, Molecular and Optical Science (AMOS) beamline and another for Angle Resolved Photoelectron Spectroscopy (ARPES) beamline, installed last year in the Indus-2 storage ring, were commissioned. Images of the synchrotron radiation beam emitted from the undulator and its neighboring bending magnet were recorded using a fluorescent screen beam viewer.

An APPLE-2 (Advanced Planar Polarized Light Emitter-2) type undulator made of permanent magnet blocks was installed in the long straight section, LS-5, of Indus-2, after carrying out offline tests.



APPLE-2 undulator installed in LS-5 along with the compatible vacuum chamber and other peripherals

A beam based alignment system has been installed in Indus-2 to minimise the closed orbit distortion of its orbit. A control system for beam based alignment was developed to control 72 active shunt power supplies. Prototype processing electronics using an embedded web server for monitoring the beam position monitors of the booster synchrotron at a higher repetition rate of 1 kHz was developed.

An upgraded version of horizontal and vertical stripline kicker magnets has been developed. These kicker magnets have been installed in the Indus-2 ring. With improved features like higher transverse shunt impedance, optimum coupling impedance and higher power handling capacity of up to 125 W, these kickers will enhance the performance of the transverse bunch-by-bunch feedback system being used to suppress coupled bunch instabilities. Upgrades were carried out in the Indus-2 Low Conductivity Water (LCW) plant which has resulted in achieving temperature stability of better than ±0.7°C as compared to the earlier stability of ±1°C of the supply cooling water. This has helped in improving the stability of Indus-2 operation.



Inside view of the new microtron

A new, improved 20MeV injector microtron has been developed for Indus synchrotron radiation source facility of RRCAT. The beam was accelerated up to 22nd orbit where the beam energy is 20 MeV. A beam current of 30 mA was measured in the 22nd orbit.

The Indus synchrotron radiation sources, a national facility, are being used by scientists and students from various universities, national institutes and research laboratories all over the country. A soft x-ray reflectivity beamline (BL-3) has been commissioned recently, which is the 13th beamline on Indus-2 and operates in the energy range of 100 eV to 1500 eV.



Two-axis high-vacuum compatible goniometer with x-y-z sample manipulation stage of the soft x-ray reflectivity beamline (BL-3)

Some of the operating beamlines have been equipped with advanced user facilities. A Closed Cycle Cryostat (CCR) based cooling system and a high temperature stage have been installed in the image plate of the Angle Dispersive X-ray Diffraction (ADXRD) beamline (BL-12). A new high temperature stage (upto 1100 K) has been commissioned which can be used both in the scanning Extended X-ray Absorption Fine Structure (EXAFS) beamline (BL-9) as well as the dispersive EXAFS beamline (BL-8). A Fourier Transform Infrared (FTIR) system with a closed cycle cryostat has been installed at the photo-physics beamline at Indus-1 (BL-5).

Using the x-ray lithography beamline (BL-7) of Indus-2, X-ray lenses for use in the hard X-ray regime have been fabricated in a new antimony free material, code named SUEX. A focal beam diameter with Full Width at Half Maximum (FWHM) of 0.8 micron was obtained when this lens was used at the Diamond Light Source, UK. Next, Fresnel Zone

Plates (FZP) with a focal length of 25 mm have been fabricated in Polymethyl Methacrylate (PMMA) on ultra-thin titanium film using 30 keV electron-beam lithography. These have been designed for focusing of capillary discharge based argon X-ray laser (wavelength: 46.9 nm).

Work on the installation and vacuum testing of various components for beamlines and frontends has also been carried out. A compact two stage differential pumping system (length 415 mm) has been developed, tested and installed on the BL-3 of Indus-2 to provide a windowless transition between high and low vacuum regions of the beamline.

At BARC, crystal structures of various important proteins were determined using Protein Crystallography beamline PXBL21 of Indus-2 and the structure data were deposited in Protein Data Bank database. An in-situ low temperature liquid nitrogen (77 K) & liquid helium (4.2 K)) infrared absorption/reflection facility has been setup at the IR beamline at Indus-1 SRS.



Low temperature experimental setup at the IR Beamline at Indus-1

Fusion and Other Plasma Technologies

At the Institute of Plasma Research (IPR), the Steady-state Superconducting Tokamak-1(SST-1) has completed the 1st phase of upgradation with successful installation and integration of all its First Wall components.

For Aditya-Upgrade, the decommissioning of the existing machine was done with accurate documentation for understanding and rectifying the problems faced before in machine operation. The



SST-1 Vacuum Vessel with installed First Wall Components

new circular vessel along with the tested and refurbished Toroidal Field coils have been integrated to the upgraded machine.

The new SS grill antenna designed for launching Lower Hybrid Current Drive (LHCD) power has been fabricated and installed in SST-1. The 1:1 prototype Edge Localized Coils for the Joint European Torus (JET) at United Kingdom has been successfully realized. State-of-the-art copper sheathed MgB_2 strands are now manufactured in-house in several meters of single length. Tungsten was studied for radiation damage and fuel retention.

Facilitation Centre for Industrial Plasma Technology (FCIPT) is dissecting the various plasma phenomena so as to exploit them for potential societal benefits through short time projects. The Centre for Plasma Physics, Guwahati took lead in different programs like development of a neutron source based on inertial electrostatic confinement fusion scheme.

At BARC, a novel technique has been developed for preparation of specific composition of Dysprosium titanate material for high temperature application. An innovative space saving online fabrication facility has been set up for the fabrication of long length Cable In Conduit Conductors (CICC). 200m long CICC on a bobbin has been fabricated in the facility.

Chemistry

BARC has developed the material technology for the anode (nano lithium titanate) and cathode (nano lithium iron phosphate carbon



Quartz certified reference material

composite) materials of lithium ion battery. BARC in collaboration with National Physical Laboratory, New Delhi has prepared the first quartz certified reference material of the country following the international guidelines.

A high end two-dimensional infrared spectrometer for advanced studies in chemistry and biology was developed. NCCCM, Hyderabad has been validated as a supplier by European Commission for homogeneity, stability and characterization of major element content in food and trace element content. Time resolved laser induced fluorescence spectrometer, for studying speciation of lanthanides and actinides, with different complexing agents, sorbents and host matrices, has been installed and commissioned. A new type of biocompatible and task-specific hydrogel beads were synthesized for controlled and sustained delivery of the anticancer drug doxorubicin.

At TIFR, a technique was developed to determine the conformation of membrane proteins in physiological conditions using Surface Enhanced Raman Spectroscopy.

Different architecture of nanomaterials have been developed at SINP which include tunable gold nano-flowers, silver nano-wires, selenium nano-spheres etc and successfully used in effective drug delivery and bioanalytical detection. The nuclear chemistry group along with the international collaboration working at GSI, Germany independently confirmed new element 117 and discovered new isotope ^{266}Lr.

NISER continued to impart high quality undergraduate and postgraduate level of knowledge to students coupled with cutting edge research activity in the School of Chemical Sciences.

Biology

An advanced and economic Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) Cascade based tool was developed at BARC and used for genome editing and gene silencing in Mycobacterium tuberculosis (Mtb).

Advances were made at TIFR in the field of malaria research with the identification of a protein that could be a candidate for a malaria vaccine. At the National Centre for Biological Sciences, advances were made in understanding cellular organization and signaling, genetics and development and in understanding ecological processes across multiple scales.

A two color Single molecule FRET imaging set up for real time monitoring of complex macromolecular systems has been developed at SINP. Research in the area of Disease Biology continued to focus on two major disorders, the haematological and neurological. New initiatives were taken to study epigenetic regulator proteins and nuclear lamins and their involvements in disease processes.

Materials Science

Several functional and energy conversion ceramics such as beta-alumina, BeO and Solid Oxide Fuel Cell (SOFC) ceramics have been fabricated at BARC. Ni-Cr based alloys were indigenously developed for high burn up clad applications. Composite fibres have been prepared

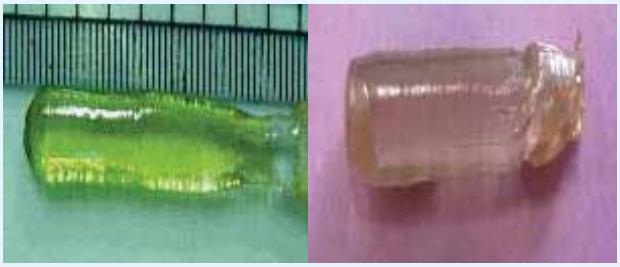
by dispersing Carbon Nanotubes (CNTs), developed in-house, in polymeric fibres with improved toughness. Aluminide coating on Ni-Cr-Fe based superalloys was developed for high temperature application. A methodology for joining stainless steel 304L to Zircaloy-4, based on a novel Ga-assisted diffusion bonding technique was developed using Ni and Ti inter-layers.

At IGCAR, in the materials development front, a high chromium oxide dispersion strengthened ferritic steel clad tube has been realised and use of zirconia as an alternate dispersoid to yttira were explored. Non-contact electromagnetic acoustic transducers and eddy current array sensor probes were developed for detection of sub-surface defects in austenitic stainless steel. The electron back scattered diffraction tomography, a state-of-the-art technique for study for 3-dimensional grain morphology and orientation was established.

For better understanding of basic sciences, activities carried out were: synthesis of novel Os_2C phase using laser heated diamond anvil cell, study on thickness controlled proximity effects in C-type anti ferromagnet / super conductor hetero structure, deep level transient spectroscopic studies for characterisation of defects in detector grade germanium, investigation of the thermal and radiation stability of Y-Ti-O nanopartilces in oxide dispersion strengthened alloy and Raman spectroscopic study at the sub-diffraction limit using coupled system with surface probe microscope.

Different samples of indigenously developed (with collaboration of BARC and NFC) Ni-Cr alloy have been irradiated with proton beam from the Variable Energy Cyclotron. A comparative study has been done with the imported alloy to assess the radiation resistant capability. Microstructural characterisations of different deformed and irradiated alloys were carried out using X-ray Diffraction and Field Emission Scanning Electron Microscopy.

At RRCAT, a new indigenous process has been developed to produce Nb pipe/316L stainless steel flange joints suitable for use in low-beta SCRF cavities. An experimental facility based on the resonant ultrasound spectroscopy technique was designed and developed for the measurement of the elastic constants materials at low temperatures (2-300 K) and in high magnetic fields (up to 70 kOe). Several high-quality crystals have been grown by different techniques for various photonic applications. These include Er and Cr co-doped YVO_4 for lasers, Cr doped Strontium Barium Niobate (SBN) crystals for pyroelectric infrared sensors and trans-stilbene for scintillation detectors.



High optical quality crystals grown using different techniques (Left) Cr co-doped YVO_4, (Right) Strontium Barium Niobate (SBN)

A key achievement in materials research at TIFR was the engineering and assembly of atomically thin layers of grapheme allowing them to be used for novel energy and sensing applications through doping. Also, an ammonia sensor-which can detect both ionized and un-ionized ammonia in sub-pico molar level, was developed using fluorinated graphene.

Cancer Research

ACTREC, located at Navi Mumbai, comprises of two sub-units the Clinical Research Centre (CRC), 111 bed Research Hospital that focuses on research and treatment of cancer patients and the Cancer Research Institute (CRI) that focuses on basic and applied research on cancer. During the year, the CRI's 20 Principal Investigator led laboratories remained engaged in a large number of basic and applied research projects.

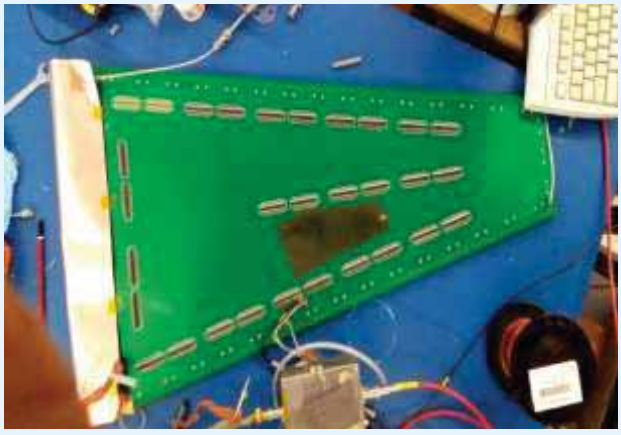
A non-toxic herbal radioprotector BRM was developed at BARC for enhancing the radio-sensitivity of human breast cancer cells. Radio-protecting technology for lungs and other organs was transferred to the private domain for clinical trials as a prophylactic/therapeutic radioprotector and an adjuvant in radiotherapy. An indigenous synthesis of the precursor of ^{18}F-FLT, a tumor imaging agent has

been developed for making the PET tracer at a cheaper cost for assessing tumor proliferation, its staging and identifying the treatment outcome of patients.

INTERNATIONAL RESEARCH COLLABORATIONS

The experimental data on piping components and systems generated by BARC has been selected by Organization for Economic Co-operation and Development-Nuclear Energy Agency for the benchmark exercise on Metallic Component Margins under High Seismic Loads. Corrosion Loop Experiment is designed to study the phenomenon of Irradiation Assisted Stress Corrosion Cracking in LWR operating conditions for installation in Jules Horowitz Reactor, France as a part of Indian In-kind contribution in the JHR Programme.

Two large-size advanced types of gaseous detectors i.e., Gas Electron Multiplier (GEM) and Resistive Plate Chamber (RPC) have been built and tested successfully at VECC during 2015. The GEM chamber of trapezoidal shape (length 80cm and larger width of 40cm) is a real-size prototype module built for the Compressed Baryonic Matter (CBM) experiment in the upcoming FAIR facility at Darmstadt, Germany.



Large size-GEM chamber at VECC

The bulk viscosity of the hadronic medium has been evaluated along the chemical freeze-out curve of the QCD phase diagram. Elliptic and triangular flow for photon and their correlation with initial ecentricity measures have been studied. Pb+Pb collisions at Future Circular Collider at 39 TeV/A energy have been simulated.

As a part of the upgradation programme of ALICE, VECC in collaboration with BARC and BEL-Bangalore has built a prototype sampling calorimeter module. The module consists of alternate layers of Tungsten converters and Si-pad detectors. The prototype has been tested successfully this year at CERN.

At RRCAT, a 20 kW, 499.75 MHz pulsed solid state amplifier and its 5 kW prototype amplifier system were designed and developed and shipped for use in the CLIC facility at CERN, Geneva. A 30 kW solid state amplifier at 650 MHz has been designed and developed for the international collaboration program under Indian Institutions Fermilab Collaboration (IIFC).



The 20 kW, 499.75 MHz solid state amplifier developed by RRCAT for the CERN CLIC facility

For the Large Hadron Collider and Compact Muon Solenoid (CMS) Experiment, TIFR has participated in data collection, data quality monitor and data analysis. Also, several analyses based on Run I data are being collated. The CMS Collaboration also pursued a comprehensive programme of Phase I detector upgrades. An important milestone in building an electrically working prototype for the Belle II Silicon Vertex Detector (SVD), was achieved. For the International Centre for Theoretical Sciences, the new campus at Shivakote, Hesaraghatta Hobli in north Bangalore was inaugurated in June 2015.The in-house research areas at the Centre grew successfully in various disciplines.

International Collaborations were continued at SINP with CERN in ALICE and CMS experiments and with SNOLab in PICASSO experiment. The two experiments, ALICE and CMS collected data with a very high efficiency and members of SINP took active

parts in the data collection, data analysis and extracting important physics results from these experiments.

The Institute of Physics (IOP) remained actively involved in the International Collaborations with CERN (Switzerland), BNL (USA), ANL (USA), GSI (Germany) and other laboratories abroad. The Institute is also participating in various research activities related to India based Neutrino Observatory.

For the Indo-Italian program on investigation of local structure and magnetism properties of, most of the experimental part has been completed at the Institute of Plasma Research (IPR). For the Indo-UK DST program Plasmonics based CZTS Solar Cells, IPR has successfully demonstrated that silver nanoparticle arrays are suitable as back reflectors and performed the MD simulation for the nanoparticle self-assembly.

IMSc continued the joint projects with International Institutes on India based Neutrino Observatory (INO) and DINO (Darkmatter at INO), EU-FP7 Indo-European Network on Mathematics in Health and Disease and Belle & Belle II Collaboration.

ITER-Project

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.

Total 14 out of 15 Procurement Arrangements (PA) have been signed. Pre-procurement activities for remaining PAs are going on. Eleven major contracts have been signed till date for the manufacturing of ITER components. Good progress is made at the manufacturing site and some components are delivered to ITER and also to other Domestic Agencies sites. Quality audits were done regularly at the manufacturing sites by both ITER-India and ITER Organization teams. Good progress has been achieved and various other R&D activities necessary are being done at the ITER-India laboratory, which will then be transferred to the vendor site after due process and approval.

Cryostat Base section Tier-1 manufacturing is completed and delivered at ITER site at France and manufacturing of Lower Cylinder is in progress. Manufacturing of first Lot of Cooling Water piping is completed and delivered at ITER site, France. Manufacturing of Acceleration Grid Power Supplies (AGPS) for SPIDER facility has been completed and will be shipped soon to Padova, Italy. Manufacturing of Prototype Grid for DNB Accelerator and for Prototype Post Insulators has been completed.

Prototype Cryoline installation at ITER-India lab is completed and qualification test is in progress. Vacuum vessel for Diagnostic Neutral Beam (DNB) is successfully installed and commissioned with all the interface needs for Operating components at ITER-India lab. Design and procurement activities for Gyrotron Test Facility at ITER-India lab is in progress. Preliminary Design of Cryostat Instrumentation is nearing completion.



Prototype Cryoline Installed at ITER-India Laboratory

For the Test Blanket Module (TBM) Program, Lead-Lithium R&D activities are focused towards the development of precise diagnostics for measurement of Pb-Li pressure, flow rate, and Pb-Li level in various tanks etc. for prolonged operation. In this connection, a sensitive flowmeter using water cooled Hallbach magnet has been developed, calibrated and successfully tested in Pb-Li environment. Pb-Li production system has also been developed and trails run have been started for indigenous development of Pb-Li eutectic alloy.

OTHER ACTIVITIES

Research Education Linkages

The Department of Atomic Energy supports the research education linkages mainly through

grants-in-aid to institutes of national eminence, funding of extra-mural research, DAE-UGC consortium for scientific research and others.

Research reactor Dhruva at BARC continued to serve as a national facility for neutron beam research. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research. The Variable Energy Cyclotron were utilized by in-house experimental groups of VECC, as well as by experimentalists from several national laboratories and academic institutions for conducting experiments in the various fields of research. Nuclear counting and calibration facilities of IGCAR were extended to various institutions involved in BRNS projects, researchers and industries in the southern region. The Indus synchrotron radiation sources, a national facility, was used by scientists and students from various universities, national institutes and research laboratories all over the country.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

The Homi Bhabha National Institute (HBNI) accredited as a deemed to be university by Ministry of Human Resource and Development (MHRD) completed ten years of its existence. HBNI continued its academic programmes by offering various courses with its eight Boards of Studies namely as Chemical Sciences, Engineering Sciences, Health Sciences, Life Sciences, Mathematical Sciences, Physical Sciences, Strategic Studies and Undergraduate Studies. Degrees and Diplomas including Ph.D. were awarded to students. HBNI continued to strengthen its linkages with premier research and academic institutes in the country and abroad.

Training

Selection of trainees under Orientation Course for Engineering Graduates & Science Post-Graduates (OCES) and DAE Graduate Fellowship Schemes (DGFS) at BARC were pursued with high standards. The Continuing Education Programme QUEST offering advanced courses to DAE staff located in Mumbai and to HBNI students continued. The One year post-M.Sc. Diploma in Radiological Physics course continued to meet the mandatory trained manpower requirement of radiation safety professionals in medical, industrial, research and agricultural applications of radiation. BARC scientists are actively engaged in teaching, project handling, conducting laboratory practical and seminars for the BARC OCES programme. Facilities were provided for practical training and executing projects for post-graduate students of various universities. National Training Course on “Physical Protection of Nuclear Material and Nuclear Facilities” for security personnel and a 2 week National Training Course on “Design & Evaluation of Physical Protection System for Nuclear Material and Nuclear Facilities” were held at Mumbai.

At IGCAR the Training programmes for Trainee Scientific Officers (TSOs) and doctoral programmes in the frontier areas of engineering & basic sciences for the inducted Research Scholars were continued. The employees, who are pursuing higher studies under the aegis of Homi Bhabha National Institute also underwent coursework at the Training School.

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

Human resource development activities at RRCAT were continued to be enhanced by extending the available research facilities for training of university students in the areas of accelerators, lasers and their applications. A large number of students carried out research work for their Ph.D. degree under the framework of Homi Bhabha National Institute. Opportunities were also provided to M.Tech / M.Sc. students to carry out their one-year / six-months project work towards partial fulfilment of their degrees.

The Administrative Training Institute (ATI), with the motto “Prashikshaneshu Dakshprayate – Training Empowers” made its presence at national level by bagging the National Award for Excellence in Training, 2015 in the Management of Training

category from Department of Personnel and Training, Government of India and UNDP. During the year, ATI offered wide range of programmes starting from induction to post retirement and periodic in-service programmes, subject specific workshops ensuring depth and range. ATI has organized over 700 programmes and has covered over 19,000 participants till now.

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 (HQs) including multiunit sites. Training and development initiatives covered the competency development for fresh as well as experienced manpower across hierarchy. Besides, well developed internal training programs and customized management development programs with the involvement of professional training institutes and experts were organized for higher levels. Harmonious employee relations have been 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 is in operation. In addition to this, award scheme for encouraging employees to work towards achievement of organization goals in efficient and effective manner is in place in NPCIL.

All the aided institutions such as SINP, TMC, IOP, HRI and IMSc of DAE continued to provide training by conducting various training programmes for the students and the research scholars.

SPONSORED RESEARCH

Promotion of Extra-mural Research in Nuclear Science

The Board of Research in Nuclear Sciences (BRNS) continued to award 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) for inducting Graduate Level students doing M.Tech. at the IITs, Visiting Scientists programme for promoting short term in-house interactions amongst senior level experts and the Raja Ramanna Fellowship for reasonably long-term involvement of the eminent scientists and engineers in the various ongoing programmes of the Department were continued. The Homi Bhabha Chair was instituted to avail the honourable services of Scientists and Technologists who have distinguished themselves at national and international levels.

During the year 2015-16, 214 new research projects were sanctioned till December 2015.

Under DAE Graduate Fellowship Scheme (DGFS), fellowship was offered/awarded to M.Tech. students studying in different IITs. New students were inducted under DGFS-Ph.D programme.

Financial support to the tune of ₹ 230 Lakh was extended for conducting 121 seminars, which were conducted by professional organizations on various topics of relevance to DAE. Out of these, fourteen symposia were solely organized by the DAE fraternity and they were fully funded by BRNS. About 73 fellowships were offered under the Raja Ramanna Fellowship Scheme (Senior Scientists Scheme) & 3 Homi Bhabha Chairs were awarded.

Promotion of Mathematics

The National Board for Higher Mathematics (NBHM) continued to provide 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 continued to be in charge of the Mathematics Olympiad activity for talented young students at higher secondary (the plus two) level. This year six-member team secured 1 Silver medal and two Bronze medals and three Honourable Mentions at the 56th International Mathematical Olympiad held at Chiang Mai, Thailand.

NBHM continued to conduct Madhava Mathematical Competition for the undergraduate students. NBHM gave grants to various mathematical centres such as The Chennai Mathematical Institute, The Kerala School of Mathematics, Calicut, The Institute of Mathematics and Applications, Bhubaneswar and the Bhaskaracharya Pratishthana, Pune, engaged in activities of promoting higher mathematics. The Board provided scholarships and fellowships to the students, selected through nationwide competitive tests, to pursue studies at masters and Ph.D. levels.

This year NBHM has sponsored 51 delegates for participation in the prestigious International Congress of Industrial and Applied Mathematics (ICIAM) - 2015 event, held in Beijing, China during August 10-14, 2015.

GRANTS-IN-AID

Grants to Aided Institutions

The aided institutions of the DAE are an integral part of the Department. The Department has nine 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. University of Mumbai & Department of Atomic Energy Centre for Excellence in Basic Sciences (UM-DAE-CBS) has been recently granted the status of Aided institution of the Department of Atomic Energy w.e.f. 1st January, 2016.

The funds (Plan & Non-Plan) allocated (in crores) to these Aided Institutions by the Department of Atomic Energy during the financial year 2015-16 were TIFR - ₹ 666, TMC-₹ 540, SINP-₹ 119, IOP-₹ 36, IMSc,-₹ 49, HRI-₹ 39, IPR-₹ 630, AEES-₹ 72, NISER-₹ 91 and HBNI-₹ 4.

Grants to Cancer Hospitals

The Department of Atomic Energy (DAE) is releasing grant to Dr. B. Barooah Cancer Institute (BBCI), Guwahati through Tripartite Agreement (which was signed among DAE, the North Eastern Council (NEC) and the Government of Assam). This hospital is a Regional Cancer Centre (RCC) for cancer treatment and control in the North Eastern Region (NER). During the year 2015 – 16, an amount of ₹12.36 crore has been released to the institute by the Department. The Department also extends financial assistance to Cancer hospitals located in other parts of the country. The budget provision for the year 2015-16 for such partial financial assistance is to the tune of ₹ 20.00 crore.

Olympiad Programme

The Homi Bhabha Centre for Science Education (HBCSE) successfully hosted the International Physics Olympiad. Several teacher professional development workshops were conducted in mathematics and science, including one for physics teachers from Karnataka. In the learning sciences laboratory, a multi-touch interface was developed.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The highlights of the Information Technology Application Development at IGCAR included Integration, Testing & Commissioning of BHEL steam water system / turbo generator Simulator; Deployment of Wireless Sensor Network for Radiation Monitoring; 3D Modeling and Animation of Power manipulator and Containment Box of Pyroprocessing R&D facility; Advanced IT Enabled Customizable Knowledge Management Portal for IGCAR and Development of continuous air monitoring system.

Software for RRCAT Secure Cloud Drive has been developed, deployed and released to senior scientists. The facility enabled access to large files over internet with necessary data security mechanisms in place. Workflow based software for activity management related to Indus upgradation/ maintenance/ shutdown has been developed and

deployed on RRCAT Infonet for use by all concerned officials working for Indus operation and maintenance.

Various Computerized Based Systems (CBSs) were introduced as part of implementation of IT at NPCIL.

TECHNOLOGY TRANSFER

A total of 26 technologies have been transferred till December 2015 to 40 Parties. Eight new technologies introduced into public domain during the year were Optical spectrometer, Compact Full Range Vacuum Gauge with Electronic Control Unit (FRVG), ANUSPECT Gamma Spectrum Analysis software, Peripheral Pulse Analyzer, Hydrogen Sulfide Sensor, Compact SMPS based Sputter Ion Pump Power Supply, Biopesticide Based on Bacillus Thuringiensis Subsp. Kenyae HD-549 and Partially hydrolyzed guar gum for dietary fiber application.

Licenses for the 5 technologies that were renewed during the period were for "Rig Testing of Combined Particulate & Iodine Filters", "Production of $CaSO_4$: TLD Card & Production of Dy. Doped Calcium Sulphate TLD Powder", "Auto TLD Badge Reader", "Spectroscopy Amplifier" & "Digital Pocket Radiation Dosemeter (DIGIDOSE)" and Renewal of MoU for incubation of Biodegradable and Edible films for Food and Pharmaceuticals.

Solar Energy driven portable domestic Brackish Water Reverse Osmosis (BWRO), Stand-alone solar Photovoltaic (PV) driven battery-less Ultrafiltration system and Bicycle mounted water purification (RO/UF) unit driven by hybrid power system were transferred to private entrepreneurs for commercial deployment.

COLLABORATIVE PROGRAMMES

Collaboration with Industry under Incubation included Incubation of Development of a Radioprotector Drug technology, Development of Diamond Waste Powder (Uniform Size Particles) Processing Methodology and Development of Fluoride Removal Reagent.

In order to promote technologies developed by BARC for rural populace, establishment of DAE Technology Display & Dissemination Facility (DTDDF) centres all over India are proposed under XII Plan in collaboration with educational institutes. Out of 24 proposals received from all over India, preliminary meetings and site visits to 7 institutes have already been concluded. Further, MoUs with two institutes have been finalized.

SOCIETAL INITIATIVES

Four agreements were approved for signing with Companies/ Organisations and Individuals to promote rural entrepreneurship with BARC technologies under Advanced Knowledge & RUral Technology Implementation (AKRUTI) Tech Pack. The agreements provide a perpetual license for exclusive rural deployment of the technologies like Foldable Solar Dryer, Domestic Water Purifier, Soil Organic Carbon Detection and Testing Kit, Nisargruna, Vibrothermal disinfestor, Solar BWRO, Dip N Drink Membrane Pouch, Litchi Preservation and Banana Tissue Culture.

INTELLECTUAL PROPERTY RIGHTS

During the calendar year 2015, ten new inventions and one national phase entry were reviewed for the patentability. DAE filed eight new patent applications which includes two applications under PCT (Patent Co-operation Treaty), five Indian and one application in USA.

Seven of the previously filed patents have been granted to the Department during the year. These includes two each in India & USA and one each in Canada, Europe & South Africa.

Apart from Patents, DAE has also filed 200 Trademarks applications during the period. These applications were filed under various Classes and consists of 49 logos, 31 word marks which include the acronyms of DAE and its 29 Units and the DAE slogan "Atoms in the Service of the Nation".

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 net profit after tax (PAT) for the year 2015-16 is about ₹ 2300 Cr. The net profit after tax for previous FY 2014-15 was ₹ 2201 Cr. NPCIL bonds continued to be rated at AAA (Highest Safety) by CRISIL and CARE.

Uranium Corporation of India Ltd.

The overall performance of the company during the year 2014-15 was satisfying. The total income of the Company during the year 2014-15 was ₹ 890.24 Cr. (Previous year ₹ 814.30 Cr.). The profit before tax during the year 2014-15 was ₹ 11.34 Cr. Performance of the Company in terms of MoU signed with DAE is expected to be "Good".

Indian Rare Earths Ltd.

During the year 2015-16, the Gross Sales Turnover anticipated is ₹ 434.64 crore (provisional) against ₹ 420.97 crore of previous year. Anticipated loss in 2015-16 is ₹ 22.67 crore (provisional) compared to profit before tax of ₹ 3.15 crore in 2014-15.

Electronics Corporation of India Ltd.

Against the MoU target of ₹ 1620 crore each for production and net sales, the Company achieved a production of ₹ 721 crore and a net sale of ₹ 690 crore upto December 2015.

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 also actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combating Nuclear Terrorism and India's own Global Centre for Nuclear Energy Partnership (GCNEP).

Cooperation at the multilateral level in peaceful uses of nuclear energy was also promoted through the European Organisation for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER), and the Nuclear Energy Agency of OECD.

Significant achievements were made in India's bilateral international engagement in civil nuclear cooperation with major partners. The fuel supply arrangements with Canada, Kazakhstan and Australia have been made which will bolster energy security by supporting the expansion of nuclear power in India. Civil nuclear cooperation with neighbouring partners Sri Lanka, Bangladesh & Mongolia was also promoted

In an important legislative development, the passage of the Atomic Energy (Amendment) Act, 2015 by the Parliament in December 2015 created the legal basis to enable NPCIL to enter into joint ventures with other Indian PSUs, thus paving the way for new equity to meet the additional funding requirements for expanding India's nuclear power programme and augmenting the nation's nuclear power generation capacity.

For GCNEP, the Phase-I construction activities were under progress. Construction work is in progress for SNSS Building in the Campus site and Wing-A of Guest House in the Township site. GCNEP continued to conduct national and international training programs. In terms of international collaborations, in November, DAE and Department of Energy and Climate Change (DECC), United Kingdom, announced the signing of a Memorandum of Understanding (MoU) between the two countries concerning cooperation on the Indian Global Centre

for Nuclear Energy Partnership. The agreement will provide a framework for further cooperation. A MoU has been signed with USA, Russia, France, UK and the IAEA.

NPCIL continued to participate in various programmes of World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), Institute of Nuclear Power Operations (INPO) and World Nuclear Association (WNA) to enhance the safety and reliability of its nuclear power plants.

CRISIS MANAGEMENT

During the year 2015, India not only ensured its participation in all IAEA conducted International exercises (popularly known as ConvEx exercises) but also successfully met all the convention requirements identified under the Early Notification and Assistance Conventions (ENAC). India's participation was facilitated by CMG of DAE and its Emergency Control Room (ECR) which is also the National Contact Point for nuclear and radiological emergency.

India's effective response during ConvEx-1a Exercise conducted on 28.07.2015 was duly acknowledged in official exercise report published by IAEA.

ConvEx-2a exercise conducted in March, 2015 met all the requirements of IAEA's Convention on Early Notification. India participated in ConvEx-2b exercise in August, 2015 and offered its assistance in real time to the affected country. All the necessary arrangements were made within the stipulated time-period. India also participated in the International Exercise ConvEx-2C on 15.12.2015 and offered its assistance to all requesting countries in their requested domains. This was the very first time that India participated in ConvEx-2c Exercise.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and heavy water plants periodically carried out a variety of emergency exercises.

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.

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.

NATIONAL SECURITY

BARC continued implementation of the necessary research and development as well as manufacturing activities required for national security.

VIGILANCE

During the year, the Vigilance section of DAE carried out various activities. As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" was observed in DAE during October 26-31, 2015 on the theme of "Preventive Vigilance as a tool of Good Governance". During the week, various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were held in which officers and staff of DAE actively participated. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resource facilities of BARC is equipped with the state-of-the-art infrastructure and technology to provide seamless access of information to BARC and DAE scientists and engineers in their day-today R&D activities. During the year, new books and e-books, standards, codes, patents and scientific and technical reports

and bound periodicals were added to the collection. Access has been provided for more than 3500 online journals through Lakshya and remote access facility for more than 1500 Science Direct Online journals to more than 750 scientists and engineers of BARC.

Designing, content management and maintenance of various knowledge portals namely BARC official website in public domain, online information gateway for e-resources Lakshya, library portal Saraswati and SIRD portal on BTS have been carried out. To extend the online digital resources access in 24x7 mode from Home, Office or Anywhere (HOoA), a cloud based facility has been evaluated and tested. A new webpage with add-on smart search facilities has been developed for eBooks at Lakshya.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of public outreach programmes to alleviate unwarranted fears, to address apprehensions harboured against nuclear energy and to keep the public abreast with the contributions of atomic energy towards societal welfare. Towards achieving this, DAE participated in and organised a host of events comprising exhibitions, seminars, workshops, essay and quiz contests in different regions of the country which were well received by the target audiences.

During the year, DAE participated in and organized several events such as the 103rd Indian Science Congress at Mysuru; "Indian Technology Congress 2015" at Bengaluru; "Vigyanene Tu Kausalam" at Varanasi; The International Conference on Science, Technology and Applications on Rare Earths (STAR-2015) at Trivandrum; a two day seminar on "Applications of Radioisotopes and Radiation Technology in Agriculture, Industry & Healthcare" at Bhopal; "11th Food & Technology Expo & Concurrent Show – Government Achievement & Schemes Expo 2015" at New Delhi; a seminar on "Benefits of Nuclear and Material Sciences in day to day life" at Mysore; National Conference on Analytical Science and Technology was held at Munnar; "Parmanu Urja Janjagruti Abhiyan" at Jabalpur; "Thorium Energy Conference 2015 (ThEC2015) at Mumbai; The 35th India International Trade Fair 2015 organised by the ITPO at New Delhi; 9th National Seminar on Peaceful Uses of Atomic Energy organised by United Schools Organisation of India (USO) at New Delhi; The 7th edition of AGROVISION held at Nagpur and many others.

The 27th All India Essay Contest on Nuclear Science and Technology was held in October 2015. A total of 307 essays were received out of which the authors of twenty nine were selected for making an oral presentation at Mumbai.

In addition to above events, several public awareness lectures/workshops on atomic energy



Participants of the 27th DAE All India Essay Contest

were conducted by DAE in different regions of the country throughout the year. Many of these were in the vernacular medium.

NPCIL has adopted multipronged communication strategy on public awareness. NPCIL's public outreach includes regular interaction with the public living nearby Nuclear Power Plants/Projects. It also includes visits of villagers, students, media persons and other members of public to nuclear power plants and 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.

NPCIL has been scaling up its public outreach programme manifold in a structured manner through a multi-channel approach and several innovative public awareness programmes have been conceived and implemented across the nation in this regard. Use of exhibitions, seminars, scientific meets, distribution of single-sheet publications, street plays, TV commercials, advertisements in print and electronic media, radio jingles, innovative comic books and animated films in vernacular languages, enhanced interaction with

press and media, e-public awareness campaigns to name a few that were adopted to scale up outreach activities.

NPCIL has also been partnering with several expert agencies like National Geographic Channel, National Council of Science Museums, Tamil Nadu Science and Technology Center, PR agencies, PIB and Department of Science and Technology etc.

NPCIL has set up permanent nuclear galleries at Science Centres in Mumbai and New Delhi and nuclear gallery set up at Chennai is in advanced stage of completion. NPCIL is also in the process of setting up of nuclear galleries at other science centres across the country to allay the apprehensions of public on nuclear power and other associated aspects.

HWB continued its commitment towards societal responsibility by conducting public outreach



Dr. Jitendra Singh, H'ble MoS, PMO along with Secretary, DAE and CMD, NPCIL during inauguration of Hall of Nuclear Power at National Science Centre, New Delhi

programmes through the employees of various Heavy Water Plants.

At RRCAT, under the Public Outreach Programme, several events were organized at various schools and colleges in Indore and in nearby cities and towns like Ujjain, Mhow, Dewas and Khargone. The events included an exhibition of specially developed working models, posters describing the DAE programs and R&D activities of RRCAT, lectures and interaction sessions with RRCAT scientists.

Public awareness programmes were continued by AMD in various cities as well as in remote field areas at 66 venues and a total of 125 events were organised for students, teachers and general public on the occasion of Anuvigyan week.

The Institute of Physics (IOP) conducted Public Awareness Programmes by spreading the awareness about the basic science among common people.

Towards inculcating scientific interest and temperament among students at all levels, GCNEP organized eight such programs in the vicinity of Bahadurgarh where GCNEP is being set up.

SOCIAL WELFARE

Corporate Social Responsibility

From the inception of nuclear power programme in the county, the units of NPCIL have been implementing numerous social welfare activities for the benefit of local population. With the issuance of Department of Public Enterprises (DPE) guidelines on CSR for Central Public Sector Enterprises (CPSEs) and enactment of the Companies Act 2013, NPCIL has re-invigorated the CSR programme in right earnestness.

Under CSR programme, NPCIL has taken up the activities in the five identified thrust areas as education, healthcare, infrastructure development, skill development and sustainable development. Support to education was extended through implementation of projects such as construction of school buildings and class rooms, scholarships to students and development of Anganwadis. Educational items were provided to the school children for motivational purpose. Based on need, transport facility was provided for the school children and teachers.

Under healthcare category, primary health centres, mobile medical van services and medical camps were operated and funds were provided for extension of hospital buildings. Construction of roads, community halls, bus stop sheds and drinking water facility etc. were taken under infrastructure development.

Skill development programmes were



Village Road near Narora, Uttar Pradesh

implemented by imparting livelihood generation skills such as welder training, masonry, computer skills, tailoring and stitching etc. Sustainable development initiatives were taken through implementation of projects like installation of solar street lights and biogas plant, conservation of turtles, rain water harvesting, artificial reefs for augmenting fish production etc.

Swachha Bharat Mission

The Department of Atomic Energy (DAE) and its constituent units continued its activities for the "Swachha Bharat Mission".

As a part of Swachh Bharat Mission, total four hundred and seventy five (475) toilets and urinals have been constructed in nearby villages by NPCIL and construction of another fifty three (53) toilets and urinals are expected to be completed by March 2016. In addition to this, contribution amounting to ₹ 10 Cr. to Swachh Bharat and ₹ 10 Cr. for Clean Ganga Kosh was also made.

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. The detailed information about RTI is given in the respective chapter of this report.

AWARDS & PRIZES

NPCIL and its sites won several awards in the areas of safety and performance, public outreach activities, CSR and Official Language.

NPCIL was awarded third prize for outstanding work done in the field of Official Language implementation among PSEs of Govt. of India by Ashirwad Sansthan, an NGO. The house magazine of NPCIL HQ "URJASWI" also bagged the second best magazine award among all the magazines published by the member PSUs of Mumbai PSU TOLIC (Town Official Language Implementation Committee). For the year 2015, MAPS received first prize from TOLIC, Chennai for the excellent implementation of Official Language in the PSU group. The coffee table book on flowers



A cheque being handed over to Honorable Chief Minister of Gujarat by Kakrapar site towards Sanitation projects in nearby schools



MAPS, Station Director receiving Gold Award from Green Tech Foundation, New Delhi under 4th Annual Green Tech CSR Awards 2015

found in and around NPPs “The Realms of Flowers" won the first prize for best coffee table book in the Public Relations Society of India (PRSI), national awards 2014. Madras Atomic Power station (MAPS) has won the "Gold Award" from Green Tech Foundation, New Delhi, under "4th Annual Green Tech CSR Awards 2015" in Nuclear Power sector for outstanding achievement in CSR.

During the year 2015-16, UCIL received many accolades for its outstanding activities in different domains such as Udyog Ratan Award -2015 by Institute of Economic Studies, Excellence Award - 2015 by Institute of Economic Studies, Greentech HR Award -2015 by Greentech Foundation, New Delhi, Greentech Safety Award -2015 to Turamdih Mill by Greentech Foundation, New Delhi and Outstanding Leadership Award -2015, Mining Engineers Association of India.

ECIL won the prestigious Governance Now PSU Research and Innovation Award for the year 2015 in recognition of its unparalleled contribution to Research and Development as well as assimilation of new technologies in Electronics and allied fields. ECIL received SKOCH Order of Merit Award 2015 for EVMs and related products and Cancer Hospital Information Management System. ECIL received "Rajbhasha Shield" for the year 2014-15 in Big Organizations category for excellent implementation of Official Language.

The HWP, Manuguru received two Indian Chemical Council Awards for the year 2014 which are Excellence in Management of Health / Safety / Environment and Excellence in Energy Conservation & Management. The HWP, Kota has been awarded with “RAJ BHASHA SHIELD” by Nagar Rajbhasha Karyanwayan Samiti, Kota for the period Jan to June 2015. Certificate of Appreciation from National Safety Council (Manufacturing Sector) under Group-B was awarded to Heavy Water Plant, Hazira for the year 2013.

AMD officers have been conferred with Outstanding Service Award – 2014 of Indian Nuclear Society, N.N. Chatterjee Award - 2015 of Geological Society of India, Bengaluru, Prof. S.M. Ramananda Setty Award – 2013 of Mineralogical Society of India, DAE Hindi Sevi Samman 2013-14, Dr. G.R. Udas – Dr. K.K. Dwivedy Medal – 2014 and 2015 by Indian Society of Applied Geochemists (ISAG), DAE Group Achievement Award – 2014 and DAE Meritorious Service Award (MSA) - 2014.

AT BRIT, the Scientific and Technical DAE Excellence Award 2014 was awarded to Mr. Tariq Saeed Anwar, Head, Regional Centre, RAPPCOF, Kota, for 'Development of Indigenous High Intensity Co-60 Teletherapy, Irradiator Sources and Sealed Sources Fabrication'. Another Scientific and Technical DAE Excellence Group Achievement Award 2014 was conferred on Dr. V.N. Yelgaonkar and Dr. A.K. Kohli, Group Leaders of the team of Scientists/Engineers/Technical Personnel for their contribution for successfully accomplishing the activity titled, 'Design and Development of Indigenous Co-60 Based Blood Irradiator and Innovative Technique for the Benefit of Industries'.

Scientists from TIFR have won prestigious national awards during the report period. The Shanti Swarup Bhatnagar Prizes for excellence in scientific research were awarded to Professor Mandar Deshmukh for Physics, Professor K Sandeep and Professor Ritabrata Munshi for Mathematics and Professor Vidita Vaidya for Medical Sciences. The Infosys Science Foundation Prize was awarded to Professor Mahan Mj for Mathematics, and Professor G. Ravindra Kumar for Physics.

Prof. R. Gopakumar of HRI was awarded the J. C. Bose fellowship this year.

CHAPTER-1

NUCLEAR POWER PROGRAMME STAGE-I



Kudankulam Nuclear Power Project -1&2: Plant view



Kakrapar Atomic Power Project-3&4: Plant view

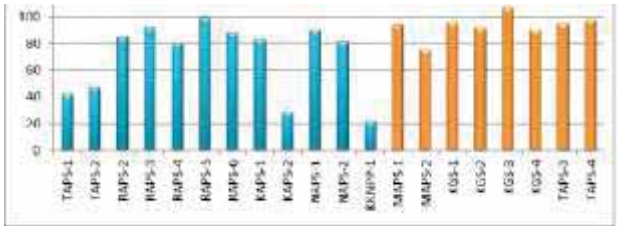
PRESSURISED HEAVY WATER REACTORS (PHWRs) & LIGHT WATER REACTORS (LWRs)

Nuclear Power Corporation of India Ltd. (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 AAA credit rating by CRISIL and CARE and is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. At present, it operates 20 nuclear power reactors (excluding RAPS-1 which is under extended shutdown and belongs to DAE) with installed capacity of 5680 MWe. Second unit of Kudankulam Nuclear Power Project (KKNPP-2) in Tamilnadu is under commissioning. First pair of indigenously designed 700 MWe Pressurised 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. NPCIL in all its endeavours is committed towards upgradation, continuous improvement in Quality Management, Quality Assurance / surveillance, Pre-Service Inspection / In-Service Inspection and interface with regulatory body.

Operating Reactors

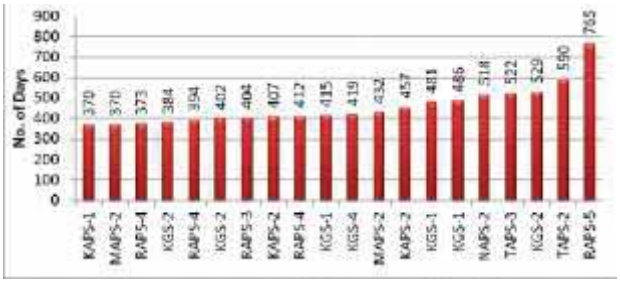
During the calendar year 2015, NPCIL recorded highest ever generation of 38364 Million Units(MUs) which was about 3% higher than the generation of 37146 MUs in the last calendar year 2014 (including 2984 MUs infirm power from KKNPP-1).

During the financial year 2015-16, NPCIL has registered generation of 27813 MUs till December 31, 2015. The expected generation for the financial year 2015-16 is about 38000 MUs. In the previous fiscal year 2014-15, the total electricity generation was 37835 MUs (including 2243 MUs infirm power from KKNPP-1).



Capacity Factor (%) of Operating Reactors (FY 2015-16 till Dec. 2015)

The overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 74% and 77% respectively till December 31, 2015 in the financial year 2015-16.



Continuous Run (more than a year) recorded by NPCIL's Reactors

During the year 2015, RAPS-4 (412 days), KGS-1 (418 days), KGS-4 (419 days) and NAPS-2 (518 days) achieved continuous run for more than a year. So far, this feat has been achieved 20 times by various reactors operated by NPCIL.

Twelve reactors of NPCIL viz. TAPS-1&2, RAPS-2, RAPS-3&4, RAPS-5&6, NAPS-1&2, KAPS-1&2 and KKNPP-1 with total installed capacity of 3280 MWe are under IAEA safeguards and operating on imported fuel. Eight reactors viz. MAPS-1&2, TAPS-3&4, KGS-1&2 and KGS-3&4 with total installed capacity of 2400 MWe are operating on domestic fuel.

Projects under Commissioning

Kudankulam Nuclear Power Project (KKNPP) Unit-2 (2x1000 Mwe)



KKNPP-1&2: Plant view

KKNPP Unit-2, located in Tirunelveli district of Tamilnadu, being implemented with Technical Co-operation from Russian Federation within the framework of the Inter-Governmental Agreement signed between USSR and India is under commissioning. Unit-1 is already completed and is in commercial operation since December 31, 2014.

In Unit-2, important commissioning milestone "Hot Run of Nuclear Steam Supply System" has been achieved in April 2015. Second inspection of primary system equipment like reactor pressure vessel, main coolant pipeline, tubes & tube sheet ligaments of Steam Generators (SG), pressurizer, hydro-accumulator tanks etc. has been completed. Inspection of balance components like core barrel and protective tube unit is in progress. Preparation for next commissioning milestone i.e. initial fuel loading (IFL) is in progress. A volume of 1600m^3 of boric acid of concentration 40g/kg has been prepared. Fuel pool & racks are cleaned for receiving fresh fuel. Endurance test of safety Diesel Generators and friction test of Self-Powered Neutron Detectors are completed. Turbine is boxed up and put on barring gear. Commissioning of secondary side systems including turbine auxiliaries & turbo-visory instruments is in progress. Generator Transformer has been charged. Commissioning of condenser cooling water pumps are completed. Commissioning of other systems like sea water systems, reactor auxiliary systems, DG systems etc. are in advanced stage. The reactor criticality process start up is expected in first quarter of 2016-17.

Projects under Construction

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



KAPP-3&4: Plant view

Kakrapar Atomic Power Project-3&4 is India's first pair of indigenously designed 700 MWe Pressurised Heavy Water Reactors. The construction activities are presently in full swing along with commissioning of electrical and process water systems.

KAPP Unit-3

Civil construction and finishing works of major buildings of Unit-3 are nearing completion. Works progress on piping, mechanical, electrical, control, reactor, ventilation etc. have gained momentum. Project critical path activities like "Erection and welding of End-Shields & Calandria" and "Calandria Tubes rolling" have been completed and Pressure Tubes installation is in progress. Feeder fabrication and mock-up testing for Primary Heat Transport (PHT) system is progressing in planned manner in order to take up installation of the same immediately after completion of pressure tube installation.

Construction of Turbine Generator Deck for both the units has been completed. Civil work for Turbine Building-3 (TB-3) is nearing completion. Both 125MT & 20MT EOT cranes are commissioned, load tested and released for Turbine Generator (TG) and condenser works. Generator Stator of KAPP-3, the heaviest single component of the 700 MWe project weighing 325 MT has been erected successfully at TG deck in TB-3. For the first time in 700MWe Indian PHWR, De-aerator Storage Tank of 40.097 m long, 4.93 m outer diameter and 715 m^3 capacity, fabricated as a single unit was successfully lifted & erected at the designated location of TB-3. Condenser work of KAPP-3 is also progressing. Preparatory & foundation readiness work for HP and LP turbine erection is also progressing.

Pipe fabrication and erection works for Common Service systems like service water, fire water, compressed air, domestic water, non-active drainage, DM water etc. are nearing completion. Hydro-test of 40% of circuits of various systems related to Common Service piping has been completed. In Primary Piping Package, pipe erection and fabrication is in progress on all fronts. Steam Generators -1, 2 & 3, pressurizer, ECCS tank, PHT storage tank etc. have been erected at location.

For commissioning of various loads, 220 KV system Start-Up Transformer and other electrical protection and control systems have been commissioned and charged. Also, Cable laying, glanding & termination activities are commenced and progressing to meet the power supply requirement for commissioning of the various process loads. 400KV switchyard structure and equipment erection work is completed. Equipment's commissioning is in progress.

KAPP Unit-4

In KAPP-4, civil works are in progressing and erection activities have also started. An important critical path activity "Erection, alignment and welding of End-Shields & Calandria" has been completed. Preparatory work for Calandria Tube rolling is in progress.

The commissioning organisation has been set up with experienced and fresh manpower to take up the commissioning activities in efficient manner and is progressing towards full-fledged commissioning team. Commissioning manpower is being trained to get the required licensing/ qualification to meet the commissioning and initial operation of the plant. Major part of the commissioning documents i.e. operation flow sheets, commissioning procedures, training manuals, operating manuals, emergency operating procedures, commissioning plans and networks, licensing and qualification procedures, severe accident management guidelines, quality assurance manual, draft technical specification of operation and emergency preparedness manuals have been completed . Actions have also been taken to setup Operation & Maintenance (O&M) infrastructure i.e. chemical lab, maintenance shop, Health Physics Unit (HPU) lab etc. Commissioning manpower are fully involved in field commissioning activities for various systems including Process Water systems, Air System, electrical systems and C&I Systems etc.

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

Rajasthan Atomic Power Project-7&8 is India's second pair of indigenously designed 700 MWe Pressurised Heavy Water Reactors. Presently, construction activities are in progress.

RAPP Unit-7

In Unit-7, a major critical path milestone "Erection & welding of End Shields & Calandria" has been completed. Inner Containment (IC) wall of Reactor Building (RB) has been constructed up to ring beam bottom and floor slab has been completed up to Elevation (EL) 118 metre. In Turbine Building (TB)-7, construction of Turbine Generator (TG) deck has been completed. Construction of Electrical Annexe Building, Pipe & Cable Bridge and Access Bridge are in progress. Construction of Control Building slab at EL 111m is nearing completion.

Construction of Waste Management Plant, Plant Water Pump House and DM Water Plant are progressing simultaneously. Construction of four Natural Draft Cooling Towers (NDCTs) is going on along with laying of 5m diameter inlet-outlet pipe at site. Construction work for Induced Draft Cooling Towers (IDCTs) is also in progress. Civil work & erection of equipment structures in 400KV Switchyard is nearing completion.



RAPP-7&8 : Plant view

RAPP Unit-8

In Unit-8, a major critical path milestone Construction of Calandria Vault has been completed. IC wall up to EL 111.7 m has been constructed.In TB-8, construction of TG deck columns is completed.Construction of RB internal structures, Electrical Bay, Pipe & Cable Bridge and Access Bridge are in progress. Ball filling in both the End Shields has been completed & preparation for lowering in Calandria Vault is in progress.

Major equipments like Calandria, End Shields, Moderator Pumps & Heat Exchangers,

Primary Coolant Pumps, Shutdown Cooling Pumps, Startup Transformer, Diesel Generators, Chillers, De-aerator, Moisture separator re-heaters etc. have been delivered at site. Various equipments like Chillers, Compressors and Pumps & their associated piping have been placed at their respective locations in Control Building & RAB-7 basements. DG Fuel Oil Storage Tanks have been erected in Diesel Oil Storage Tanks area of Unit-7& Unit-8.

Completion of Calandria Tube installation in Unit-7, erection of Diesel Generator sets in SAB-7B, completion of 400KV Switchyard, completion of Plant Water Pump House and DM Water Plant Buildings, etc. are expected by end March 2016.

RAPP Unit-7&8

The overall physical progress of RAPP-7&8 was about 57% till December 2015.

Sanctioned Projects

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

Kudankulam Nuclear Power Project, Units-3&4 which is an expansion program of Units-1&2, located in Tirunelveli district of Tamilnadu is being implemented with co-operation from Russian Federation (RF) within the framework of the Inter-Governmental Agreement signed between Russian Federation and Republic of India in December 2008. General Frame Work Agreement (GFA) for setting up of KKNPP Units-3&4 has been signed with M/s. Atomstroyexport (ASE) and made effective in December 2014. Government administrative approval and financial sanction of the project exists. Environmental clearance and CRZ clearance from MoEF are obtained. AERB Siting consent and Excavation consent have been obtained.

Manufacturing of equipment/components under contract, "Supply of Long Manufacturing Cycle Equipment & First Priority Equipment (LMCE & FPE)" is started in Russian Federation (RF). First consignment of doors is ready for shipment from RF. Draft contract for supply of balance plant equipment at discussions/negotiations stage. First priority design activities, for which a contract is already signed with M/s. Atomstroyexport (ASE) are in progress (91% completed). The first priority works include design of hydro-technical structures, changes of Units-3&4 w.r.t. Units-1&2, layout finalization, interface documents, excavation drawings & raft foundation drawings for main plant etc. which are essential to take up the First Pour of Concrete (FPC). Contract for elaboration of working documentation is signed in December 2015 with M/s. Atomstroyexport (ASE).

In-principle approval for construction of hydro technical structures has been received from Tamil Nadu Maritime Board in December 2015. Tendering completed for main plant pit excavation, consolidation grouting and confirmatory soil investigation. Work has now been awarded for excavation. Administrative approval is obtained for tendering of main plant civil works, construction of hydro technical structures and engineering, procurement, construction and commissioning of common services mechanical systems.

Various site infrastructure development works are in progress. Construction of main approach road with parking areas and storm water drains, compound wall along sea shore of KKNPP site, fire and industrial safety complex with first aid facility, construction of pass section and 6 nos. of sub stations, electrical infrastructure works etc. have been completed. Sub station is charged and construction power supply and area lighting is made available. Construction of project office complex and sewerage treatment plant is nearing completion. Construction of external services such as water supply, fire water and sewage disposal for infrastructural buildings started. Tendering is under progress for design and construction of central stores and closed warehouse facilities for storage of equipment.

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

Land acquisition for the plant is completed. Government administrative approval and financial sanction of the project exists. Environmental clearance from Ministry of Environment, Forest and Climate Change (MoEFCC) has been obtained for project site. Haryana State Pollution Control Board

has granted Consent to Establish GHAVP. Siting consent from AERB is received. Site Geotechnical studies are in advanced stage of completion. Boundary wall construction is in progress and site mobilization by contractor for Site Management Building is in progress. Tendering action initiated for long delivery equipments. However, conditional offers related to Civil Liability for Nuclear Damage (CLND) Act clauses by various bidders need to be resolved for further progress and the same is in progress. Site preparation activities like ground improvement, construction power, water supply and infrastructure development, etc. are being taken up progressively.

New Expansion Sites

In respect of Jaitapur Nuclear Power Project (JNPP), land is acquired and site office is established. Environmental clearance is obtained from MoEFCC and Siting clearance is under review by AERB. Pre Engineering Agreement (PEA) for the Engineering Services is signed between NPCIL and AREVA and contract has commenced. Techno-commercial discussions with AREVA/ALSTOM are in progress. Public Awareness activities are ongoing.

Land acquisition, environmental studies, public outreach activities, various site studies to the extent possible etc. are under various stages at new sites namely Chutka and Bhimpur Madhya Pradesh, Mahi Banswara in Rajasthan, MithiVirdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga Unit-5&6 in Karnataka and Haripur in West Bengal.

Land is already available for Kaiga-5&6. Section-11 notification has been issued for land acquisition by respective State Govt. authorities for Chutka site in Madhya Pradesh and Mahi Banswara site in Rajasthan. In respect of Chutka, R&R package is announced and part amount has been remitted to Govt. of Madhya Pradesh towards land acquisition. In respect of Kovvada and MithiVirdi, land is to be acquired as per the new RFCTLARR (The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement) Act, 2013.

Quality Assurance

NPCIL, in all its endeavours is committed towards upgradation and continuous improvement in Quality Management, Quality Assurance, Quality Surveillance, Pre-Service Inspection / In-Service Inspection and interface with regulatory body. Quality Assurance/Surveillance activities are being carried out for projects and stations. Pre-Service/In-Service Inspection of KKNPP-1&2, TAPS-1&2, TAPS-3&4, KAPS-1&2, NAPS-1&2, RAPS-5&6, RAPS-3&4 and KGS 3&4 has been completed successfully. Corporate QA audits of projects i.e. KAPP-3&4 and RAPP-7&8 have been completed in a planned way. Corporate 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 at NPCIL HQs (Directorate of Engineering, Directorate of QA, Directorate of Procurement, Directorate of Reactor Safety & Analysis, Directorate of Health, Safety & Environment, Directorate of HR (Knowledge Management Functions) are ISO: 9001 certified. Surveillance/Re-certification audits of these Directorates by the certifying body have been completed successfully.

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. 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.

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

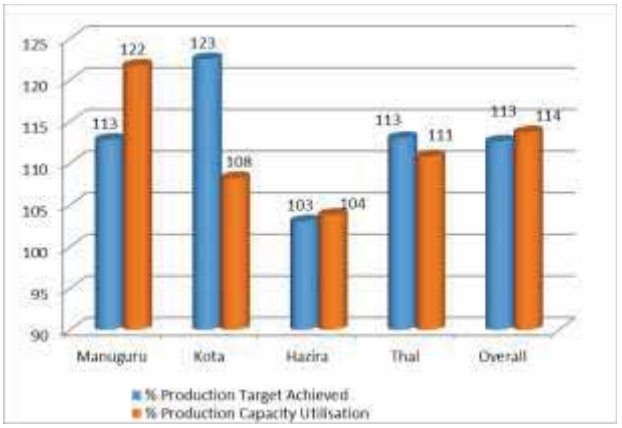
energy consumption, on stream factor and plant safety. As per the Annual Action Plan for the year 2015-16, HWPs at Manuguru, Kota, Hazira & Thal have carried out the Annual Turn Around jobs during the period. However, the overall specific energy consumption including the non-productive consumption during the planned shutdown period could be brought down to less than the targeted figure due to continual and meticulous review of the process parameters to ensure optimum levels of plant operation. Further, the plants could achieve nearly continuous run with an on-stream factor close to 1, excluding the planned shutdown periods. Consequently, during the period the Board could surpass the production target by more than 12% and also achieved 113.7% of overall capacity utilization.

The Heavy Water Board achieved more than 112% of targeted production for the financial year 2015-16 and the specific energy consumption was 28.6 GJ/Kg.

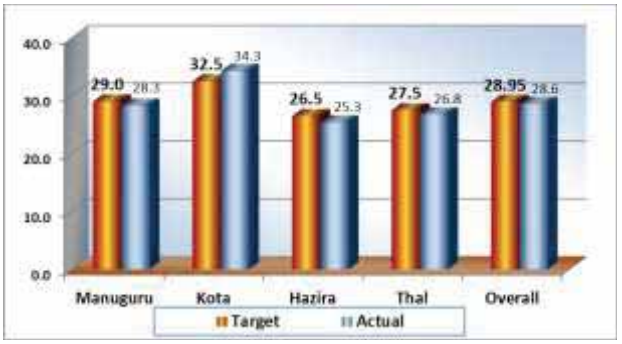


Column Section

Plant wise % production target, capacity utilization & specific energy consumption achieved during the period w.r.t. target fixed are furnished below:



Percentage production target and capacity utilization



Specific energy consumption (gj/kg) during 2015-16

Filling of packing modules inside 2 Nos. of heavy water upgrading column sections for KAPP-3&4 was completed by BARC. Surface activation and performance evaluation of column sections is in progress. This technology is import substitute for highly efficient upgrading column internals.



Packing modules for filling

Heavy Water Plant, Manuguru

The performance of HWP, Manuguru during the year 2015-16 was excellent, achieving 112.8% of target production and on stream factor close to 1.0.

After successful commissioning of DCS, Exchange Unit-I was re-started in June 2015 after Annual Turn Around and the plant continued to operate on a sustained basis. Plant operated with an average feed rate of 491.5 MT/hr. and recovery of 18.7%. System gas purity was consistently maintained at around 99.7% and system gas pressure was at 19.4 kg/cm^{2}g.

Specific energy consumption remained low at 28.3 GJ/kg in spite of plant shut down taken for installation of DCS for Exchange Unit-1. The smooth operation of Auxiliary Steam Turbo Generator (TG-4) and installation & commissioning of Variable Frequency Drives (VFDs) has reduced the power consumption enabling export of surplus power at the rate of 10 MWe, totaling 46.86 MU as per the agreement with PTC resulting in substantial revenue receipts.

For utilisation of waste heat / low grade heat to generate refrigeration, Hot Water Vapour Absorption Refrigeration machines are being procured and Mist Cooling System (MCS) is commissioned.

Installation of Mist Cooling system for Effluent Treatment Plant resulted in saving of about 200 KW power.

The 12 MWp Solar Photo Voltaic Power Plant set up as mandated under Renewable Power Purchase Obligation achieved full capacity generation in July 2015 and operating satisfactorily. About 9 MU of solar power has been generated so far.



12 MWp Solar Photo Voltaic Power Plant at HWP(M)



Boron Enrichment Plant at HWP, Manuguru

Elemental Boron Plant for production of Elemental Boron is being operated on sustained basis.

Heavy Water Plant, Kota

The first indigenous Heavy Water Plant based on H_2S–H_2O chemical exchange process at Kota has completed 30 years of sustained operation. Performance of the plant during the first quarter was affected due to steam and power failure from RAPS 2&3 on 3 occasions. The plant has carried out the Annual Turn Around during July – August 2015 during which healthiness of the bottom dish end of 2nd stage Hot Tower was verified. Subsequently, the plant operated on a sustained basis with an average feed rate of 483.3 MT/hr. and recovery of 16.4%. System gas purity was consistently maintained at around 99.4% and system gas pressure was at 18.7 kg/cm^{2}g.

Heavy Water Plant, Hazira

The plant carried out Major Turn Around in April- May 2015. Thereafter the plant operated continuously except for a power failure from GEB sub-station in September 2015 with an average feed rate of 43.6 MT/hr. and recovery of 80.3%. Despite low load operation of the plant due to restricted feed synthesis, gas supply from only one ammonia plant of M/s KRIBHCO HWP, Hazira could achieve the targeted production during the period.

To avoid loss of heavy water in the Burner unit a back end unit was installed to transfer Deuterium from rich ammonia to DM Water. Several innovative modifications were carried out including replacement of packing and increasing the height of the column. The Ammonia-Water exchange column (Unit 24) was operated successfully after incorporating modifications.

Heavy Water Plant, Thal

The plant operated continuously with on stream factor near to one except for external reasons namely non-availability of feed gas from the Ammonia Plant of M/s RCF and power failure from grid. The plant operated with an average feed rate of 46.7 MT/hr. and recovery of 78.3%. The plant was under annual shutdown since 21.11.2015 coinciding with the annual turnaround of Ammonia plant of M/s. RCF.

With effective monitoring and following multi prong control of CO_2 ingress, plant performance with respect to production & specific energy consumption has been very good. Plant could achieve the targeted production within the targeted specific energy consumption.

As a measure towards energy saving, 60 percent of the plant internal lights have been replaced by LED lights resulting in significant reduction in energy consumption towards plant internal lighting.

Heavy Water Plant, Baroda

The Tributyl Phosphate Plant (TBP) and the Potassium Metal Plant operated on a sustained basis. To improve the performance of ETP for the TBP plant, a system has been developed for the recovery of costly Butanol from the effluent. The existing column has been modified for processing effluent with indirect heating in Multiple Effect Evaporator (MEE). The recovered Butanol is re-cycled after purification. POCl3 drum unloading system has been improved by incorporating fume extractor and thus reducing the personal exposure during connecting / disconnecting the unloading pipe.

Subsequent to operating and collecting engineering data of the 2000 Amp test cell for production of Sodium metal, two new 2000 Amp cells were fabricated & operated. The new cells were further revamped and operated to produce sodium metal. About 996 kg of sodium has been produced during the period. Validation of Analytical procedure for purity analysis of Sodium is completed. Validation of analytical procedure for trace level impurities for elements (Fe, Ca, Mg & K) is under progress. One unit of Sodium distillation assembly was commissioned successfully.

Based on the operational experience gained, the 600 MT/annum industrial facility for production of sodium metal will be set up at HWP, Baroda. MoU between BHAVINI and HWB to utilise the product from this project, has been finalised. As the project has been classified as strategic, MoEF clearance has been obtained

Heavy Water Plant, Tuticorin

A fresh proposal for restarting HWP, Tuticorin has been sent to DAE subsequent to change in Government policy on Naptha for Urea producers and also in view of the recent development of award of contract to M/s IOCL for laying of natural gas pipeline from Ennore to Tuticorin.

Operation of Versatile Solvent Synthesis Pilot Plant (VSSP) facility was continued for generation of engineering data for production of Mono ester of 2-ethyl Hexyl Phosphonic Acid (D2EHPA –II) & Tri Octyl Phosphine Oxide (TOPO). Based on the engineering data, a process package was prepared for setting up of industrial scale plant for these solvents. As desired by IGCAR Di- iso Amyl Phosphate, Tri- Hexyl Phosphate and Tri-iso Butyl Phosphate were synthesized in lab & bench scale and basic process was established.

To cater to the requirement of new generation solvents in the nuclear fuel cycle of NPP, sanction from DAE has been received to set up an Industrial scale Solvent Production Plant (SPP) at HWP, Tuticorin for production of five solvents, namely TiAP, DHOA, D2EHPAII, TBP & TOPO. Basic engineering has been completed and process package is prepared. An application has been submitted to SEIAA for environment clearance. Clearance of AERB for siting & construction has been obtained subject to environment clearance.

To carry out R&D activities for development of the process for various solvents as required by R&D units of DAE, an analytical facility is being set up at HWP, Tuticorin under XII Plan BARC scheme.

Heavy Water Plant, Talcher

At HWP, Talcher, the production facilities for D2EHPA and TBP were operated continuously to meet the target production. At the R&D pilot plant facility, synthesis of TOPO was taken up and target production of TOPO has been achieved. Quality of product was as per Benchmark. Integrated effluent treatment plant was operated for treating effluent from VSPP and TBP facilities. The solid waste produced was sent to M/s Ramky for disposal.

During the period Boron Enrichment Facility was in operation with 100% flow factor for enriching ^{10}B in complex to 65% isotopic purity. Required quantity of enriched KBF_4 (^{11}B~90%) has been produced and dispatched to HWP Manuguru. BF_3-CaF_2 complex was dispatched to RD& I Division, ECIL, Hyderabad.

Technology Demonstration Plant (TDP) at Chembur for solvent extraction technology demonstration has achieved intended deliverables and has successfully demonstrated continuous stripping operations with WPA in Solvent Extraction Cycle 1 and change-over of Solvent Mix in Solvent Extraction Cycle 2 which resulted in elimination of kerosene in the system.



Technology Demonstration Plant for RMR at Mumbai

During operation of the plant, various modifications were carried out namely, in Iron dosing system, in Clarifier for pre-treating feed phosphoric acid of higher solid content, Incorporation of inventory management system. Asymmetric Rotating Disc Contactor (ARDC) unit was commissioned, stabilised and operated in sustained mode for extraction cycles and also tested for stripping cycles successfully. Bench scale studies were carried out for eliminating third phase formation during stripping operation in solvent extraction cycle-2 and for bench scale studies for reduction of nitrate concentration in feed phosphoric acid.

The yellow cake (CSDU) produced in TDP has been dispatched (under shipment intimation to NUMAC) to RED-IREL for recovery of heavy Rare Earths and further processing. The facility is providing vital process and technological inputs which will go a long way in achieving efficient configuration of industrial scale facilities. The radiological status of the unit was normal.

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, the integrated multi-disciplinary approach adopted for uranium exploration with substantial inputs of radiometric, geological, ground and heliborne geophysical, geochemical surveys and drilling have resulted in augmentation of in-situ reserve by 15,778 tonnes U_3O_8 making the XII plan total to 54,926 tonnes.



Portable Calibration Pads Developed by AMD



Uranium removal kit developed by AMD

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

In addition, pegmatite belts of Chhattisgarh, Odisha and Karnataka for rare metals, rare earths and sand bodies of coastal stretches (east and west coasts) for heavy minerals were explored for augmentation of rare metals, rare earths and heavy mineral resources respectively.

The laboratories at AMD Headquarters and in Regional Headquarters are equipped with state-of-the-art instruments and every effort was made to utilise them to full capacity. All the laboratories 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 (6,552sq km) and detailed (289.30sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

Kaimur Group, Karwi district, Uttar Pradesh: Sandstone at Bariyari and Mohara Nala

Dharmapuri Shear Zone, Krishnagiri district, Tamil Nadu: Pink syenite at Pudur



Uraniferous Pink Syenite, Pudur, Krishnagiri District, Tamil Nadu



A View of Krol-Tai Sequence with Higher Himalayas in the Background, Uttarakhand

Krol Group, Mussoorie Syncline, Tehri-Garhwal district, Uttarakhand: Argillaceous limestone with phosphatic cementing material at Goth.

Chilpi Group, Kawardha district, Chhattisgarh: Carbonatite at Pipradhar and quartz vein at Chhinda.

Betul Gneissic complex, Betul and Chhindwara districts, Madhya Pradesh: Pink granite near Kumkal.

Iron Ore Group, Quartz Pebble Conglomerate, Mayurbhanj district, Odisha: Near Baliabadi.

Bomdila Group, Papum Pare district, Arunachal Pradesh: Micaceous quartzite near Ampuli.

Geochemical Surveys

Geochemical surveys (4,040 sq km) in parts of Jaisalmer, Hanumangarh, Sri Ganganagar districts, Rajasthan and Sirsa district, Haryana have indicated high U (upto 712 ppb), V (upto 118 pbb) and K (upto 2,292 ppm) along the trend of Saraswati river palaeochannels. Water samples (n=61) from Mohanpur-Kalwa area, Mahendragarh district, Haryana and Jhunjhunu district, Rajasthan have recorded upto 70 ppb U.

Ground Geophysical surveys

Ground geophysical surveys of about 560 sq km have been carried out in parts of Singhbhum Shear Zone, Jharkhand; Dharmapuri Shear Zone, Tamil Nadu: Bhima basin, Karnataka; North Delhi Fold Belt, Haryana and Rajasthan. Three NNE-SSW trending parallel conductors have been delineated in Dhanota-Dhancholi, Mahendragarh district, Haryana. A consistent E-W trending high chargeability (16-20mV/V) zone, extending over a strike of 3 km and 400m width was delineated at Dornahalli-Halbhavi tract, Yadgir district, Karnataka. High chargeability (upto 25mV/V) zones have been delineated in Gurulpada, Banaykela and Sankadih blocks, Saraikela-Kharswan district, Jharkhand.



Structural Training in Singhbhum Shear Zone, Jharkhand

Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 42,559.40 line km in parts of Aravalli Fold Belt, Rajasthan, Kaladgi and Bhima Basins, Karnataka.

Preliminary interpretation of heliborne geophysical data has indicated two major parallel magnetic linears in Kaladgi East block. In Bhima-South block, the total magnetic intensity image indicated four parallel E-W trending faults, one of which is the western extension of the Gogi – Kuralagere fault, beneath the Deccan Trap cover.



Calibration of Gamma-Ray Spectrometer before Heliborne Survey

Exploration by Drilling

A total of 1,90,585.45m (Departmental drilling: 83,801.45m and Contract drilling: 1,06,784m) reconnoitory, exploratory and evaluation drilling has been carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of mineralisation in the new promising areas.

The drilling has established significant correlatable uranium mineralised intercepts / bands as listed below:

Tummalapalle, Kadapa district, Andhra Pradesh: Hangwall and footwall lodes in Tummalapalle Block-I, Tummalapalle Block-II, Tummalapalle Block-II Deeper (550-825m), Kanampalle, Rachakuntapalle, Rachakuntapalle East, Motunutalapalle and Gidankivaripalle blocks in Vempalle dolostone.

Subbareddipalem-Bodanampadu, Guntur district, Andhra Pradesh: Along the unconformity between Banganapalle quartzite and basement granite and within the Banganapalle quartzite.

Rohil and its extensions, Sikar district, Rajasthan: Albitite zones in Rohil Central and North blocks, Guman Singh ki Dhani, Narsinghpuri and Jahaz areas.

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

Kanchankayi, Yadgir district, Karnataka: Associated with brecciated limestone in a similar geological setup as that of Gogi uranium deposit.

Devri, Surajpur district, Chhattisgarh: Associated with brecciated granite, grey granite and granite-gneiss in Devri, which is situated between Dumhath and Jajawal uranium deposits.

Nalpani, Balod district, Chhattisgarh: Bortalao sandstone of Khairagarh Group and also in Pitepani metabasics of Nandgaon Group (Dongargarh Supergroup) near the unconformity.

Narwapahar Deeper, East Singhbhum district, Jharkhand: Associated with quartz-chlorite-sericite schist at 600-800m depth.

Banadungri-Singridungri, Rajdah, Hitku and Jaduguda North, East Singhbhum district, Jharkhand: Associated with quartz-chlorite-sericite schist.

In addition to the above, the potential/significant blocks have also been identified through sub-surface exploration at Gorir-Ilakher-Modi, Jhunjhunu district and Karoi, Narsinghpuri, Sikar district, Rajasthan; Rambas, Golwa-Gangutane, Mahendragarh district, Haryana; Suldhal – Gujanal block, Belgaum district, Karnataka; Rasimalai, Vellore district, Tamil Nadu; Gurulpada, Mahalimurup, East Singhbhum district, Jharkhand and Sie Rimi-Dupu-Maro-Baririzo, West Siang district, Arunanchal Pradesh.



Drilling Operation in West Siang district, Arunachal Pradesh



Uraninite-Magnetite-Apatite Bearing Quartzite, Bhatin Mine, Jharkhand

Exploratory Mining

Uranium Resources

AMD has established an additional reserve of 15,778t uranium oxide (U_3O_8) as detailed below:

- 12,481t U_3O_8 established in Tummalapalle and its extensions, Kadapa district, Andhra Pradesh.
- 1,545t U_3O_8 in Wahkut, South West Khasi Hills district, Meghalaya.
- 982t U_3O_8 at Banadungri-Singridungri, East Singhbhum district, Jharkhand.
- 770t U_3O_8 at Rohil, Sikar district, Rajasthan.

The country's uranium reserve has been updated to 2,29,936 tonnes of U_3O_8 as on 31.10.2015.

Rare metal and rare earths investigations

Reconnaissance (940 sq km) and detailed (5.09 sq km) surveys have been carried out for location and evaluation of columbite-tantalite and beryl in pegmatites of Karnataka, Odisha, and Chhattisgarh.

Additional reserve of 4,564kg of columbite-tantalite was estimated in pegmatites at Jangapara, Jharsuguda district, Odisha; Metapal, Bastar district, Chhattisgarh; Kotwalpara, Bastar district, Chhattisgarh and Marlagalla, Mandya district, Karnataka.



Crystal of Columbite-Tantalite, Marlagalla, Karnataka

Production of columbite-tantalite (3,820kg), beryl (1,850kg) as by-product and xenotime concentrate (7,000kg) was achieved at Pandikimal and Jangapara unit, Jharsuguda district, Odisha; Bodenar unit, Bastar district, Chhattisgarh; Allapatna-Marlagalla sector, Mandya district, Karnataka and at Siri River, Jashpur district, Chhattisgarh.

A total of 4,000m drilling has been carried out for RMRE in carbonatites at Ambadongar (2,000m), Chhota Udepur district, Gujarat and in pegmatites at Jangapara (2,000m), Jharsuguda district, Odisha.

Beach Sand and Offshore Investigations

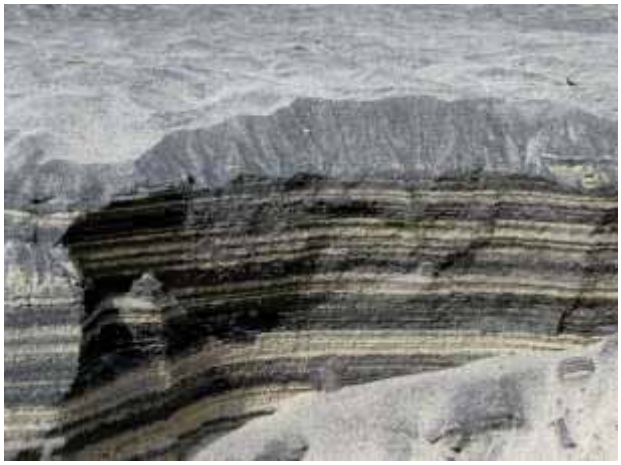
Survey (Reconnaissance - 342.28 sq km and detailed - 8.69 sq km) and prospecting (drilling, sampling and evaluation) were continued along the coastal tracts of Andhra Pradesh, Gujarat, Odisha, Kerala, Karnataka and Tamil Nadu to establish additional beach sand heavy mineral resources.

Exploration/Evaluation

Total 1,957 boreholes with a cumulative depth of 9,599.30m were drilled and 6,963 individual and 34 bulk samples have been generated. Composite samples were processed for resource evaluation and bulk samples for separation of monazite and zircon.



Sonic Drilling Operation at Neendakara-Kayamkulam Beach, Kerala



Heavy Mineral Layering, Neendakara-Kayamkulam Beach, Kerala

Sonic drilling, on contract, has been initiated at Neendakara – Kayamkulam sector (Chavara Major Deposit), Kollam district, Kerala to evaluate deeper horizons (>12m) and a total of 889m drilling has been carried out in 21 boreholes.

The following potential heavy mineral zones have been delineated:

Hazira and Devla coasts, Surat and Bharuch districts, Gujarat contain heavy mineral assemblage comprising dominantly of pyroxene, amphibole, magnetite and ilmenite (7.36-56.22% THM; average 21.86%).

Chavara-Thotapally, Kollam district, Kerala (5-20% THM with occasional values as high as 95%).

Naripaiyur-Valinokkamcoast, Ramanathapuram district, Tamil Nadu (0.52-49.75%THM; average 5.11%).

Bendi creek-Mela Ganguvada tract (1.60% to 51.92% THM; average 12.96%) and Metturu-Sompeta-Ichapuram tract (1.48 to 32.04% THM; average 6.57%), Srikakulam district, Andhra Pradesh.

Arjipalli-Agastinuagaon (1.11-68.01%THM; average 16.87% THM), Ganjam district, Odisha.

Detailed Reports

Six project reports pertaining to beach placer deposits along the east and west coasts of India have been completed.

Resources

The country's total heavy mineral resource now stands at 1,064.79 MT which include ilmenite rutile, monazite, zircon, garnet and sillimanite. Survey, exploration and evaluation are in progress to augment these BSM minerals.

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. A new mine and a processing plant are also under construction at Tummalapalle, Andhra Pradesh. The Indian Rare Earths 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.

The overall performance of UCIL during the year was satisfying. The Tummalapalle Uranium Project at Andhra Pradesh is readying for commissioning in 2015-16. The mine has achieved the desired ore production capacity and adequate ore has been stockpiled. During the year 2014-15, “Incidental production” has gone up by 35.67% with respect to previous year.

UCIL has started augmentation of the mining operations at Bhatin mine by deepening of one of the winzes, development of levels delineating the ore body, up-gradation of critical equipment and procurement of new trackless machinery etc.

The Banduhurang mine is continuously improving its performance. A new project of installation of gyratory crusher at Banduhurang open cast mine is being taken up to improve capacity utilization.

Mining lease of Mohuldih mine has been granted by State Govt.

Construction of a new Uranium Peroxide facility at existing Turamdih Uranium processing plant has been completed. Uranium peroxide is an environmentally benign and value added product benefitting processing practices at NFC.

UCIL has proposed to construct uranium recovery plants for recovery of uranium from copper tailings of M/s Hindustan Copper Ltd's operations at Mosabani.

UCIL has also proposed seven projects, grouped under Debottlenecking of Singhbhum and Tummalapalle operations to remove hindrances in smooth and sustained operations in its facilities at Singhbhum and Tummalapalle with high capacity utilization level. The activities at Singhbhum will include, Winder up-gradation in Narwapahar; Improvement of hoisting system and crushing at Turamdih; protection of river bank and weir at River Kharkai; System modification to handle mixed leached slurry at Jaduguda mill and Adoption of mechanically agitated system for leaching & neutralizing at Jaduguda mill.

The activities at Tummalapalle will include Trial stoping in Hangwall lode and Controlling elevated activities of environmental discharge from the plant.

The major achievements of IREL was the commercial production of the 10,000 tpa monazite processing plant at OSCOM, Odisha which commenced on 1st January 2015 after obtaining clearance from AERB.

Project report prepared by IREL for setting up of the technology demonstration plant for producing nano titanium and zirconium oxy-chloride has been vetted by the consultant. Draft EIA/ EMP report prepared by the environment consultant has been submitted to OSPCB seeking suitable date for public hearing.

Licensing Agreement for Transfer of Technology has been signed with Defence Metallurgical & Research Laboratory (DMRL), Hyderabad for transfer of rare earth based magnet making technology to IREL. Agreement for transfer of process for preparation of Sm-Co magnetic alloy powder technology has been signed with Bhabha Atomic Research Centre (BARC), Mumbai. Based on the above technologies available, IREL is contemplating to set up a rare earth based permanent magnet plant. For this, preparation of detailed project report is under way.

During the year, two patents a process for production of pure Zirconium oxide from Zircon and a process for the production of thorium phosphate from thorium oxalate and recovery of oxalic acid has been filed.

The new hydro-processing facility Upgradation of Metal Reduction Technology & Effluent handling (UMRT&EH) has been commissioned at BARC for purification of natural U concentrates & recycles to produce nuclear pure



2L batch experiment



Appearance of MDU



MDU after settling



Plant scale experiment

Ammonium Di-Uranate (ADU) suitable for U metal ingot production and to manage & handle generated nitrogen bearing effluent in systematic manner.

Calcination, reduction and hydro-fluorination studies were conducted on the ADU precipitated under different process parameters and the products at different stages were characterized with X-Ray Diffractometry (XRD). This will help in designing criticality safe reactor for Ammonium Di-Uranate (ADU). High purity Th metal was produced for making Th-foils used in basic research activity.

Setting-up of large-scale facilities for processing of U ores, including those of refractory nature, by H_2SO_4 route progressed well with the installation and commissioning of critical units such as, Hastelloy C 2000 leach reactor, filtration units, IX/SX equipment and high pressure compressor. Other allied tanks, conditioners, high pressure pumps, gas manifold for oxygen supply etc. are under installation.

A study was undertaken to assess the suitability of mill tailing based composites for backfill material in Tummalapalle Uranium Mine (in collaboration with IIT Kharagpur). Yield stress measurement, slump-cone testing and pipe-loop test studies were conducted on slurry with solids residue material concentration of about 78% (weight/weight).

Miniature slump cone tests were used to optimize binder (cement) and super-plasticizer contents at 4% and super-plasticizer 1-3.0%, respectively. Apparent yield stress tests by stress growth technique showed the mill tailing based paste obeyed a non-Newtonian flow characteristic given by Y = 1181*SR + 1304. Pipe loop test indicated increase in pulp density from 78 % to 81% after 310 minutes of pumping operation.



Consistencies of the paste at the start & after 310 minutes

The leaching of U from Tumallapalle ore is carried out in carbonate medium at high pressure and temperature. Due to lesser U concentration (<1g/L U_3O_8) in the leached liquor, U recovery was not adequate. An improved precipitation technique for recovery of U with improved particle size and settling rate of precipitate was developed and demonstrated at Tumallapalle mill based on enhancing the concentration of leach liquor from 1 g/l to 2.5 g/l U_3O_8 by dissolving Sodium Di-Uranate (SDU) followed by its precipitation in two stages using NaOH solution as precipitating reagent. This improves precipitation and separation efficiencies of SDU up to

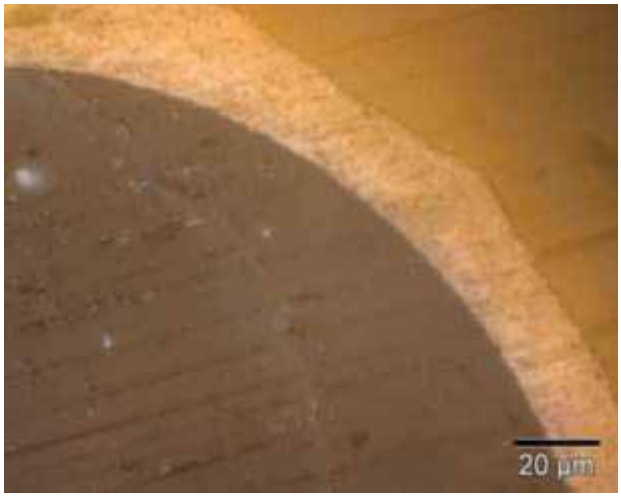


Experimental set up for the precipitation of Sodium Di-Uranate from leach liquor of Tummalapalle uranium ore

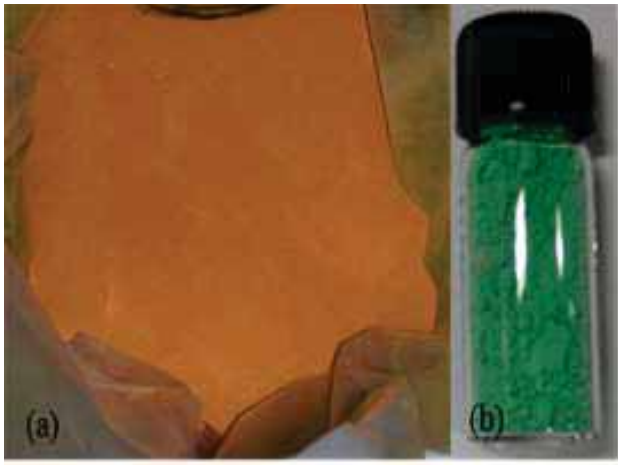
level of 99% and 97% with lesser reagent consumption and lower precipitation time.

A study was undertaken to lower U content in the mine waters of Tummalapalle uranium mines. Of the various Strong Base Anion exchange resins (SBA) screened for their efficiency for sorption of U values w.r.t. loading capacity and kinetics, commercial SBA coded PFA 4759 gave the best performance. Elution with sodium salts of various anions indicated desorbing about 95% of loaded U values with chloride and bicarbonate salts. Work on reducing sulphate levels in U depleted effluent is in progress.

Improvements in throughput for direct thermal denitration of uranyl nitrate to uranium oxide powder has been demonstrated in a pilot scale



Uo_3 layer deposited on glass bead



Powder received from reactor and UF_4 product

fluidized bed reactor. Trace amounts of sulphate addition improved specific surface area. UO_3 formed could be completely reduced to UO_2. Particles less than 53 microns could be fluorinated to acceptable grade Uf_4.

A study on the recovery of Rare earths from secondary sources by hydrometallurgical route was carried out on Neyveli Lignite Plant Flyash. Process involved agitation leaching with 1.5 M H_2SO_4 at ambient temperature, removal of gangue impurity with gelatin strike (6.7 g/L dosage), single stage extraction with Di-(2-ethyl hexyl) phosphoric acid (D2HPA) in kerosene and cross current stripping using 6M HCl.

Nuclear Fuel Fabrication

Nuclear Fuel Complex, a constituent unit of DAE in its Industries Sector is engaged in the production of natural uranium oxide fuel bundles for PHWRs, enriched uranium fuel assemblies for BWRs, reactor core structurals, reactivity control mechanisms and special materials like tantalum, niobium etc. In addition, NFC produces all the core sub-assemblies and other critical components like fuel cladding tubes, Hexagonal wrapper tubes etc., made out of special stainless steels/ D9 materials for Fast Breeder Reactors. NFC also caters to the demand of high quality stainless steel tubes/ pipes, Al-6Mg alloy tubes, Nimonic-75 tubes, MDN-400B tubes, 30KHGCA tubes, SuperNi-42 tubes and titanium alloy products for critical and strategic application in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

PHWR Fuel

During the year, NFC has successfully manufactured a record no. of PHWR fuel bundles and met the requirement for all the PHWRs in time. All the indigenous raw material in the form of MDU/HTUP/SU received from M/s UCIL was converted into 19 element and 37 element fuel bundles for meeting the requirement of Out of Safeguard (OSG) reactors.

NFC has achieved highest ever production of 1023.69 MT of PHWR fuel bundles in the financial year till December, 2015 and is marching towards production of 1500 MT during the year 2015-16, which will be the highest ever production since the inception of NFC.

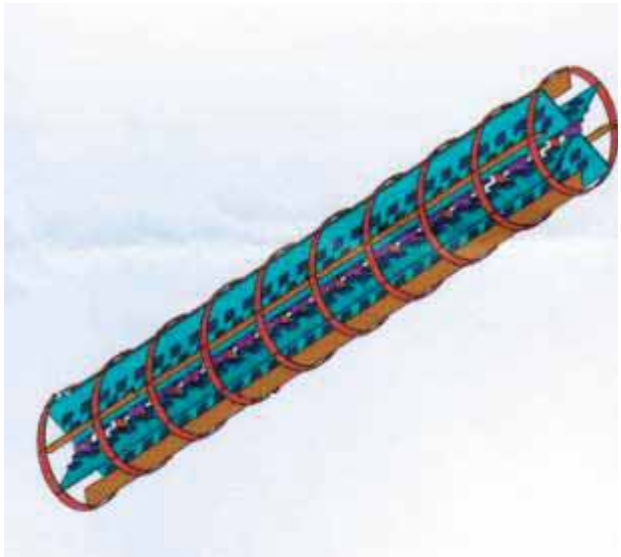
Production of 50 BWR fuel assemblies was achieved during the year and target of 100 assemblies would be completed during the financial year 2015-16.

Developmental works in fuel plants

The developmental works in fuel plants at NFC involved the following:

Innovative design of new baffle for calcination furnace

A first of its kind, cascade lifters were designed for an existing Rotary Calcination Furnace at UOP, for optimal internal heat transfer area. The newly designed baffle was fabricated in house. The successful commissioning of new baffle resulted in drastic reduction in Calcination temperature from 730^{0}C temperature to 665^{0}C. The unique screw type internal cascades also drastically reduced the powder entrainment in off gases and thereby increased period of scrubber cake removal from 50 batches to 100 batches. This has increased furnace availability and reduced consumption of valuable man hours. This design has undergone two stage modifications and the present design uses 85% of furnace circumferential area compared to 15% of existing setup.



Design of new baffle for calcination furnace

Process development for chemical treatment of Ammonium Nitrate filtrate

An innovative process was developed for chemical treatment of ADU filtrate by mixing UNR with ADU filtrate and neutralisation with ammonia before disposal by sale. This resulted in reduction of nitric acid and ammonia consumption by 0.5 MT and 80 kg respectively per ton of UO_2 production.

Process development of Continuous neutralisation and precipitation of Clear Pregnant Liquor (CPL) to increase uranium recovery for production of SU

A new innovative continuous neutralisation, precipitation and filtration process was developed at NFC at pilot scale. The pilot plant also includes thickener fabrication & utilisation.

Design, Fabrication and commissioning of final compaction press



Design, Fabrication and commissioning of final compaction press for production of Uranium Di Oxide powder

For the first time in the history of NFC, the hitherto imported final compaction press for production of Uranium Di Oxide powder compact was indigenously developed, erected and commissioned. It has sophisticated features like programmable controlled double compaction and synchronous ejections. The press is now being operated continuously.

Pick & place system for final compaction press

A new pick & place system was developed using precision linear actuator driven by servo motors for precise movements in horizontal and vertical directions, which improved machine availability time for production, reduced rejection rate and radio activity during handling.



A new pick & place system driven by servo motors



Automation of End Cap Welding Machines

Automation of End Cap Welding Machines

Three machines were converted from manual operation mode to fully automated mode and put into production. Safety curtains were installed for enhanced operator safety during operation.

Introduction of Metallic Jigs

Perspex jigs used for maintaining inter-element spacing during endplate welding were replaced with more environmental friendly metallic jigs with much higher life which also ensured better surface quality of the fuel bundles.



Metallic Jigs



Perspex jigs

Design & development of De-canning machine

Separate dry cutting & de-canning machine was designed & developed with facility for cutting of rejected elements and retrieval of UO_2 pellets on a single machine thus avoiding external contamination of pellets & substantially improving the overall recovery of pellets during de-canning.



Design & development of Dry cutting & De-canning machine

Design and fabrication of automatic cutting and polishing machine

Automatic cutting and polishing machine was designed & fabricated in-house and put into use



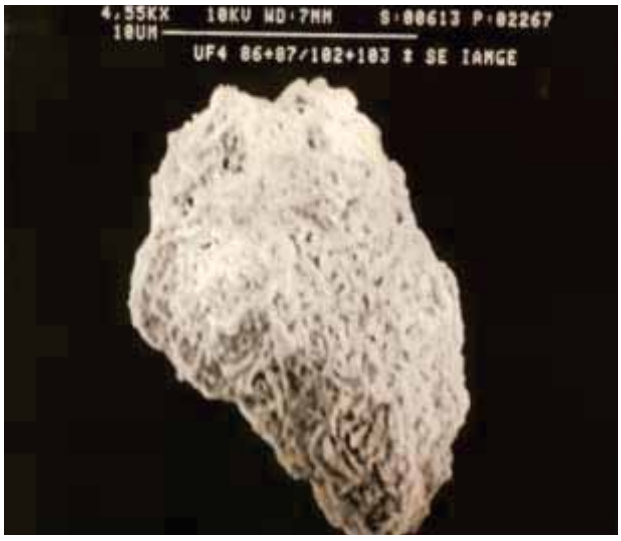
Design and fabrication of automatic cutting and polishing machine

at Block-A for the setup and process end cap sample welds. This unit is capable of cutting and polishing 11 samples at a time. This has reduced the sample preparation time and also increased productivity.

Metallic Fuels

Production of nuclear grade U metal continued to support operation of DHRUVA at elevated power level.

Achievements in the field of U-metal production includes operation of mechanized unit for reactor charging (UF_4 & Mg mixture), Rotary Slag (MgF_2) drying system for further utilization of the produced slag and mechanized system for MgF_2 handling and treatment for uranium recovery from the slag.



Morphology of UF_4 powder



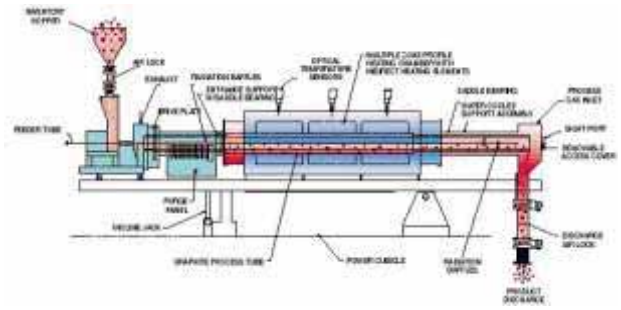
Magnesiothermic process units



U – metal ingots (Product)



MTR reactor charging



Slag drying unit

Structural Materials & Components

Zirconium activities

Zirconium Oxide Plant has achieved production of 452.389 MT of Zirconium Oxide powder during the year till December, 2015, which is the highest ever production for this period.

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.

Developmental works in Extrusion and Piercing Plant (EPP)

Expansion and extrusion of a new material MDN 400B which is an advanced material than MDN 350 alloy for Midhani for strategic Nuclear application.



Expansion and extrusion of a new material MDN 400B



New alloy grade of 30KHGCA for BrahMos application

A hot product in new alloy grade of 30KHGCA for BrahMos application was successfully developed.

Core Structurals

Special Tube Plant (STP)

Around 202 nos. of pressure tubes were produced for 700 MWe PHWRs through new route of double radial forging and single pilgering, thus, meeting the complete requirement of KAPP-3 & 4 and RAPP-7 & 8 reactors.

Following developmental works were carried out in Special Tube Plant (STP):

Manufacture of SS D9 hexcans

STP manufactured 100 nos. of SS D9 hexcans of size 47.3mm (A/F) x 0.7 mm WT and 50 nos. of hexcans of size 49.8mm (A/F) x 1.0 mm WT by round-to-hexagonal pilgering route. These are to be used as wrappers in Fast Breeder Test Reactor.

Development and manufacture of 9Cr-1Mo PFBR hexcan

9Cr-1Mo material has excellent swelling resistance to doses even up to 200 dpa and has been reported to show the lowest increase in Ductile-Brittle Transition Temperature (DBTT) among the various grades of ferritic-martensitic steels. These materials are very promising for wrapper applications and are likely materials to be chosen for subsequent cores of PFBR. Process route for manufacture of 9Cr-1Mo hexcans of sizes 47.3mm (A/F) x 0.7 mm WT and 49.8mm (A/F) x 1.0 mm WT through pilgering route was successfully developed. Trials were carried out at various temperatures and quenching rates to optimise the normalising and tempering parameters. The hexcans so produced successfully met all the requirements of metallurgical and mechanical properties.

Design and fabrication of Fuel Tube End Cap Weld Sample Preparation machine

It has two cutting heads and two polishing heads. One cutting head is mounted horizontally while the other one is mounted vertically to enable



Design and fabrication of Fuel Tube End Cap Weld Sample Preparation machine

horizontal slitting and vertical cutting in sequential manner. There is a turn table on which upto 10 nos. of fuel tubes can be held for cutting and polishing simultaneously. After completion of cutting and slitting, the table can be rotated 180^0 to polish the tubes with the help of two polishing heads mounted on the other side. This machine improved the productivity and reduced the manpower requirement.

Development of Zr-1%Nb Tubes

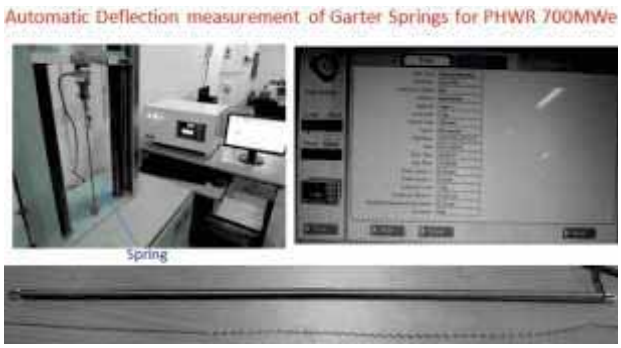
Manufacturing process for Zr-1%Nb tubes of size 60mm OD X 0.8mm WT was successfully developed as an import substitution. The process route involves 3 stage pilgering with intermediate annealing.

Development of a unique process of end spinning for carrying out crimping of ends of the tubes

NFC developed a unique process of end spinning for carrying out crimping of ends of the tubes. Studies on the crimped end revealed that they were free from any discontinuities and cracks.

Reactivity Mechanisms

For the forthcoming 4x700 MWe reactors, a process route was established for production of various reactivity control mechanisms such as Adjusted Rod Guide Tube (ARGT), Shut off Rod Guide Tube (SRGT) and Control Rod Guide Tube (CRGT), Liquid Zone Control Unit (LZCU), Vertical Flux Unit (VFU), Horizontal Flux Unit (HFU) and Liquid Poison Injection Unit (LPIU). One complete set of these assemblies were manufactured for KAPP-3.



Computerized load testing system

Developmental works in Reactivity Mechanisms (RM)

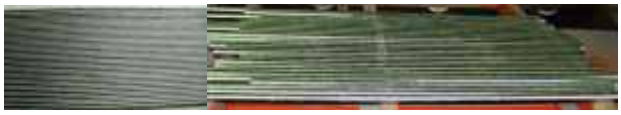
A Computerized load testing system for measurement of length, deflection and residual extension of garter springs was developed and installed for higher reliability and productivity on which all the garter springs of 700 MWe PHWR were tested.

Fuel Tubes & Components

More than 14 lakh fuel tubes were manufactured during the year with a record monthly production of ₹ 2.05 lakhs during December, 2015.

Developmental works in Fuel Tubes Plant

Tubes for strategic application are made of super alloy of Chromium & Nickel. SuperNi-42 tubes were developed in collaboration with BARC and were supplied. These tubes are highly corrosion resistant and have high strength at very high temperatures making them most suitable for critical and demanding applications. A special purpose continuous furnace was developed for the repeated annealing involved as a part of the developed process. After the first set of 230 trial tubes, the bulk order is being initiated.



Development of SuperNi-42 tubes

Around 200 nos. of Zr4 tubes of 8.1 mm outer dia and 0.7 mm thickness were produced for Fuel pins of PRP reactors. Small diameter Zr4 tubes (6mm to 19 mm dia) of extremely thin wall (0.3mm - 0.75mm) and 7m in length requiring very close

control of parameters for various RM assemblies (LZC, VFU & HFU) were produced. Optimisation of pilgering parameters and annealing parameters was done at each stage for development and production of double clad trail tubes of AHWR.

Complete replacement of Polyurethane foam plug by bio-degradable pure wool felt plug was successfully carried out at Tube Degreasing unit, NZFP. This has made the tube production process more environment friendly apart from improving the surface quality of the tubes.



Bio-degradable pure wool felt plug

Special Materials

Antimony trioxide oxide filled SS capsules were produced and supplied to meet the full core requirement of neutron source sub assembly of PFBR. Produced & supplied micron size zirconium metal powder to meet emergency requirement of Defence department. Micron size Zircaloy & Zr2.5Nb powder for coating studies in high temperature applications were produced & supplied.

Commercial activities

The Stainless Steel Tube Plant (SSTP) specialises in manufacturing speciality tubing in advanced grades of Stainless Steels and special alloys such as SSD9, Mod. 9Cr-1Mo, Incoloy-800 (UNSN08800), Inconel-600, Ni-Cr-Mo alloy, Al-Mg alloys, Titanium alloys, Nimonic-75 tubes, MDN-400B tubes, 30KHGCA tubes, SuperNi-42 tubes etc. for strategic applications in areas such as Nuclear, Space and Defence.

SSTP has established the critical facilities for operations such as U Bending, Glass Bead Shot Peening, Inspection & Testing, etc. for manufacturing extra-long Seamless Steam Generator tubes up to 30 m length required for Nuclear Power Plants. SSTP has successfully supplied Incoloy-800 U-bend Steam Generator tubes for 700MWe PHWRs.

During the report period, SSTP manufactured and supplied critical products which include 1 set of Incoloy 800 U-bend Steam Generator (SG) tubes for upcoming 700MWe PHWRs, 2800 nos. of SS-D9 grade Fuel clad tubes for Prototype Fast Breeder Reactor, SS304L hollow bar tubes for TAPS, 4200 nos. of FBTR fuel clad tubes in SS316M & D9, IFAC fuel clad tubes for future FBR, 1100 Kg of Al-6Mg tubes for Defence application, Nimonic-75 for nuclear strategic application, Titanium full alloy and Titanium Half Alloy tubes for Space applications.

Developmental works in SSTP

In addition to the above regular production activities, a number of developmental activities of strategic nature were also under taken at SSTP for advanced Nuclear, Defence and Space programmes of the country.

D9 cold worked tube is used as clad material for Prototype Fast Breeder Reactor. Moderate Void swelling resistance of D9 clad tube limits the life of the fuel subassembly. As a result, it is not possible to achieve high burn-up with D9 as a clad tube. 18 Cr-ODS (Oxide Dispersion Strengthened Steel) is one of the potential materials having excellent void swelling & corrosion resistance. Manufacturing process for 18-Cr ODS clad tube was developed successfully.

Projects

Green field Projects of NFC

NFC-Kota

NFC-Kota, Rawatbhata, Rajasthan, a green field project, is being established to produce 500 tpy of UO_2 Pellets and 65 tpy of Zircaloy Products to meet the fuel requirement of four 700 MWe PHWRs viz., RAPP 7&8 and Kakrapara 3&4.

Consent for establishment was obtained from Rajasthan State Pollution Control Board (RSPCB) and site clearance from AERB were obtained. Site grading work is in progress. Orders were placed for site infra structural works and for

construction power supply. These works are in progress. Design Basis Reports and Preliminary Safety Analysis reports were reviewed and approved by AERB. Pre-qualification of bidders is in progress for Plant civil works and action is on for procurement of long delivery equipment. An overall progress of 9.9% was achieved in the project till December, 2015.

NFC-5 & 6

These projects were earlier planned to meet the fuel and Zircaloy requirements of 16 more nos. of 700 MWe PHWRs planned by NPCIL during XIII and XIV Plan periods. NFC-4 will be set up at NFC-Kota site and will be taken up at appropriate time to meet 100 tpy of Zircaloy fuel component production. The requirement of NFC-5 & NFC-6 is reviewed and it is now proposed to augment the facilities at NFC, Hyderabad and NFC-Kota to meet the above requirement.

Other sanctioned projects of NFC

Some of the major equipment like Horizontal Vacuum Annealing Furnace, 10-20 type pilger mills, Band Saw machine for blanks, 3-axis & 5-axis Vertical machining centres, Sintering furnace, Walking beam furnace were commissioned and put into production line.

Air monitoring station and Electro coagulator were commissioned to meet the requirement of statutory bodies.

Activities of procurement of balance equipment and works are in various stages of execution.

Approval of proposal for expenditure sanction for the 6 projects (3 proposed originally for setting up AHWR fabrication facility & Radial Forging Facility and 3 during MTA) are under consideration at DAE.

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. 356.2 MT of nuclear pure zirconium oxide and 180.62 MT of zirconium sponge were produced during the year till December, 2015.

Desalination Plant at Zirconium Complex

Desalination Plant with two streams each of capacity 30 m^3 per hour of product water is being set up at Zirconium Complex at a sanctioned capital cost of ₹ 20 Crores. Construction of RCC storage tanks for seawater, product water, reject water etc. was completed. Civil construction works for plant buildings were almost completed. Structural fabrication and erection works were completed. Major equipments were received. Transformers were installed and charged. Laying of pipelines for product water and reject water was completed. Erection activities for installation of equipment and other electrical systems are in progress.

Construction of sea water pump house is in progress. Welding of pipes required for sea water intake system was completed. Clearance from Tamil Nadu Maritime Board is awaited for taking up off-shore works.

Magnesium Recycling Technology Development & Demonstration Facility

It is planned to set-up a Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF) at Zirconium Complex, Pazhayakayal, Tuticorin with a capital cost of ₹ 32.4 Crores to perfect the technology developed by Defence Metallurgical Research Laboratory (DMRL) for industrial scale operation. The project is being implemented jointly by NFC, HWB, and DMRL under a Memorandum of Understanding (MoU).

Geo-technical investigations were conducted. Detailed engineering is in progress. Tenders were floated for civil construction works, melting furnaces, cables, transformers and electrical panels. Tender specifications for various equipment systems / materials such as electrolytic cells, dehumidification system, Chlorine handling system, cooling towers, refractory, graphite and electrical equipment were finalised.

Documents required for issue of siting and construction consent from AERB were submitted.

NFC Safety Committee reviewed the documents and recommended for issue of consent for siting and construction.

Melt shop

The process of salvaging of Zirconium fines was continued and 78 Tons of Zirconium sponge fines were salvaged. Electron beam gun filament assembly of 45 KV / 60KW Electron Beam welding unit was indigenised. Process of producing double melted 350 mm dia Zircaloy-4 ingots, without machining at intermediate stages was established to increase the recovery. 134MT of Zircaloy scrap was recycled through plasma melting.

Niobium Thermit Production Facility

Various activities are in progress towards the establishment of Niobium Thermit Production Facility (NTPF), a project jointly executed by NFC & VSSC.

BACK END FUEL CYCLE

Fuel Reprocessing

Nuclear Recycle Board (NRB) is responsible for execution of projects and operation of plants in the back-end of the fuel cycle at Tarapur and Kalpakkam. All the plants are operating at their design capacity. PREFRE-2 plant achieved its name plate capacity and is expected to achieve 122% of its rated capacity by March 2016.

Kalpakkam Reprocessing Plant (KARP) has achieved an all-time highest operation capacity during this year. Nuclear fuel from the above operating plants is supplied to Fuel Fabrication Plant for fuel loading of Prototype Fast Breeder Reactor (PFBR).

Warm Commissioning of Power Reactor Fuel Reprocessing Plant-3A (PREFRE- 3A) at Kalpakkam started by chopping and dissolution of Deep Depleted Uranium (DDU) fuel bundles. The DDU trials in solvent extraction cycles and evaporation of various process streams are in progress. Construction of front end blocks of Integrated Nuclear Recycle Plant (INRP) and civil and mechanical works for Additional Spent Fuel



In-cell piping at PREFRE- 3A, Kalpakkam



Control Room, PREFRE- 3A, Kalpakkam



Uranium Separation System at WIP, Kalpakkam

Storage Facility (ASFSF) at Tarapur is in progress. Civil works of Vitrified Waste Storage Facility (VWSF) at Kalpakkam are nearing completion.



Shielded Ion exchange treatment columns for ILW system at Kalpakkam

Power Reactor Thorium Reprocessing Facility (PRTRF) was hot commissioned to recover ^{233}U from irradiated Th. Two batches of power reactor irradiated thoria were processed using 5% TBP based THOREX process. Technology based on laser was used to cut the end plates of thoria bundles to recover ^{233}U. Demonstration of reprocessing of irradiated thoria bundle and quantitative separation/recovery of ^{233}U is an important milestone in the 3 stage nuclear power program based on thorium.

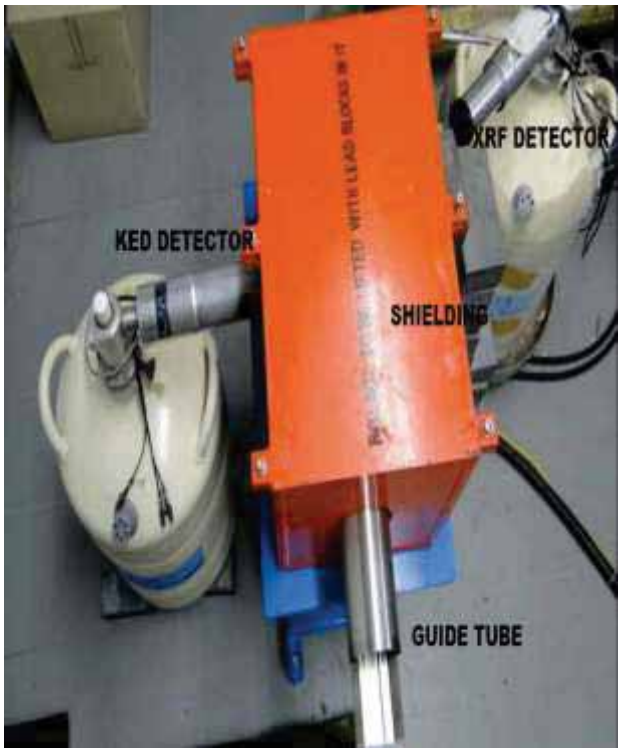


Dismantled Fuel Pins after Laser cutting

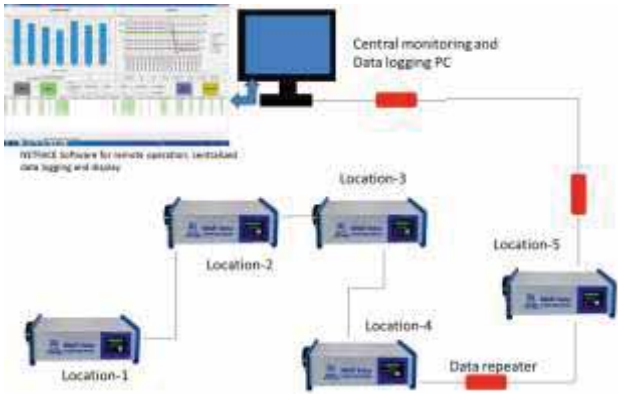


^{233}U Oxide

A Hybrid K-edge Densitometry (HKED) system was designed and fabricated for the online Non-Destructive Assay (NDA) of mixed actinide solution in dissolver solution in a reprocessing plant. The instrument can be deployed for the analysis of U/Pu in samples from dissolver equipment of reprocessing plants. An online Thoron monitoring network has been installed and made operational at the Power Reactor Thoria Reprocessing Facility (PRTRF) at Trombay to monitor the thoron gas concentration at various locations in the facility. It utilizes indigenously developed ZnS(Ag) scintillation technology based thoron monitors wherein the counts obtained are converted to thoron concentration (Bq/m^3) by a micro-controller built smart algorithm. Online data from six such monitors, connected to a RS-485 network, is transmitted to a PC situated at control room for centralized data logging and display. The in-house built GUI named "NETFACE" is used for remote operation, accessing history of logged data and monitoring of health status of monitors at any time.

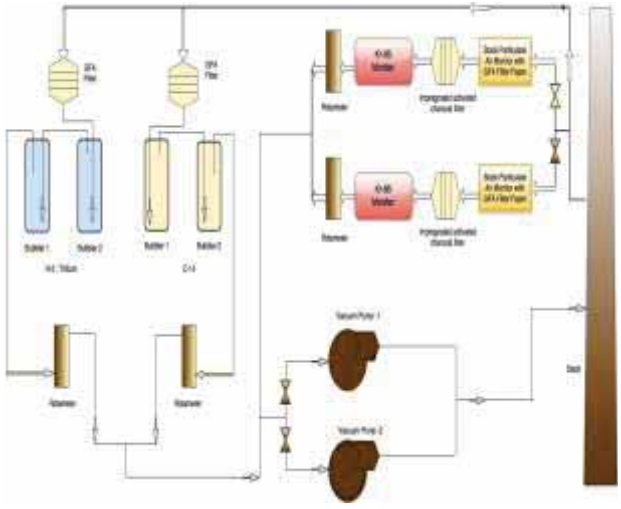


K-edge densitometer



Block Diagram of OnLine Thoron Monitoring Network installed at PRTRF

A comprehensive off-gas continuous sampling methodology for the estimation of gross, β particulate activities, ^{85}Kr, ^{3}H, ^{14}C and ^{129}I in gaseous effluents has been developed for fuel reprocessing plants. Suitable radiometric methods such as gross / β air monitors for online sampling & monitoring of particulate activity and GM tube based ^{85}Kr monitoring system (online) have been incorporated.



Comprehensive off gas sampling system for effluents

Large scale synthesis of a Pu (IV)-selective bifunctional resin with uniform particle size and morphology was accomplished to selectively sequester Pu (IV) ions from the LLW over a wide pH range and the segregated Pu (IV) can be easily recovered at a lower acidity. A new class of diamides with a triarylpyridine spacer, developed indigenously, showed high selectivity for separation of Pu (IV) ions from U (VI) and Am (III) ions with nitrobenzene or dodecane as diluent.

Computational Fluid Dynamics (CFD) based simulations for various types of pulsed columns were continued at BARC. A 3D model was developed to simulate pressure gradient and axial dispersion in single-phase pulsatile flow in Pulsed Sieve Plate Column (PSPC) and validated against experimental results. Single-phase CFD simulations of Annular Pulsed Sieve Plate Columns (APSPC), Pulsed Disc and Doughnut Column (PDDC) and Annular Pulsed Disc and Doughnut Column (APDDC) were done and validated with experimental results. This study is useful in optimization of pulse column size.

Waste Management

About 100 mCi of radio chemically pure ^{90}Sr was separated from PUREX-HLLW using multi step solvent extraction, ion exchange and precipitation techniques. Separated product was used for the separation of carrier-free ^{90}Y using two stage ^{90}Sr-^{90}Y generator system for routine radiopharmaceutical applications.



^{90}Sr-^{90}Y Generator System

Industrial scale synthesis of 1,3-dioctylcalix[4]arene-crown-6, for the recovery of Cs^{1+} ions from HLW was accomplished with appreciable cost reduction. Recovered radioactive Cs^{+} ions are useful in blood irradiator and brachytherapy.

Advanced Vitrification Systems (AVS), Tarapur completed vitrification of 80 m^3 of radioactive liquid waste (High Level Waste - 67 m^3 & Secondary Waste - 13 m^3) in Joule Melter against the rated capacity of 50 m^3 of HLW. Total 75 canisters were produced. Intermediate Level Waste (ILW) from Waste Tank Farm (WTF) and Additional Waste Tank Farm (AWTF) were received and treated in Tank Remediation by Ion Exchange (TRIX) & ILW-2 plants. A total of 315 m^3 ILW treated against the target of 200 m^3. To augment the capacity of ILW processing, an intermediate level waste treatment facility (ILW-2) was set up, commissioned and made operational.



(AVS), Tarapur



ILW-2 at Tarapur

Waste Immobilization Plant (WIP), Kalpakkam has created an operational record by processing more than 650 m^3 of ILW, leading to emptying of more than two waste storage tanks of KAlpakkam Reprocessing Plant (KARP).

Uranium from HLW has been successfuly recovered in Uranium seperation plant and one high level waste storage tank of KARP was emptied. Other back-end fuel cycle facilities such as Liquid Waste Treatment Plant, Tarapur Rad-Waste Augmentation Plant and Solid Waste Management Facility operation continued satisfactorily to meet the waste management requirements of Tarapur.

Centralised Waste Management Facility (CWMF), Kalpakkam continued to provide uninterrupted radioactive waste management services & filter testing services to various units of DAE at Kalpakkam. Treatment of about 1500 m^3 Technetium-rich waste from ILW Plant of WIP was successfully carried out. To meet the requirements of solid waste disposal, Tile holes, RCC trenches and Brick Walled Trenches were constructed. Installation

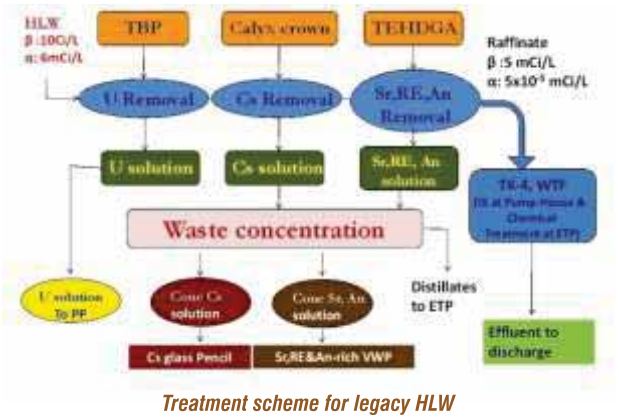


200 Te Compactor at CWMF Kalpakkam

of 200 Te Compactor for volume reduction of compressible waste will be completed by March 2016. Design and procurement activities of waste management equipment and piping systems of WMP, Fast Reactor Fuel Cycle Facility (FRFCF), Kalpakkam are in progress.

Operation of Plutonium Plant, Trombay was continued to complete processing of all the spent fuel from Dhruva to fissile and fertile material. Metallurgical Waste Processing Facility (MWPF) was operated using solvent extraction process developed in-house employing indigenously synthesised solvent. The heavy metal recovered was converted to oxide through oxalate route for its subsequent use in fuel fabrication.

An innovative method based on partitioning of the radio-elements from the inactive salt constituents by deploying indigenously developed solvents has been made operational and proved successful in management of radioactive waste with multifold advantage. HLW was subjected to three step separation process involving TBP for U - separation, Calyx crown solvent for Cs- separation and Tetra (2-ethyl hexyl) diglycolamide (TEHDGA) solvent for Sr and actinide separation. 40,000 L of HLW was treated/conditioned in a year indicating a threefold increase in the processing capacity of the plant. This scheme also facilitated the recovery of valuable components from waste, thereby redefining it as wealth. 800 kg of U has been recycled to Plutonium Plant. Cs was selectively separated from this HLW stream and utilised in pencil preparation.



Treatment scheme for legacy HLW



Handing over of Cs-pencil for blood irradiation

80,000Ci Cs was separated selectively from HLW using in-house developed calyx crown-6 solution and immobilized in vitreous matrix on engineering scale. 33 nos. of Cs pencils of 1.7 Ci/gm specific activity have been produced and handed over to BRIT for application in blood irradiators. India stands out as the first country to realise recovery of Cs from waste. Effluents generated from this treatment were in very low level of gross β, γ activity and by and large non-alpha. Solidified HLW volumes have reduced 15-fold on adoption of this methodology. By adopting this scheme, the strategy of waste management on minimising the volume of waste and concept of recover & recycle of waste components has been implemented.

Indigenously available Synthetic zeolite 4A (as such) and 13X (with Copper Ferrocyanide impregnated) were tested for pickup of Sr and Cs respectively from LLW. Use of synthetic zeolites will not only minimize the dependence on dilution but also significantly reduce the absolute quantity of radioactivity disposed to the environment through aquatic route.



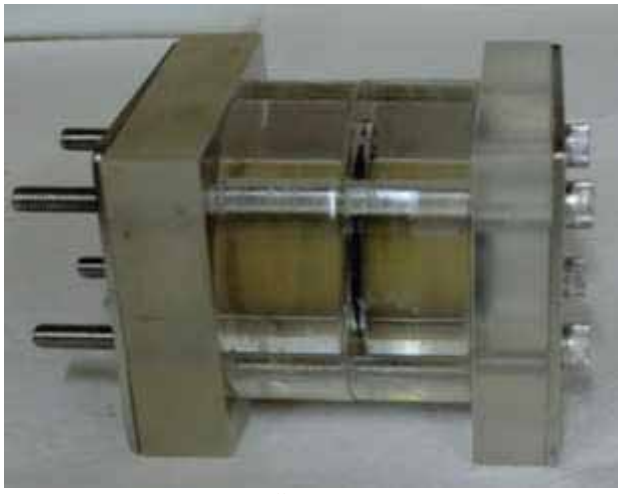
Disc Tube Type Module Configuration



Spiral Wound Type Module configuration

To lower the discharge of radioactivity to the environment by liquid route, innovative processes such as reverse osmosis was tried on pilot scale to treat LLW. Two pilot plants using disc tube and spiral wound module membrane configurations of capacities 30 m^3/d and 100 m^3/d were operated to treat 800 m^3 and 2400 m^3 of LLW respectively. The permeate activity was brought down from 10-15 Bq/ml to less than 1 Bq/ml in both the pilot plants, volume reduction factor of disc tube was 5 and that of spiral was 2.

Diffusion of fission products in smectite rich natural clay, proposed as a backfill material in the Indian geological repository, was studied using the out-diffusion method. A thin planar source of radioactivity placed between two clay columns diffuses out, was used to obtain the diffusion coefficients of long lived fission products, namely, ^{137}Cs, ^{90}Sr and ^{152}Eu (as chemical analogue of ^{241}Am). The study is useful in assessing the performance of the clay in retaining the radionuclides over long period of time.



Diffusion cell

A campaign for contact dismantling of several -contaminated un-serviceable Glove Boxes (GBs) stored at the Alpha Waste Transit Storage Facility (AWTSF), Trombay were planned and a temporary facility for active contact dismantling was developed, designed & erected in the AWTSF. Active dismantling demonstration was successfully carried out generating valuable data on the radiological aspects as well as usage of tools & handling systems.

Safety Performance of Reactors

NPCIL is carrying out the deterministic and probabilistic safety assessment of nuclear power plants for regulatory clearance including design, siting, commissioning of new projects, safe operation, periodic safety review and extension of operating license/life management of operating plants.

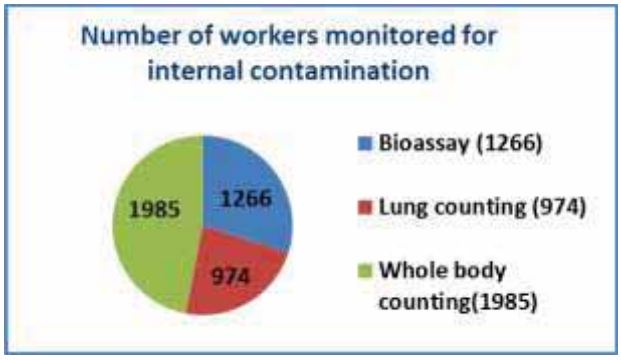
During the financial year 2015-16, following major activities were completed:

A test program was taken up for evaluation of internal coating of scrubber tank on the sample coupons to replicate the actual condition seen by the coating during accident condition. An epoxy tank liner by M/s Berger was qualified for use. Experimental studies for 700 MWe PHWR Containment Filtered Venting System were carried out at a design pressure in a scaled down model of scrubber tank with air and steam as carrier medium and for simulated radio nuclides. Studies for 700 MWe PHWRs for predicting the flow and temperature profiles inside the Mobile Transfer Machine to assess cooling adequacy of the spent fuel bundles were carried out.

Other major jobs include modelling of countermeasures such as iodine tablets, sheltering and evacuation and its effect on Radiological Impact Assessment during the severe accident condition for Decision Support System. Containment response during extended Station Black Out for KAPP-3&4 following manual crash cooling was analysed along with the Severe Accident Management Guidelines for arresting the progression of core degradation. Simulation of planned Passive Decay Heat Removal System experiment was conducted at indigenously developed R&D centre, Tarapur for the integrated system. Feasibility study of integral Inconel Self-Powered Neutron Detectors (SPND) in place of modular SPNDs in 540 MWe reactor regulation and protection system, in 1 pitch, 2 or 3 pitch configuration etc. were carried out. A comprehensive list of fire rating requirement of different plant areas for KGS-1&2 was prepared based on Fire Hazard Analysis to optimize the fire door requirements.

HEALTH, SAFETY AND ENVIRONMENT

Internal exposure assessment of occupational workers from various facilities of BARC at Mumbai and Tarapur was carried out by whole body/lung counting and bio-assay (urine/fecal) sample analysis. A total of 4225 radiation workers were monitored for the detection of internal contamination. Sensitive detection systems and analytical methods were used for the detection and measurement of internal contamination.



Radiological protection and environmental surveillance services were provided to front-end facilities like fuel fabrication plants, back-end facilities like fuel reprocessing plants and waste management facilities, RMP Mysore, PRP and Particle Accelerators. Environmental Surveillance around NPP sites and BARC, Trombay is carried out for radiological impact assessment of general public. Personnel monitoring services to ensure radiation safety of the workers and the installations for external radiation are being provided to about 30,000 radiation workers working in DAE. The Personnel Monitoring of non DAE radiation workers is provided through Laboratories accredited by BARC. The quality control of these accredited laboratories is being regularly and stringently maintained. BARC ensures accurate radiological measurements by maintaining Primary and Secondary Standards for radiation measurements.

A stainless steel calibration chamber has been designed, developed and commissioned for calibration and intercomparison of various indigenous and commercially available active monitors and passive devices for the measurement of radon, thoron and their decay products. This is



Radon and Progeny Calibration Chamber

envisaged as a national facility to be available to all institutes and universities engaged in radon research.

An indigenous radiation monitoring system was developed for long term environmental surveillance to provide time-correlated dose rate information of a location where it is placed. The system can store 4,00,000 data points of 1 minute interval and has a measurement range from background (100 nGy/h) to 5 mGy/h. The system has been conditioned for operating in extreme environmental conditions and has been installed at Indian station 'BHARATI' at Antarctica for carrying out gamma radiation mapping.



γ Register for Environmental Surveillance

A thin NaI(Tl) detector housed in graded shielding steel room was commissioned at Health Physics Laboratory, Tarapur for the in-vivo measurement of actinides (Lung counting) in occupational workers from fuel reprocessing and fuel fabrication plants. Calibration of the system was carried out using LLNL (Lawrence Livermore National Laboratory) thorax phantom for ^{241}Am and U (Nat.) standard sources. Regular monitoring of workers from the above plants has been commenced.



Lung counting system in graded steel room (the bed and detector are inside the steel room)



HPGe detector based Scanning Whole Body Counting System

A new Shadow Shield Bed Whole Body Counter (SSWBC) incorporating an HPGe detector has been developed for internal contamination monitoring of radiation workers. The system has been calibrated using standards of ^{133}Ba, ^{137}Cs and ^{60}Co uniformly distributed in water filled BOMAB (Bottle Manikin Absorption) phantom.

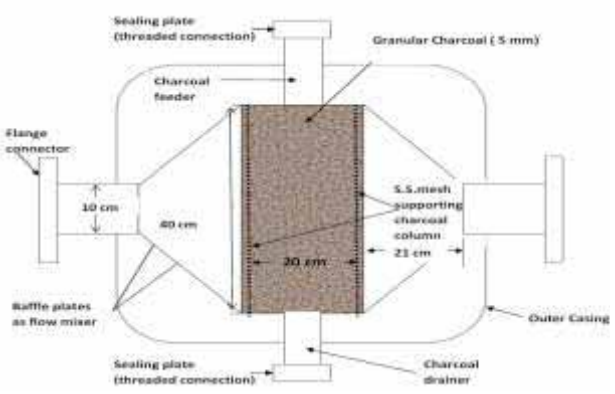
An automated image analyser system capable of counting the tracks produced by fast neutrons in CR-39 solid state nuclear track detectors was developed. The system is capable of processing 20 detectors at a time in a time space of about 2 minutes. System generates data file which is used for dose evaluation. It is used for extending neutron personnel monitoring services to DAE and non-DAE institutions.



Automated Image Analyser System

A tool to ascertain exposure condition of a Thermoluminescent Detector (TLD) personnel monitoring badge, particularly in case of excessive exposure, the technique based on the analysis of CCD images of TL light emitted from a TLD disc exposed under perforated copper filter for identification of static and dynamic exposure conditions has been developed.

A charcoal based iodine filtration system has been designed for use in the validation experiments of Containment Filter Venting System (CFVS) of TAPS 1&2. The charcoal bed is designed for an inlet iodine concentration of 500 mg/m3. This system is based on the theory of breakthrough time and pressure drop across a packed bed as given by Kozeny-Carmen equation.



Charcoal based iodine filtration system

Studies were carried out using the Weather Research and Forecasting (WRF) model to simulate two cyclones namely Mahasen and Phailin. Cyclone track obtained from the model and best track data available from Indian Meteorological Department (IMD) reports on the two cyclones were found to be in good agreement.

Multiple Alpha Counting System (MACS) has been indigenously designed and developed by BARC for simultaneous counting of 9 filter paper samples for a given preset time for use in Advanced Fuel Fabrication Facility (AFFF), Tarapur. The system has identical 9 nos. of ZnS(Ag) scintillator probes coupled to a front loading drawer type assembly having 9 nos. of circular wells to hold filter papers. The entire assembly is covered by secondary light leak



Multiple Alpha Counting Sytem

tight housing on which LCD display & keypad is mounted. The system has an inbuilt algorithm for background subtraction and PC connectivity to store and print data. Counting time for 150 samples in a day is reduced from 12 h (with single counting system) to 1.5 h with this system. This will be very useful in many nuclear facilities handling Pu.

NPCIL has recorded about 430 reactor years of safe operation of reactors by the end of December 2015. 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 ALARA (As Low as Reasonably Achievable) 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 all operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001:2004 and Occupational Health and Safety Management System (OHSMS) as per ISO-18001:2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

For Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP), evaluation of Met Data, Pre-operational Radiological Survey, Dose Apportionment Studies were completed and siting consent obtained for GHAVP from AERB. The Coastal Regulation Zone (CRZ) clearance and clearance for diversion of forest land for NPP at MithiVirdi Gujarat was obtained from MoEFCC. Prepared and obtained approval of State Government and initiated implementation of Conservation Plan for Schedule-I species for NPP at Mithi Virdi, Gujarat. Three seasons environmental monitoring was completed for Environmental Impact Assessment (EIA) study in line with MoEFCC approved Terms of Reference (TORs) for NPP at Mahi- Banswara, Rajasthan. Form-1 was submitted along with required documents to MoEFCC for revalidation of Environmental Clearance for Jaitapur Nuclear Power Project (JNPP), Ratnagiri, Maharashtra Form-1 was submitted along with required documents to MoEFCC for obtaining approval of Terms Of Reference (TORs) for EIA for Kaiga-5&6, Karnataka. Studies for Special Plan for fisheries for Jaitapur region were completed in line with the requirements of environmental clearance for JNPP, Maharashtra. The updated EIA reports for NPPs at MithiVirdi, Gujarat and Chutka, Madhya Pradesh were submitted to MoEFCC for grant of environmental clearance for these projects.

The Environment Stewardship Programme (ESP) is a voluntary activity of NPCIL. Protecting environment in and around nuclear power plants is the main aim of ESP. Each site/ project of NPCIL is having a nature club named after a threatened bird of that area. A variety of nature programmes focusing on scientific studies of the bio-diversity in and around all nuclear power plants are done through ESP. Through ESP, training of local volunteers, surveys, organizing public awareness campaigns on environment, informing local public on various environment related issues, publishing articles on ESP etc. are also carried out.

An exclusive garden for butterflies is established inside the exclusion zone of Kaiga Generating Station. With nectar and host plants, the garden acts as a safe habitat for numerous butterflies. At Narora Atomic Power Station, a turtle breeding project has been taken up by NPCIL. The turtle project aims to increase the population of two

turtle species viz. Batagurdhongoka and Chitraindica, in association with an expert conservation agency.

A coffee table book on flowers found in and around nuclear power plants, “The Realms of Flowers" won the first prize for best coffee-table book in the PRSI (Public Relations Society of India) National awards 2014. A special feature on NPCIL's environment stewardship programme is published in the features page of PIB website. A feature on ESP "Towards zero emission of greenhouse gases", role of nuclear energy in reducing emissions is published in the Electrical India magazine in January 2015.

At NAPS, under the Project Turtle, an initiative has been taken up to conserve the Gangetic turtles. Through the turtle breeding facility setup in NAPS Township, about 150 neonates of turtles are hatched and released in the wild. An article named "Project Turtle - Narora" on the turtle conservation programme was published in the Science Reporter in June 2015. A survey on the bio-diversity and aquatic animals at RAMSAR of Brijghat to Narora site was done by the ESP members of NAPS. The survey of 3 days, found 69 species of birds with a total count of 5306, 6 species of turtles, 18 endangered Gangetic river Dolphins and an endangered Ghariyal.



Mudflat established in KKNPP to attract birds

NPCIL organized Bird marathons at Narora and Kaiga through ESP. A feasibility study at Rawatbhata for the vulture conservation was taken up through ESP. Similarly, a pair of mudflats was established at KKNPP Township in association with BNHS to provide a safe foraging habitat for water birds and migratory birds.

At NFC, an industrial scale (10 kl/hr) Electro Coagulator Facility was erected and commissioned, for treating the non process active water from Block A Fuel Plants and bringing down the uranium levels to less than drinking water limits, prior to its use for horticultural purposes. The Electro Coagulation facility consists of Electro Coagulator (EC), Dissolved Air Floatation (DAF), Pressure Sand Filter (PSF), Manganese Oxide (MnO_2) Filter and two numbers of filter presses for separation of solids from water after the DAF. The EC Facility can be operated in manual and auto modes through SCADA. Active waste water, containing Uranium in the range of 100 ppb to 79000 ppb (spiked up for the purpose of testing), were treated in this facility. The Uranium values in the treated water were maintained less than the permissible limits.



Electro Coagulator Facility at NFC

Continuous Ambient Air Quality Monitoring Station (CAAQMS) was procured, erected and commissioned. This facility comprises analysers to continuously monitor chemical pollutants like NOx, SO_2, CO, NO, NO_2, NH_3, Cl_2,PM_{10}, $PM_{2.5}$ and weather parameters like atmospheric pressure, temperature, relative humidity , wind speed, wind direction and rainfall, along with a Data Acquisition System. The unit was commissioned in April 2015 and has been in operation since then. The 24-hrly averaged data monitored with hourly / minutely observation was stored and reported to PCB, AERB and ISO audits on monthly and quarterly basis. Provision was also made for online hook up of the data to the TSPCB web site.



Weather Monitoring Station

All plants are certified for ISO Quality Management system, Environmental Management System and OSHA System. The overall safety standards of Heavy water Plants are far better than similar chemical industries in the country.

During the year, the HWP, Manuguru has achieved 246 days of continuous working without any RDI. The HWP, Kota achieved 594 days of continuous working without any RDI. The overall safety record of HWP, Hazira was excellent and it was in continuous operation for 2596 days without any reportable injury / accident. The overall safety record of HWP, Thal was excellent and plant remained in continuous operation for 2215 days without any reportable loss time injury / accident.

In the field of environment management, the Manuguru plant is implementing the road map for fly ash management during next five years for complete disposal of dry fly ash. This includes supply of fly ash to cement industries, ash bricks making, land filling and other uses. About 51% of fly ash generated during the reported period was utilized by HWP, Manuguru. Agreement is being worked out with an industry for setting up an ash brick unit at plant site. Two industries were given permit to lift ash from HWP, Manuguru for ash brick making.

RESEARCH & DEVELOPMENT

NPCIL's Technology Development activities are grouped under four verticals: R&D Facilities, Remote Tooling, Indigenisation and Construction Time Minimization encompassing design, analysis, development, engineering, procurement, construction, installation, commissioning, O&M, experimentation and equipment qualification related to these verticals. Inputs are provided from NPCIL HQ, then Corporate R&D Centre, Tarapur carries out execution related to experimental set ups and mock-ups for remote tooling.

These activities are aimed at achieving continual enhancement of nuclear & radiation safety, reliable operation and reduction in costs of Nuclear Power Plants, Indigenization, Construction time reduction and Development of New Reactor Systems.

R&D Facilities

Containment Filtered Venting System (CFVS)

A scaled down experimental test facility of the proposed design of Containment Filtered Venting System (CFVS) for 540/ 700 MWe PHWRs to mitigate Beyond Design Basis Accident (BDBA) scenario is erected at R&D centre, TAPS-3&4 site. Fission product scrubbing tests were conducted for assessing Decontamination Factor (DF) with respect to specified acceptance criteria. About fifty tests, including the characterization tests to establish the repeatability were carried out using injection of non-active chemicals such as elemental Iodine, Cesium iodide (CsI) and Methyl iodide mixed with compressed air/ steam flow as carrier medium. Based on analysis of these test results, the design parameters for the proposed CFVS for various Indian PHWRs are arrived at and the relevant Design Basis Reports are being prepared. Work on full scale CFVS test facility is in progress.

Iodine Scrubbing through Containment Spray System

The Iodine scrubbing tests for evaluation of iodine scrubbing efficiency by containment spray droplets and the effect of spray on containment pressure was completed at IIT, Mumbai. Tests on Cesium Iodide (CsI) scrubbing with spray are in progress.

Hydrogen Recombiner Test Facility (HRTF)

Further to AERB review of reports on Passive auto Catalytic Hydrogen Recombiner Devices (PCRDs) tests were conducted at HRTF. Additional tests were conducted with PCRD unit at different elevations/ positions within test vessel. Subsequently, PCRD tests with water spray in steam atmosphere simulating Containment Spray System operation in Reactor Building have also been conducted. Additional tests with steam, hydrogen injection and water spray are also being done. In parallel, Technical Specification for bulk production of PCRD for operating stations including testing & qualification criteria has been issued and tendering is in progress.

Integrated Thermal Hydraulic Test Facility (ITFT)

This facility comprising of NPCIL Thermal Hydraulic Test Facility (NTTF), BARC's AHWR Thermal Hydraulic Test Facility (ATTF) and AHWR Fuelling Machine Test Facility (AFMTF) has seen significant progress on all fronts in spite of several challenges. NTTF is being readied with simulation test of PDHRS for 700 MWe PHWR. The commissioning of all major NPCIL Thermal Hydraulic Test Facility (NTTF) process, control and electrical systems has been completed. Heating of primary system by directly heated channels with a heat load of 544 KW has been successfully demonstrated. The Passive Decay Heat Removal System (PDHRS) simulation test is expected to take place in 2016.

Fuelling Machine Test Facility (FMTF) for 700 MWe PHWR

The facility including all sub-systems is commissioned and made operational. Two numbers of Fuelling Machine Heads (KAPP-3&4) are received. Various calibration activities, testing & qualification of sub-assemblies were successfully completed. The FM Heads were installed on respective FM Test Carriages. After hooking up with coolant channel assembly, fuelling operation in semi-auto mode was completed at channel low pressure and temperature conditions. Fuelling operation at channel high pressure with fully auto mode is in progress.



Both FM Heads installed on Test Carriage at FMTF, R&D Centre

Environmental Qualification (EQ) Activities

Testing and qualification of 700 MWe PHWR components like airlock seals, Electrical Penetration Assemblies etc. and operating station components like FM Vault cooler motors have been conducted using the Gamma Chamber, Thermal Chambers and Loss of Coolant Accident (LOCA) Test Facility. Upgradation of LOCA test Facility for assessment of performance of safety related equipment for Main Steam Line Break (MSLB) / LOCA conditions of 700 MWe PHWR is completed. Pressure Transmitter (PT)/ Differential PT for Beyond Design Basis Accident (BDBA) nuclear application is being taken up.

Remote Tooling

Reactor Fuel Channel inspection Campaigns

Fuel/ Coolant Channel (CC) In-Service Inspection (ISI) campaigns using BARCIS for 220 MWe PHWRs (KAPS-1&2, RAPS-4, KGS-4, NAPS-2 & MAPS-2) successfully carried out in 2015 for which technical support, detailed training and qualification were rendered to respective operating units as scheduled. Technology enhancement of BARCIS Inspection Heads for 220 & 540 MWe reactor coolant channels and tool development for Coolant Channel (CC) sag measurement have been taken up.

Tools for repair works

Remote tools were developed for Pressure Tube Removal and end-shield repair works.

Carrier Tube Assembly (CTA) Removal Tool

To enable replacement of 13 m long CTA of TAPS-3&4 Vertical Flux Units (VFUs), integrated tool system developed, tested and qualified at vendor's workshop. The tool system includes gripper unit, cutter unit, shielding flasks and doughnuts. Shielding flask design optimized and is under manufacturing stage. All other items delivered to site and full scale

trials & qualification are being taken up at R&D Centre prior to deployment in next BSD.

Special Purpose Tools

Many special purpose remote tools were developed to meet the challenges at operating stations as well as to meet 700 MWe applications. Multiple tools and associated accessories were developed to meet the postulated scenarios and full scale trials & qualifications were done at R&D Centre.



Special purpose tools


Tool accessories and full scale trials

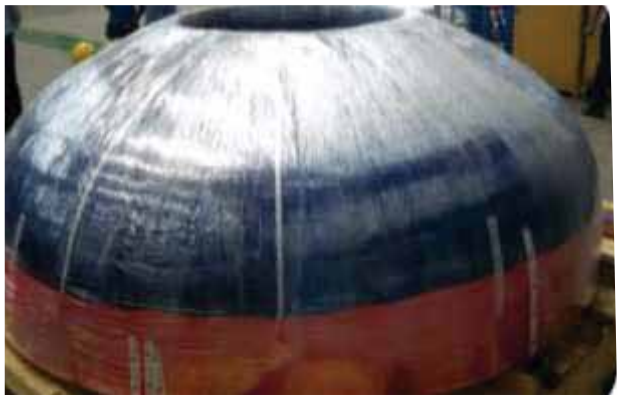
Eight types of tools were developed for 220 MWe Absorber Rod element retrieval and after full scale qualification and operation; the best suitable tools were adopted which led to smooth completion of field activities and immediate reactor start up.

Indigenization initiatives

Steam Generator (SG) Critical Heavy Forgings

Three critical forgings of 700 MWe PHWR SGs viz. Conical Shell, bottom and top heads were developed and delivered by NPCIL Joint Venture


Head Under Forging


Toripherical head Under Dispatch


Conical Shell-After Forging


Spherical Shell-Under Inspection

Company. The development faced many challenges and special heavy forging tools and fixtures for machining of heads were developed for these items.

Bleed Condenser Forgings

Development Purchase Order (PO) was issued for Bleed Condenser (BCD) component forgings for the 700 MWe PHWRs. These heavy forgings were successfully developed and delivered within the delivery schedule of 12 months.



BCD Conical Shell



BCD Shell Flange



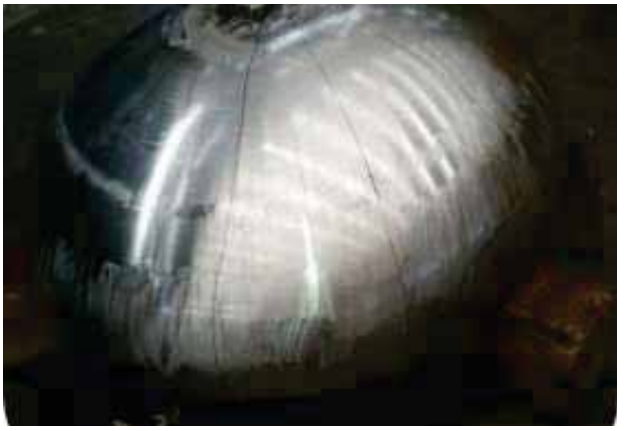
Shell



Flange with Integral Nozzles



Ellipsoidal Head



Hemispherical Head

FM Supply Pump Alternate Vendor Development

As part of the development of indigenous vendors for imported equipment or equipments with only one indigenous vendor, a new vendor was developed for Fuelling Machine Supply Pump for 700 MWe PHWR projects successfully. The triplex reciprocating plunger pump for fuelling machine supply system as per NPCIL specifications was designed and manufactured by the vendor in coordination with Directorate of Technology



700 MWe Fuelling Machine Supply

Development, QA and Procurement. The pump and motor are mounted on the same base frame and the unit is qualified for SSE seismic level.

Indigenous vendor base broadening

For other major forgings for components such as 700 MWe End Shield Lattice Tubes and Tube Sheet Plates, indigenous vendor development has been initiated and PO has been placed for the latter. Similarly, development of major equipment viz. Primary Coolant Pump motor and Shut Down Cooling Pump are in progress to ensure availability of indigenous supply chain.

Cobalt Absorber Rods (CoARs)

To produce Cobalt irradiation sources with high specific activity for both medical and industrial applications in India, design and development of 700 MWe CoARs has been completed. Technical specification and drawings for the CoARs for 700 MWe projects have also been issued.



New rope attachment Co coupler

CoAR Flask & Tools for 700MWe

Fabrication of dummy Shielding Flask for handling of CoARs at Site for full scale tool trials related to removal of CoAR is underway. Development of CoAR Handling Tool has been completed with full scale handling trials of ARs. Tendering has been done for the 9 m long remote tool fabrication for under water remote separation of Cobalt Bundles from the CoAR assembly. CoAR Bundle Dismantling Tool design optimized with trials and drawings issued. Vendor development for Cobalt



Co bundle opening tool



700 MWe Cobalt Adjuster Rod Bundle and Assembly

Bundle Retainer Ring, special conical helical springs etc. has been completed.

Pt-Clad SPND in-Core Qualification

Subsequent to development and in-core qualification/ characterization of 3 Pitch Coaxial Integral Inconel Self Powered Neutron Detector (SPND), development of 3-Pitch Integral Coaxial Platinum (Pt) clad SPND was completed. Two numbers of Pt-clad SPNDs was installed in TAPS-4 along with 2 nos. of 1.6 mm diameter cable in

December 2014 for reactor study. Performance of these Pt-clad SPNDs have been reviewed for about one year for their static and dynamic characteristics and compared with 2 nos. of Inconel SPNDs which have been installed in same HFU in 2011. Pt-clad SPNDs are evaluated to be 25-30% more sensitive in comparison to Inconel SPNDs and seen to be about 85-90% prompt over aged (3 FPY) Inconel SPNDs. This is in line with international literature with more than 70% promptness over Ion Chamber for Reactor Protection System application. Development of Vanadium SPND is in process.

Development of Primary Coolant Pump

Indigenous development of the 6 MWe Primary Coolant Pump (PCP) for 700 MWe reactors has been initiated and the development order is in process. Design and detailing of foundation & superstructure of proposed PCP Test Facility at R&D centre is in progress.

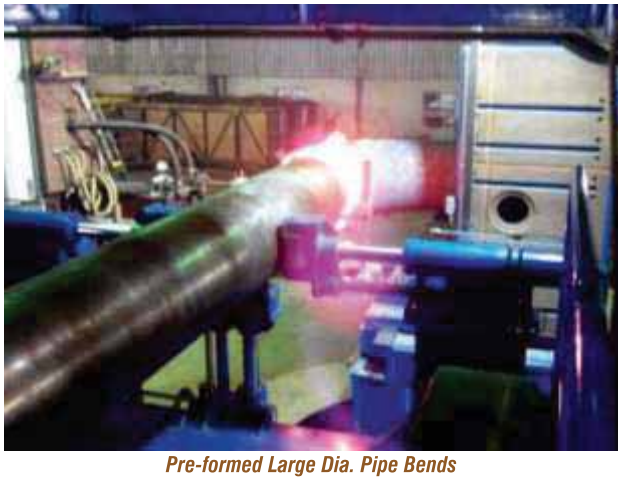
SS-Tube Fittings

Development of potential Indian manufacturers for supply of compression type SS-tube fittings are under execution with four vendors in parallel. Development process including hydro/tensile tests and type tests as per standards is in advanced stage by two vendors & expected to be completed by March 2016.

Construction Time Minimization

Pre-formed Large Diameter Pipe Bends

Construction time minimization of NPPs has been identified as one of the major thrust areas for development efforts in NPCIL. In this context, piping erection has been given due consideration and has been identified as a major area for utilizing technological advancements in the field. The potential benefits of using preformed piping spools include considerable reduction in project construction time, cost and better system integrity due to lesser number of welded joints, substantial reduction in In-Service Inspection requirements during plant operation etc. This technology would be useful for both PHWR & PWR Reactors. Technical evaluation of the process against specified requirements for NPP application has been taken up by NPCIL. Development order has been placed and detailed inspection/ testing is under progress.



Pre-formed Large Dia. Pipe Bends

End Shield Calandria Integral Assembly (ESCIA)

Erection of reactor vessel Calandria along with its End-Shields is a challenging task and is a critical activity in NPP construction. Implementation of ESCIA concept in 700 MWe PHWR has the potential to reduce this time. During the year, the various sub-concepts involved in ESCIA implementation were formulated. Various 3D models were created to represent these concepts. These sub-concepts were assessed with the help of engineering calculations, analysis and feedback from experts and site. After due diligence, final sequences of pre-fabrication, mock up, placement and alignment are being finalised.



End Shield Calandria Integral Assembly

Construction simulation of ESCIA implementation with the help of a state of the art software tool is taken up to effectively communicate the scheme to showcase the advantages from use of such state of the art tools in NPP construction.

Engineering and R&D in Electronics

Ongoing 700 MWe Projects

Detailed Engineering of KAPP-3&4 and RAPP-7&8 have almost been completed. Stress analysis including seismic qualification of major reactor components and nuclear safety related equipment pertaining to mechanical, electrical and Control & Instrumentation are completed. Stress analysis of high energy piping, nuclear system piping and qualification of its supports & EPs are also completed. Leak Before Break (LBB) analyses of the PHT system has been completed for the new compact layout after feeder-interleaving. Shielding & sealing constructions details for the ongoing projects are finalized. Engineering deliverables of Turbine Generator Package (TGP) and Balance of Turbine Island Package (BoTIP) for KAPP 3&4 are finalized.

As a part of the implementation of post-Fukushima safety upgradation measures, development of methodology for safety assessment of NPPs under extreme natural events (Beyond Design Basis Accidents other than earthquake) including its assessment for a typical NPP site has been completed. As a part of this exercise, detailed non-linear analysis of the 100m high ventilation stack was carried out to assess structural adequacy under beyond design basis wind loading. Similarly, the effect of beyond design basis climatic temperature on the structural adequacy was studied considering the longest building (Control Building) of PHWR based NPP.

Finalization of methodology for seismic margin assessment of safety-related nuclear power plant structures under beyond design basis earthquake scenario and assessment of the same for a typical NPP safety-related structure have been completed including regulatory acceptance.

Fabrication and installation of self-supporting type design of Reactor Building (RB) Inner Containment (IC) dome liner system with two large openings, a first-of-its-kind in the world, have started in KAPP-3. Detailed engineering of Containment Filtered Venting System (CFVS) and Passive auto Catalytic Recombining Device (PCRD) is completed. Environmental Qualification (EQ) requirements for various Systems, Structures & Components (SSCs) were finalized and the EQ is in progress.

Development & integration of various process and safety systems replica of Operator Training Simulator for KAPP-3 are completed and station transients were tested with various simulator scenarios. Simulator validation is in progress. Flow interruption tests for the qualification of main steam isolation valves of KAPP-3&4 and RAPP-7&8 were successfully completed and other functional tests are in advanced stage. FM Head Assemblies (FMHA), FM Bridge and Carriage Assemblies (FMBCA) and channel plug components required for KAPP-3&4 have been delivered. Performance tests of the FMHA are in progress at Tarapur FM Test facility to qualify for reactor operation.

Regulatory consent for the construction sub stage of Major Equipment Erection (MEE) obtained for both KAPP-3&4 and RAPP-7&8. Product/Project Life cycle Management System has been implemented at NPCIL HQ, KAPP-3&4 and RAPP-7&8 which will provide collaborative work environment for all technical and engineering processes at HQ and projects with a centralized repository.

Software Development using model based Safety Critical Application Development Environment (SCADE) tool for digital C&I systems for 700 MWe is completed and documentation and testing are in progress. Independent Verification and Validation of the real time executive software which is developed for digital C&I systems for 700 MWe plants, is going-on, testing and code review have been completed. Development and Validation testing of Thermal Power Monitoring System and development and internal testing of Delayed Neutron Monitoring (DNM), Emergency Transfer (EMTR) and Electric Supervisory Control and Data Acquisition (ESCADA) are also completed.

Operating Stations

Multi-support seismic tests on full scale Primary Shut down System (PSS) assembly of 220 MWe have been performed for PHWRs for the design as well as scaled up seismic input motion to know the margins available for Beyond Safe Shut down Earthquake level.

Structural integrity assessment of TAPS-1&2 Reactor Pressure Vessel (RPV) was carried out and demonstrated the healthiness of the vessel. Snubber test benches required for periodic testing of the snubbers to check their functionality is introduced in all the operating stations. Life management activities of coolant channels are being carried out to assess the degradation, if any, and to evaluate the operating margins & fitness to service.

Up-gradation of the three existing training simulators at KGS, RAPS and TAPS to match the changes in their respective reference plants and make them capable to simulate postulated accidents is completed. An Online web based application called Simulation Information Management System (SIMS) is made functional for implementation of change in configuration, version control and annual upgrade reports for all operating simulators.

Based on post Fukushima accident safety assessment of Indian NPPs and subsequent recommendations, standardized standalone design of On-Site Emergency Support Centre (OESC) is finalized. From this support center, on-site actions in case of emergency can be coordinated. OESC is a shielded building, designed to withstand site specific external hazards namely earthquake and flood. Construction drawings have been issued for Rajastan Reactor site and Kaiga site. Commissioning of up graded Reactor Regulating System in TAPS unit-4 and up graded Channel Temperature Monitoring System at NAPS Unit-2 have been completed.

Upcoming Projects

After review of Site Evaluation Report (SER) and Design Basis Information (DBI) by Atomic Energy Regulatory Board (AERB), siting consent is obtained for four 700 MWe units at Gorakhpur Haryana Anu Vidyut Pariyojna (GHAVP). Preliminary Safety Analysis Report (PSAR) on the GHAVP-1&2 completed and the same is under internal review in NPCIL. SER, DBI and plant layout drawing of Chutka Madhya Pradesh Atomic Power Project (CMPAPP) unit-1&2 have been issued. Application for regulatory consent for siting of this project is being submitted to AERB. Overall plant layout drawing of GHAVP-1&2 is issued, incorporating changes on account of higher seismic isolation gap envisaged and also finalized the layout of tunnels & trenches for GHAVP-1&2.

R&D relating to PHWRs

A Fuelling machine operated Remote pressure tube Inside Diameter Measurement tool (FRIDM) has been developed by BARC for measuring the inside diameter of pressure tubes of 220 MWe PHWRs. Operation of the tool with fuelling machine in water-filled condition has been carried out successfully at RAPS 3&4 site and is ready for reactor deployment.

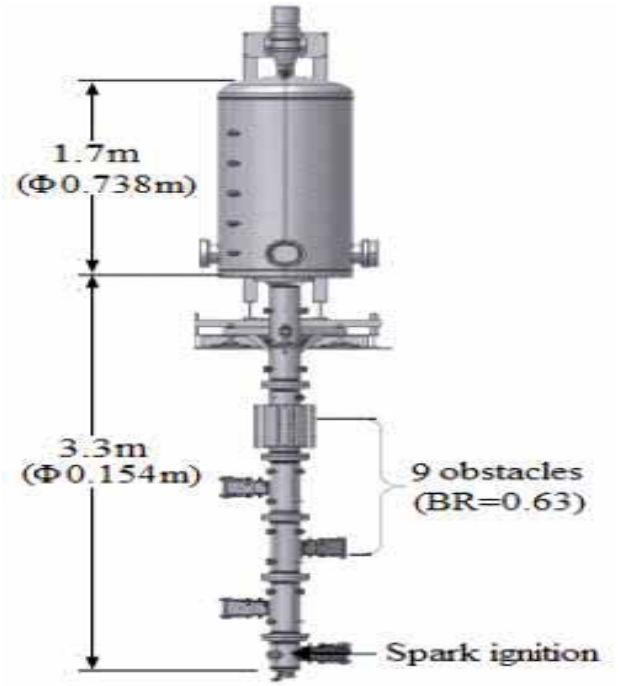


FRIDM being loaded into fuelling machine for trials

In the unlikely event of core meltdown in PHWR, due to the presence of large quantity of coolant in the calandria vault, calandria itself can act as core catcher and the same has been demonstrated experimentally.



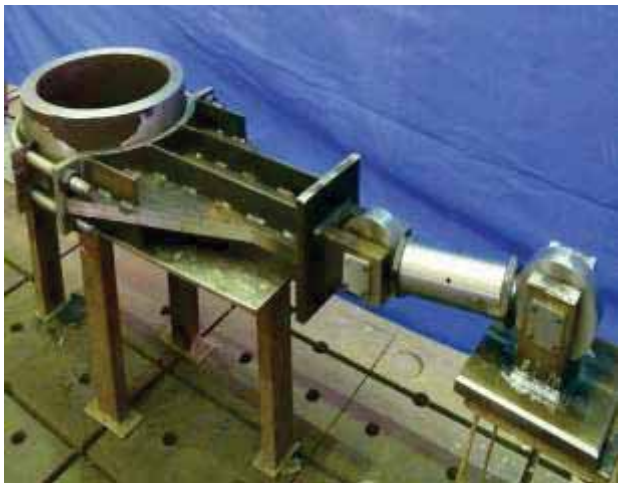
Corium retention experiment in PHWR



Model for validation of hydrogen combustion studies

Numerical models have been developed to understand the different physical and chemical processes occurring in hydrogen combustion. The indigenous models developed have been validated for deflagration, flame acceleration and detonation using experimental data.

Fitness-for-Service and assessment of remaining life of hemispherical bottom head of second stage hot tower of Heavy Water Plant, Kota was carried out by finite element analyses and limit load calculations. Integrity of the component was ensured for continued operation.



Rigid Struts for Reactor outlet header

The design of the Reactor Outlet Header (ROH) of TAPS 3 & 4 was modified using spherical bearings at both the ends to take care of misalignment and by providing fulcrum type of support for linear adjustments due to temperature variation. Modified rigid struts (8 Nos) have been manufactured and delivered to TAPS-3 & 4.

A fixture was developed and used for forming radial hydride in Zr-2.5Nb alloy in pressure tube sections for the first time. Curved compact tension samples of width 16 mm were machined and used for evaluating fracture toughness parameters as a function of test temperature in the range 25°C - 300°C.

Room temperature tensile and charpy tests were carried out at temperatures from 800°C to 950°C on Alloy 693 samples aged for different time periods to understand the effect of precipitation of additional phases in the -matrix on its mechanical properties. Tensile tests revealed a significant increase in yield strength (YS) and Ultimate Tensile Strength (UTS) while a decrease in the ductility (D) with the precipitation of phase in the matrix compared to solution treated state. Charpy experiments revealed a significant decrease in the fracture toughness of the alloy with the formation of additional phases in the -matrix.

As a part of the activities towards developing technologies for fabrication of ceramic fuels for advanced reactors, about 250 grams of sintered UO_2 microspheres of O/M ratios of 2.00 and 2.15 were prepared.

A novel and green separation method for the accurate determination of Mo in U based fuel materials using ion chromatography was developed by extracting Mo from U matrices using pyrohydrolysis for the first time. The method has scope for its application in separation of Mo from spent fuels.

A new hot cell facility for evaluating the performance of irradiated nuclear fuels and structural components has been commissioned at BARC. Four PHWR fuel bundles, each consisting of 19-pins have been examined for their performance at intentionally taken to high burn up in order to produce more

energy. These fuel bundles have undergone burn up from 10,000 to 20,000 MWD/TeU. Fuel pins at high burn up show ridging (increase in diameter at pellet corners) effect which may initiate an incipient crack. The white circumferential marks having higher diameters at equal intervals were measured.

Two Mixed-Oxide (MOX) bundles of 220 MWe PHWR reactor were taken for Post Irradiation Examination (PIE). The bundles had seen a burn up of 20,331 MWd/TeU and 10,788 MWd/TeU respectively and consist of inner seven pins with MOX pellets and outer twelve pins with natural U pellets. Microstructure of an irradiated intermediate and central MOX pellets prove that it can be adopted for generating power in future.

BARC developed, manufactured and tested an Electrochemical Filter (ECF) for 235 MWe operating plant for removal of suspended Nano Particles (Nps). The device uses fibrous graphite felt disks for electrodes, which do not affect the chemical parameters of the system while removing NPs. These fibrous graphite felts can be cleaned and regenerated by heating at 350^{0}C and reused. A prototype electro-chemical filter has been designed for 10 kg/cm^{2} and flow of around 200 lpm.



Electrochemical Filter

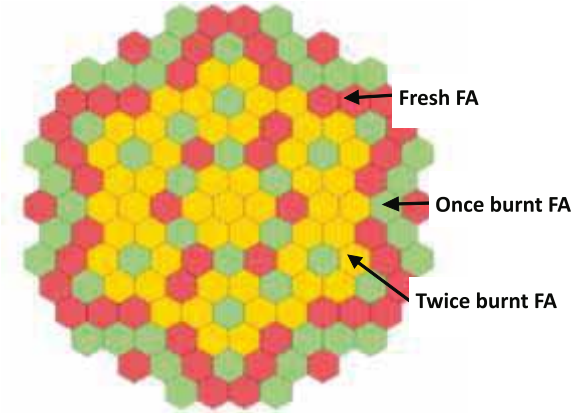
The technology of BARC designed passive Hydrogen Recombiner Device for the Nuclear Power Plant containment was transferred to ECIL for its large scale manufacture and deployment.

A numerical simulation procedure has been evolved and validated through experiments to understand the performance of Tuned Liquid Damper (TLD) to control wind and earthquake induced excitations on structures such as super tall towers and bridges.

Degradation of polymeric materials used in instrumentation and control cables was assessed using Oxidation Induction Time (OIT) and temperature measurements by accelerated thermal and radiation ageing process.

R&D relating to LWRs

The fuel utilization in Indian Pressurised Water Reactor (IPWR) equilibrium configuration has been enhanced to get a discharge burn-up of 45 GWd/T with a profiled fuel assembly having an average ^{235}U content of 4.22% as compared to uniformly enriched fuel assembly with 4.5% ^{235}U. The power and burn-up distribution over complete equilibrium cycle was determined and the peaking factors are found to be within acceptable limits.



Core configuration of IPWR equilibrium core

Required number of fuel pins and Burnable Poison Rods (BPRs) were fabricated and after the non-destructive evaluation, sent for making fuel assemblies for compact light water reactor at Kalpakkam.

Spark erosion, spot welding, ultra-sonic cleaning equipment, electrodes, holding fixtures, heat treatment retorts and heat treatment fixtures for advanced B-core spacer were received and quenching facility was setup. Trial spacers were

fabricated and flow sheet was established. Weld specification and Spacer report card was prepared. Optimization of parameters were carried out for twisting of Aluminium tubes with various pitches and geometries. Required number of tubes were produced for experiments.

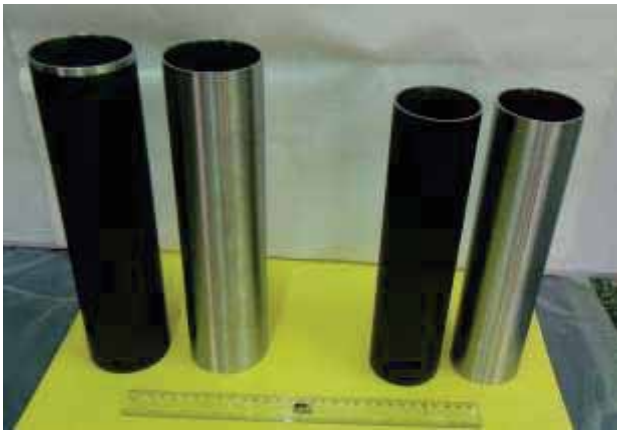
Ultrasonic inspection methodology using focused longitudinal wave transducers was standardized on a mock-up block of dissimilar weld metal joint containing reference defects as shown in the figure. This will be used for periodic ultrasonic examination of several low alloy steel to austenitic stainless steel weld joints in the primary heat transport system at Kudankulam Nuclear Power Plant (KKNPP). Based on the experiments on the mock-up, an examination procedure with combination of longitudinal and shear wave transducers was standardized to detect flaws and adopted for in-service inspection of dissimilar weld metal joints at KKNPP.

A process has been developed for the graphite (Aquadag E) coating of Perspex tubes used in Tissue Equivalent Ionization Chamber for Gamma Radiation Area Monitors of LWR. The process was used in coating the ID of 10 Perspex (L= 300 mm, ID=72 mm) tubes, which were supplied to ECIL for assembly of the Ionization Chambers. Training of ECIL personnel and the transfer of process know-how has been completed.



ID of Perspex tube coated with Aquadag E and Uncoated and graphite coated perspex tubes

An electrodeposition technique was developed for the synthesis of enriched UO_2 coated substrates of different shapes and sizes for the fabrication of electrodes of fission based neutron detectors for monitoring neutron flux in research and power reactors. Grazing Incident X-Ray Diffraction (GIXRD) of as-deposited UO_2 coatings indicated that the coatings are amorphous and rapidly crystallize to UO_2 on annealing beyond 500^{0}C. Eight numbers of



Uo_2 coated SS-321 OD & ID tubes

highly enriched UO_2 coated SS-321 tubes (both ID and OD) have been supplied for assembling neutron detectors for LWRs.

Gold (15 µm) coating of 25 mm diameter copper discs was done by electroplating and provided to the Radiation Medicine Centre for the preparation of ^{64}Cu isotope. Functional coatings of Ni-19.4W-7.6P alloy with superior corrosion and wear



Main Power Plant Control for Compact LWR



Sensors and electronic converters for Compact LWR



Hanger assemblies and source range Monitors for Compact LWR

resistance have been prepared by electrodeposition. The annealing temperature for crystallizing the as-deposited amorphous coating was optimized using XRD analysis to create a homogeneous nanocrystalline microstructure. An electrodeposition process was developed for applying 50-100 micron thick Ni coating selectively on the circular grooves situated in the ID of SS sleeves for enabling diffusion bonding of the sleeve to titanium tubes of LWR heat exchangers.

In continuation of the setting up of Integrated Test facility for validation of C&I systems of Compact LWR under development at BARC, control racks of main power plant control system were populated with electronic modules, integrated with the Operator Console and external plant simulator. This was followed by loading of in-house developed control software and initiation of system integration tests.

Following the development of process sensors for compact LWR, the sensors and electronic converters have been manufactured with participation by Indian industries. One complete set was delivered at the project site.

Hanger assemblies with Gamma Compensated Boron Lined Ionization Chambers have been developed and qualified to meet the vibration and shock requirement for compact LWR. Source Range Monitors are developed for carrying out core fuel loading of compact LWR.

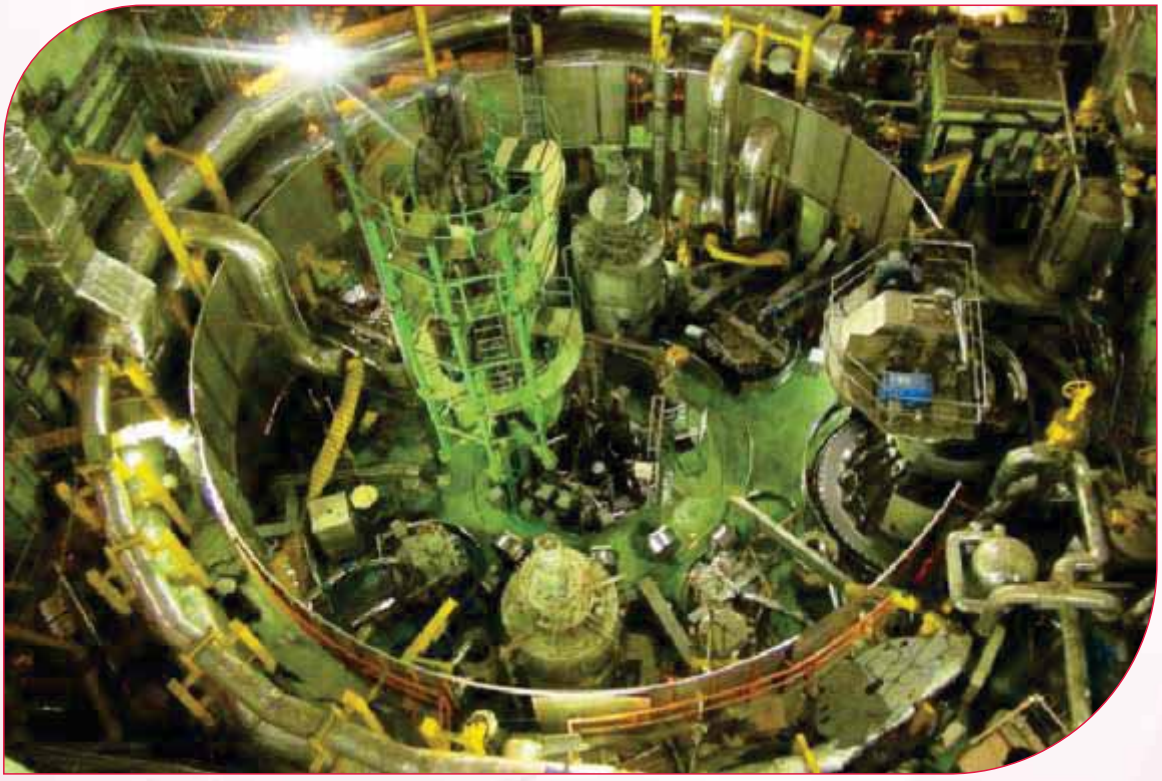
A computer code for fuel-assembly-level lattice and burnup calculations of LWRs (PWRs and BWRs) was developed.

CHAPTER-2

NUCLEAR POWER PROGRAMME STAGE-II



Overall view of PFBR



Top view of Reactor Assembly of PFBR

FAST REACTORS

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

IGCAR is engaged in the design and development of liquid sodium cooled fast breeder reactors, with associated fuel cycle technologies. This programme is supported by a strong research and development endeavour of IGCAR in disciplines such as reactor engineering, chemistry, metallurgy, materials 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 MWe Fast Breeder Reactor project.

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

Prototype Fast Breeder Reactor (PFBR)

PFBR is a pool type reactor using mixed oxide of uranium and plutonium as fuel. The coolant used is liquid sodium. The project is located 500m south of the existing Madras Atomic Power Station.

Towards reactor assembly, the most significant activity that has been completed is the improvement of aesthetic look of the plant, particularly on the top of reactor assembly. Cleaning the reactor assembly including dummy sub-assemblies for removing the dust that got settled during manufacturing, erection and functional testing of various gaseous systems was also carried out with highest care in compliance with regulatory requirements.



Top view of Reactor Assembly

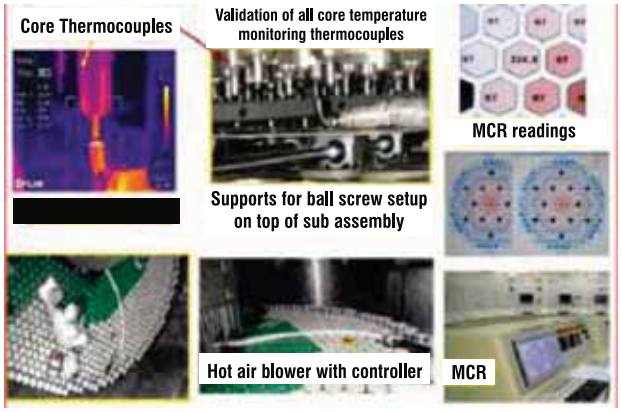


Cleaning of Reactor Assembly internals

Periscope on top of Reactor Assembly



Trailing cable system



Gas Jet system for Validating core temprature monitoring thermocouples

Primary Sodium Pump has been integrated with the coupling for manual rotation to gain confidence before coupling the pump with the motor. Towards commissioning of two primary sodium pumps in their respective locations in the reactor, no-load test on motor with variable frequency drive was done and the functional performance in air has been completed by demonstrating free rotation of the pumps.

Activities related to the core temperature monitoring were completed and the total system has been validated physically. The thermo-well tips inside the reactor vessel were exposed to hot air jets one by one and simultaneously respective temperature readings in main control room were monitored. In order to meet the regulatory requirements and to ensure proper functions of core monitoring thermocouples, a dedicated mock up test facility was commissioned to measure the response time of thermocouples in hot air jet, water bath and finally sodium at simulated temperatures.

In the reactor assembly, the instrumentation cable layout has been rerouted, particularly cables on the control plug to demonstrate the removal / assembly operations for the shutdown systems in case of maintenance. Further the cables have been dressed to eliminate any possibility of electromagnetic induction effects. The trailing cable system along with robust support structures housing 18 no. of cables to transmit the signals from various sensors incorporated in the components mounted on the rotatable plugs has been commissioned.

For the reactor assembly and primary circuits, the major activity completed is the erection, commissioning and functional tests of periscope in main vessel. Baseline data for inner vessel to assess the deformations under seismic loadings has been collected. All preparatory activities for the pressure hold test of the reactor vessel and connected primary sodium circuits has been completed.

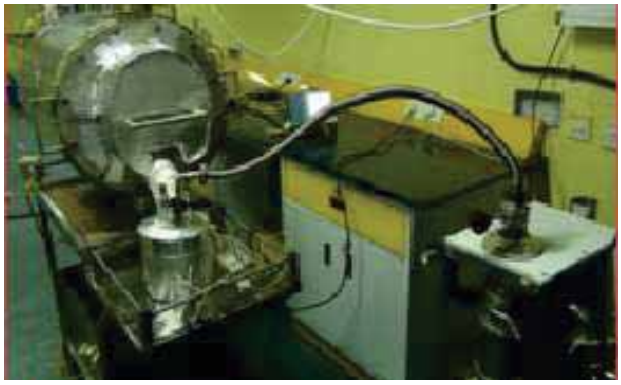
As a pre-requisite for main vessel preheating, insertion of nitrogen purging tool in central canal location, modification of preheating circuit spool pieces for interspace region, installation of dummy flanges in in-vessel transfer port & sodium sampling point with inlet/outlet pipes were carried out.

The major steps towards commissioning of primary and secondary sodium systems, viz. cleaning of internal surfaces of components and piping with flushing of instrument air and preheating before sodium filling have been completed by adopting optimized and logical sequences.

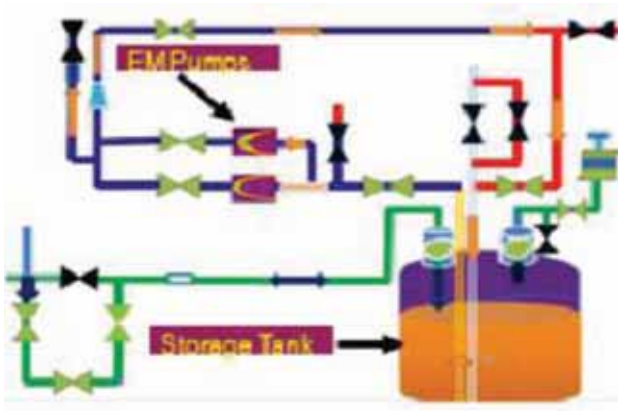
All the preparatory work for preheating of sodium circuits to calibrate the system has been completed before taking up the actual experiments. This includes work such as mock up trials, thermal displacement analysis, identification of reference locations to fix the displacement sensors for validations, confirmation of robust performance of valves etc.



Sodium purification circuit with cold trap & Electromagnetic Pump



Sodium Sampling



Sodium Recirculation by EM pump

Recently, melting of large quantity sodium (230t) in the tanks has been completed and steady & stable flow of sodium with full control has been established in the purification loop and sodium has been ultra-purified (<1ppm of Oxygen). An integrated pre-heating exercise of secondary sodium loop-2 comprising main circuit along with associated purification circuits has been commenced. BHAVINI is planning to carry out integrated preheating of Nuclear Steam Supply System (NSSS) along with Safety Grade Decay Heat Removal (SGDHR) loops shortly. The total commissioning programme has been revised based on the experience accumulated so far.

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

- About 2,694 Fuel clad tubes (crimped with middle plug), were dispatched to BARC, for fabrication of MOX fuel pins.
- 40 Fuel Sub Assemblies (SA) (Cum qty.-160 nos.) and one Delayed Neutron Detection (DND) SA..
- 1067 Antimony capsules required for Source subassemblies.

For the fuel handling system, installation and commissioning of all necessary instrumentation for the fresh fuel handling scheme starting from transfer cask to placing into the ex-vessel transport port have been completed. As a part of technical demonstration, a full-scale mock-up drill has been carried out with the transfer of dummy fuel sub-assemblies from BHAVINI entry gate to Fuel Building (within DAE complex).

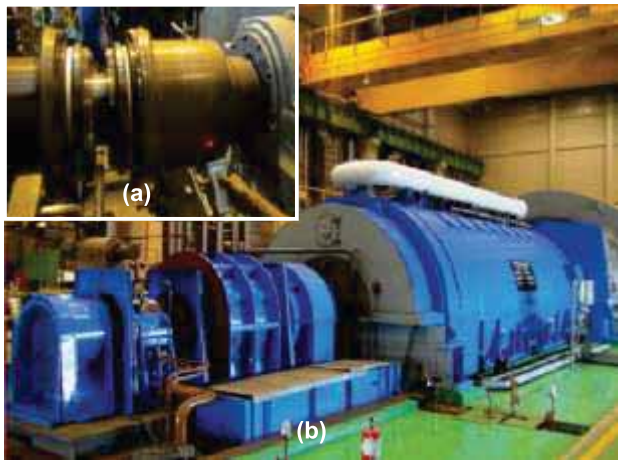
The components and systems lying in the spent fuel subassembly transport path have been commissioned. All the 9 Control & Safety Rod Drive Mechanisms (CSRDM) have been operated from main control room and the drop time, torque, force and displacements were measured. The results clearly demonstrated the perfect alignments achieved with all possible manufacturing and erection tolerances thus raising confidence on the operation of control rod drive mechanism.



Fuel Handling System

Smooth operations of inclined fuel transfer machine have been exercised by transferring the dummy subassemblies between the in-vessel and ex-vessel transfer ports at room temperature in air. Under this task, operation of transfer arm motor from variable frequency drive has also been completed.

A full scale mock-up drill has been demonstrated to the Specialist Group of AERB with the transfer of randomly selected sub-assembly from the reactor to spent fuel washing facility and vice-versa. During this task, operation of Transfer Arm, Large & Small Rotatable Plug from Handling Control Room and Inclined Fuel Transfer Machine, Cell Transfer Machine through variable frequency drive has been perfected. The baseline data for monitoring the horizontality of core support structure as well as large & small rotatable plugs have been generated through Transfer Arm operations. The same have been confirmed through optical measurement techniques.



(a)Turbine rolling of barring gear operation
(b) Overall view of Turbine floor

In Turbine Generator system, the hydrotest of operation grade decay heat removal pipes were completed. Generator air leak tightness test for 72 hours have been completed successfully. Motor driven Boiler Feed Pump load operation was done with 60% scoop position and full load operation was carried out for about 12 hours. Motor Driven Boiler Feed Pump, booster pump and Hydraulic coupling have been commissioned through Distributed Control System. Complete Turbine, Generator & Exciter assembly has been put on barring gear again. Leak tightness of isolation valves for all the eight Steam Generators have been checked with pneumatic operation and closed loop flushing is in progress before preheating of Steam generator tubes with DM water.

For tertiary systems, sea water intake offshore concrete works is nearing completion and Bell mouth concrete of sea water intake structure has been completed. Temporary coffer-dam in the caisson have been dismantled which enables drawl of sea water. Grouting of horizontal tunnel has been completed and anti-bio fouling painting has been completed.

Auxiliary Sea Water Pump has been commissioned along with Steam Water System components by circulating sea water from the off-shore in take structure to cool the raw water thereby to maintain the temperature of high power motor (10.2 MW) driving the boiler feed pump. With this, the commissioning of steam generators has been taken up. Regarding steam water system commissioning, the temporary stop log gates have been removed from sea water intake structure to draw sea water into condensate cooling system. Condenser tube side water fill test has been completed.



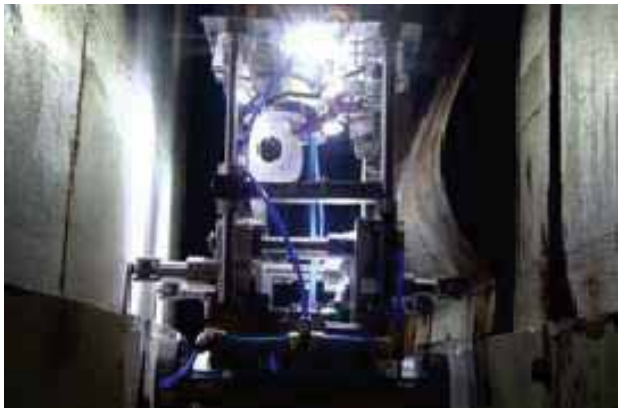
Auxiliary Sea Water System Commissioning



Motor Driven Boiler Feed pump Commissioning



Sea Water intake structure



In-Service Inspection vehicle

The movement of In-Service Inspection (ISI) vehicle for main vessel bimetallic joint (DISHA) has been successfully demonstrated in the mock up facility. On gaining adequate confidence in mock up facility, DISHA vehicle was moved in reactor assembly and the Roof Slab bimetallic joint was visually recorded towards accumulating the base line data. In this process, the vehicle insertability, retrieval and visual inspection of the weld joints on the upper portion of the main vessel were established.

All the construction activities have been completed and commissioning of sodium systems is in advanced stage. AERB granted permission on December 11, 2015 to carry out the pre-requisite activities before filling the sodium in secondary sodium circuit-1 (east loop). BHAVINI has successfully commissioned the activities meeting all the stipulations without having any safety problems particularly without any sodium leak.

Proposal for loading the blanket sub-assemblies along with security arrangements and documents has been put-up for the regulatory approval to enable quicker transition to raise the power level after reactor criticality.

The project has achieved an overall physical progress of 97.64% at the end of January-2016 and is marching towards attaining its first criticality in Mid-2016. Power evacuation system of PFBR is already in poised condition to feed the southern grid with the designed full power of 500 MWe by September 2016.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

Fast Breeder Test Reactor (FBTR)

During 2015-16, Fast Breeder Test Reactor (FBTR) continued to play an important role in testing the fuel, structural materials and special neutron detectors for FBR programmes. The twenty third irradiation campaign commenced on 11th Oct 2014 and was completed on 23rd May 2015 with a total operation of 2491 hours. On 29th December 2015, the reactor power was raised to 26.1 MWt for the first time, with turbo generator generating a power of 5 MWe. The total thermal energy and electrical energy generated were 1939 MWd and 7.411 Million units respectively. In this campaign, irradiation of Yttria, natural U-Zr sodium bonded metal fuel pins, uranium (14.3% enriched) metal pins, ternary fuel pin U-Pu-Zr and impact specimens of 304LN & 316LN for low dose irradiation were carried out.

Twenty third irradiation campaign was completed with the two Mark-II subassemblies attaining their target burn up of 100 GWd/t. Safety clearances from authorities were obtained for loading the Thoria blanket subassemblies in the tenth and eleventh rings of the core. Thoria blanket subassemblies were loaded and the core was configured for the twenty fourth irradiation campaign. Three fresh Mark-I fuel subassemblies were loaded after transferring two burnt Mark-II fuel subassemblies with burn up of 100GWd/t to the storage location. Two experimental sub-assemblies (one containing metallic fuel pins and other with low dose irradiation material) were discharged. Reactor startup for the twenty fourth irradiation campaign has commenced. Irradiation of two metallic fuel pins one with uranium (14.8% enriched)-6Zr and the other with Pu-U-Zr in the first ring will be continued in the twenty fourth irradiation campaign.

At the end of twenty third campaign, gripper of one of the Control Rod Drive Mechanisms (CRDM) could not be opened. Hence, the lower part of CRDM along with the control rod was removed and a new control rod was loaded. After installation of new lower part, reactor was started for checking the adequacy of the reactivity worth of the fresh control rod.

NFC manufactured and supplied various types (3 nos. of Mark-I Fuel sub-assemblies, 9 Carrier sub-assemblies & 1 Special sub-assembly required for Cesium trap) of FBTR sub assemblies towards annual replacement & irradiation experiments planned by IGCAR. 1404 SS 316M clad tubes and 944 Bottom plugs were supplied by NFC to BARC to be used in the production of FBTR fuel assemblies.

An experiment for measuring the replacement reactivity worth of fresh Mark-I fuel subassembly replacing a burnt Mark-II fuel subassembly with a burn up of 100 GWd/t in the third ring was carried out. Towards this, the reactor went critical two times and all the six control rods were calibrated during the period.

During the period, major surveillance tests such as calibration of the high range gamma monitor, filter replacement and testing for iodine and particulate efficiency of reactor containment building, filter banks, containment integrity test on inspection of reactor vessel internals and viewing of sodium flow through siphon break pipe & emergency injection pipe and ultrasonic examination of six severely stressed joints in secondary sodium east loop were carried out.

Towards post Fukushima retrofits, life extension and ageing management, activities such as up-gradation, relocation and relicensing of diesel storage installation of emergency DGs, replacement of the aged 33kV paper insulated cable from central substation, elevating entry points and providing flood gates and reinforcement of unreinforced masonry walls (Brick walls) of service building having safety related rooms etc. were completed.

R&D relating to PFBR

Extending the design expertise and R&D support towards commissioning and obtaining safety clearances for PFBR was continued at IGCAR. Through experiments at high temperature, the structural integrity was verified for the cut and re-welded fuel pins, which helps in increasing the recovery of fuel pin manufacturing. Trial run was carried out successfully for the six dummy fuel sub assembly in the transportation cask along with the trailer from the Interim Fuel storage Building to PFBR Fuel Building. Technical training and checklist clearance exercise for reactor, sodium systems and its auxiliary circuits were provided towards obtaining licence for plant operators. Methodology was evolved for melting and heating of sodium in large storage tanks using the electrical heaters provided on the outer surface of the tanks. Comprehensive in-service inspection / pre-service inspection manual, highlighting various requirements for entire reactor systems was prepared and submitted to the safety committee. The commissioning procedures of sodium circuit systems and its auxiliary circuits were reviewed towards obtaining commissioning clearance from AERB.

Structural integrity assessment of re-welded fuel pin

During manufacturing, some of the PFBR fuel pins were cut open and re-welded resulting in shortening of the clad length and thereby heat affected zone of around 200 microns got inside the weld zone. Towards ensuring the required life for PFBR and comparison of the reduction in life due to the deviation in manufacturing, four typical fuel pins with and without manufacturing deviation were subjected to out-of-pile high temperature high pressure testing equivalent to the reactor conditions.



Cut and re-welded fuel pin test arrangement

The result indicated that all the four fuel pins had the required structural integrity for the reactor operating conditions.

Integrated seismic analysis of safety grade decay heat removal system

Integrated seismic analysis of the safety grade decay heat removal system, including main and dump lines, heat exchangers, storage tank and expansion tank was completed for operation basis earthquake and safe shutdown earthquake conditions. The dynamic response of the coupled model is found to be different from that of the uncoupled model due to the interaction of the lines with connecting components. It is seen that the loop meets the requirements of RCC-MR code.

Mock-up for Transport of Fresh fuel transport cask

A mock-up of transport of fresh fuel transport cask from the interim fuel storage building to PFBR

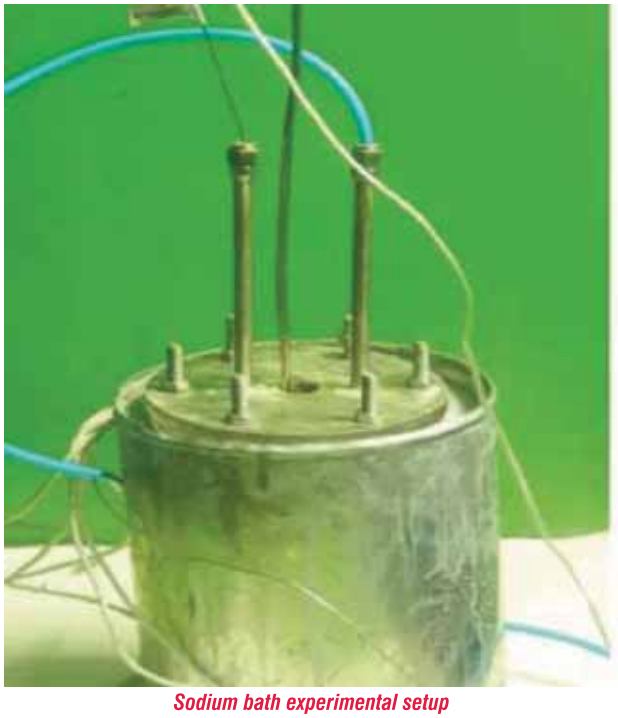


Mock-up of trial transportation arrangement

was made to assess the time-motion study for cask loading and transport. The shock and vibration experienced during transport was also measured using accelerometers fixed to the trailer/cask. The measured values were well within the values considered in the design indicating availability of large safety margins in the design.

Response time evaluation of core temperature monitoring thermocouple

In PFBR, probes for core temperature monitoring consists of duplex insulated K-type thermocouples inserted into a thermo well. The response time of the 12 metre length thermocouple was evaluated by dipping in sodium bath at 350°C and 450°C and the response time and deviation between thermocouples were observed well within allowable limits.



Sodium bath experimental setup

Estimation of U-233 Production from Thoria Blanket in PFBR

Studies carried out for the various aspects of using thoria as blanket in PFBR indicated that, it is possible to produce U-233 about 38 kg from the axial blankets and about 105 kg from radial blankets out of the total annual inventory of 143 kg of U-233. With thoria in radial blanket, core reactivity reduces by 5 mk and breeding ratio shows a slight reduction (0.2%). Therefore, there is no significant change in the core neutronics parameters due to the presence of thoria blanket.

Numerical Investigation of sodium melting in large storage tanks

The methodology for heating the frozen sodium stored in large storage tank was investigated by computational fluid dynamic modelling. Transient thermal analysis, including latent heat addition was carried out to estimate the time required for melting of sodium from the top of the tank sequentially up to the bottom of the tank. The sequential heating is considered to avoid loading of tank wall due to volumetric expansion of sodium. The time required for raising the temperature to 150 and 200°C was estimated as 120 and 139 hours respectively. Studies were also carried out with the failure of some of the heaters towards quantifying additional time required for completion of heating operations.

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

It is planned to construct two more oxide fuelled Coceptual Breeder Reactors (CBR) of 600 MWe at Kalpakkam. The conceptual design of these reactors is being evolved with improved economy and enhanced safety features approaching towards the Gen-IV safety criteria. Conceptual and process design of the reactor core, reactor assembly, sodium heat transport systems and its major components were completed. Economic assessment is being carried out for the future FBRs in the context of limited scope IAEA-INPRO assessment of liquid metal cooled fast reactors.

Approach towards Improving the Economy of future FBRs

Economic assessment of CBR 600 was evaluated and the unit energy cost, internal rate of return including return on investment were worked out. Influences of the interest rate and the capital cost on unit energy cost were assessed. Various measures taken up to reduce capital cost in CBR-600 and the influence of cost reduction on unit energy

cost were brought out in the study. The approach adopted towards economy was presented in the IAEA-INPRO meeting.

Conceptual & process design of liquid poison based passive shutdown system

Detailed literature survey was done on the failure experiences of fast and thermal reactors shutdown systems to identify the possible common mode failures. A suitable concept of the diverse passive shutdown system, which is very different from the existing systems is proposed. Dimensions and positioning of the arrangement inside subassembly was worked out. Time required for the system actuation was estimated. These studies have given confidence on the feasibility of the chosen concept to shut down the reactor during anticipated transients without SCRAM.

Post Fukushima Safety Criteria Review

IGCAR and AERB have jointly prepared the safety criteria for the MOX fuelled twin type future FBRs. The safety criteria of both the general and reactor system wise requirements were reviewed critically in the light of the lessons and experience from Fukushima. Necessary modifications /amendments / additions were carried out before submission to AERB.

Metal Fuel Test Reactor

A report on the need and rationale for Metal Fuel Test Reactor was prepared and communicated to DAE for consideration. Towards this, core design for 100 MWt Metal Fuel Test Reactor was evolved and the conceptual design of other systems is being worked out.

R&D on FBRs

100 Tonne high capacity shake table

A multi-axis shake table with 100 tonne capacity was commissioned successfully. This unique, large capacity shake table helps in providing robust seismic design for the future CBRs with the full scale testing. Accurate reproduction of popular earthquakes such as Elcentro, Kobe and Tarapur was demonstrated with the new facility.



Testing of Tarapur spent fuel storage facility in shake table

Design and Development of rupture and ballooning in tubes Test Facility

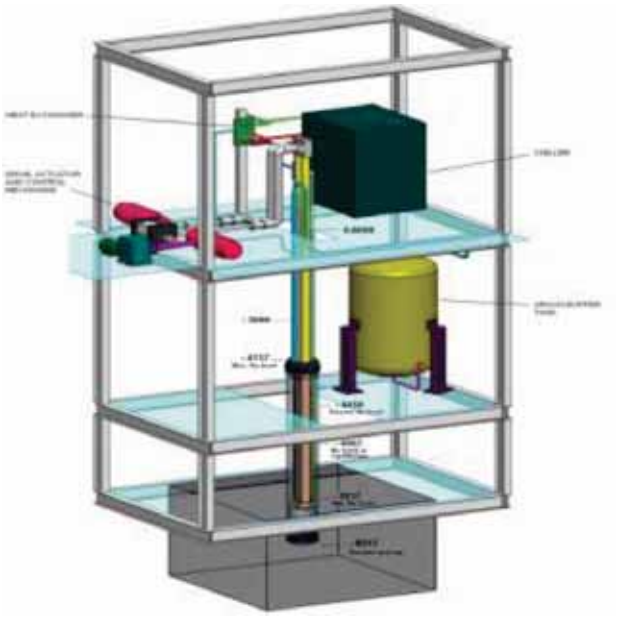
Fuel clad behaviour under extreme loading conditions can lead to considerable plastic strains in the form of localized bulging (ballooning), eventually leading to rupture. To understand the ballooning behaviour, a unique multiple fuel pin test facility, capable of simultaneous testing of multiple fuel pins with independent control of the temperature, pressure and online monitoring using X-rays, was set up.



Test facility for Rupture and ballooning in tubes

Experiment in research facility for irradiation studies

An innovative experimental research facility for irradiation studies in sodium at high temperatures was designed, fabricated and erected. Experiments carried out demonstrated the attainment of constant specimen temperature within ± 2°C.



Schematic of research facility for irradiation studies

Experimental performance evaluation of modified wire type leak detector layout for sodium leak detection for the future FBR

Towards development of special detectors for the study of sodium leaks, wire type leak detectors working on conductivity principle are used as one of the methods. Performance assessment of wire type leak detectors of PFBR layout was carried out. The experiments carried out at IGCAR and as a part of IGCAR-CEA, France collaborative project, revealed that leak rate of 200 gram/hour could be detected within 6.7 hours. The performance evaluation for modified wire type leak detector revealed that the leak rate of 200 gram/hour can be detected within one hour by modified layout.

Testing of integrated cold trap in sodium loop using newly developed sodium submersible annular linear induction pump

Demonstration of full scale model of Integrated Cold Trap (ICT) was carried out in a test vessel of Large Component Test Rig. In the first stage, the DC Conduction Pump (DCCP) was used for pumping the sodium in to ICT. In the second stage of experiment, newly developed sodium submersible Annular Linear Induction Pump (ALIP) of similar capacity and dimensions as that of DCCP was used for pumping sodium. ICT and ALIP both were



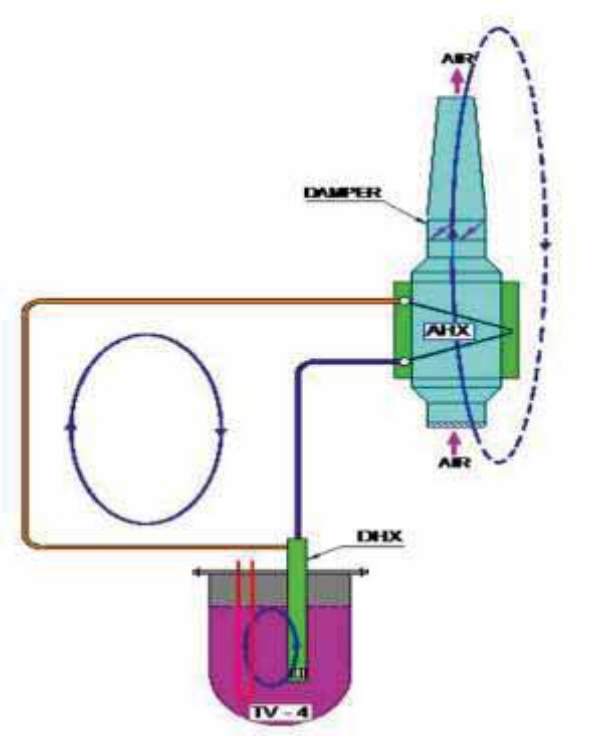
Erection of ICT along with ALIP in Test Vessel

submerged in liquid sodium in the test vessel. During the experiment, about 16 ton of sodium, circulating in the test vessel, was purified using integrated cold trap. The successful testing has opened a way for these two new technologies for their application in future fast reactors.

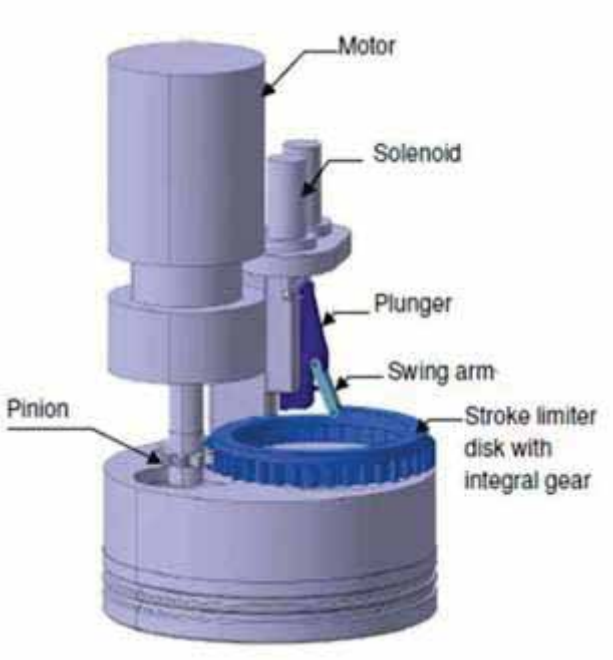
Experimental simulation of the behaviour of model Safety Grade Decay Heat Removal system of PFBR during SCRAM and Station Black Out

Experiments were conducted to study the response of the heat transport system to design basis reactor transients like SCRAM and Station Black out (SBO). It is observed that the heat transport

capability of the system follows the hot pool sodium temperature for most of the cases. The direction of flow in secondary system of SGDHR remained unchanged during all the design basis plant transients without any flow reversal.



Schematic of the facility



Schematic of Stroke Limiting Device

Integrated testing of stroke limiting device with control and safety rod drive mechanism

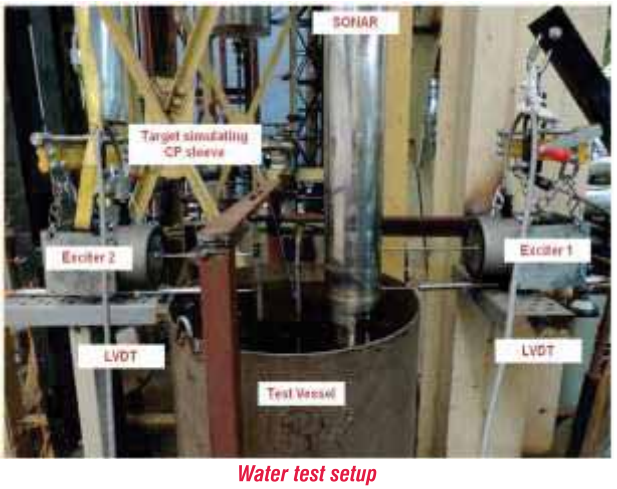
Stroke Limiting Device (SLD) is an add-on device to Control and Safety Rod Drive Mechanism (CSRDM) to provide additional safety in the event of uncontrolled withdrawal of control rod. SLD limits the consequences of inadvertent withdrawal of control and safety rod. The performance of a prototype SLD assembled with the upper part of prototype CSRDM was tested. Overall performance of the mechanism was smooth during testing and the maximum torque for translation did not change much. Thus, the integrated performance of CSRDM with SLD was demonstrated.

Performance testing of PFBR- Sonar device

Vibration measurement of PFBR fuel subassemblies during commissioning is a safety requisite. Conventional contact type sensors such as accelerometers, strain gauges or any other optical



Bottom end of Sonar device



Water test setup

devices cannot be used for high temperature under sodium measurements due to opaqueness of sodium. Hence sonar device employing ultrasonic technique was developed for measurement of vibration of subassembly. The result indicated that the sonar device and its associated system were able to measure the vibration of subassembly and hence it is qualified and ready for measurement of subassembly vibrations in PFBR during its isothermal operation.

Commissioning of large scale thermal hydraulic test facility for future FBRs

An experimental facility with 5/8scale 90°sector model of primary circuit was commissioned for carrying out various hot pool thermal hydraulic studies with prime focus on gas entrainment phenomena related to future FBR. Performance testing of various gas entrainment mitigation devices are planned in the facility.

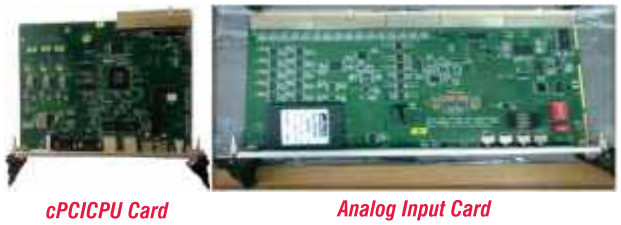


5/8 scale model Hydraulic loop

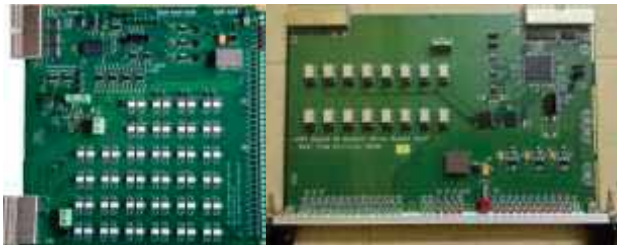
Control systems & sensors

Compact PCI bus based diversified Real-Time Computer System for Safety Class-2 I&C Systems of FBRs

The current Safety Class-2 instrumentation and control system architecture for PFBR consists of dual VME bus based RTC systems with Switch Over Logic System. Since both the VME systems are exactly identical, the dual redundant system is prone



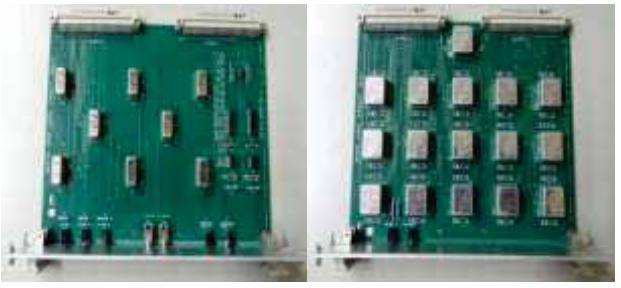
cPCICPU Card *Analog Input Card*



Components of diversified RTC system

to common cause failure. Probability of the same can be reduced by adopting diversity in RTC systems. Hence a Compact PCI (cPCI) bus based RTC system was developed to replace one of the RTCs in dual redundant systems. The diversified RTC system components are based on 32 bit ARM-9 processor CPU card, 30 channel Analog Input card, 32 channel Digital Input card and 16 channel relay output card.

The Switch Over Logic System plays an important role in checking the healthiness of both VME and cPCI system and also for sending the output of the healthy system to the plant. A Switch Over Logic System with provision to read-back the status of routed output was designed and developed, using highly reliable hermetically sealed electromagnetic relays.



Switch Over Logic Card *ORing Logic Card*

Components of switch over logic system

STUDIES ON MATERIALS FOR FBRs

Development of ZrO_2 dispersoid based Oxide Dispersion Strengthened (ODS) Steel

Towards enhancing the in-pile swell and creep resistance of reactor clad and wrapper materials and thereby achieving an increased burnup, a ZrO_2 dispersoid based 9Cr-ferritic ODS steel (a prospective clad material) which has good high temperature stability and low fast neutron

absorption cross section was studied at IGCAR. The ball-milled Fe-15% ZrO_2 powder was studied for various durations of time for accurate characterization of basic thermal and structural stability of ZrO_2 dispersoid in ferritic steel matrix. The results confirm the stability of ZrO_2 nanoparticles against coarsening even at 900°C.

Characterization of High Density Concrete

Investigations on high density concrete (2.4, 3.6 and 3.9 g/cc sizes) were carried out to study the physicochemical changes that occur during constant exposure at 120°C, resembling the conditions of the roof slab of PFBR. Among the three sizes of concretes studied, high density concrete showed much lower degradation in its strength after sustained thermal ageing for 56 days.

Superhydrophobic Coating on 304L SS

Attempts were made to develop and characterize suitable superhydrophobic coatings on Type 304L SS for enhancing corrosion resistance in aqueous chloride environment. Long term stability tests performed after 1000 hours of exposure to sea water showed considerable promise for the applicability of these coatings.

Long term exposure to flowing sodium in a bi-metallic loop

AISI Type 316LN stainless steel and modified 9Cr-1Mo steel were exposed to sodium at 525°C in a bi-metallic loop for 40,000 hours, which simulated the secondary loop of PFBR with respect to operating conditions as well as the material sequence. Extensive property characterization studies of post exposed samples were carried out to assess the damage in quantitative terms.

Stability of Fe-Ti dissimilar weld joints

In order to quantitatively evaluate the phase and microstructural stability of Fe-Ti dissimilar joints that arise in reprocessing applications, investigations on the diffusion couples at 500-800°C were carried out. The investigations revealed that inter diffusion in Fe-Ti system under equilibrium resulted in a reaction zone of width limited to 12 µm, while non-equilibrium diffusion resulted in 120 µm wide diffusion zone. The difference could be attributed to faster diffusion of elements assisted by the high volume fraction of lattice defects in the explosively clad joints.

Thermo physical Property Studies on Advanced ultra-super critical materials

Capitalizing the expertise of IGCAR in developing and characterizing high temperature materials, an extensive materials development program for India's maiden advanced ultra-supercritical power plant is underway. Towards this, studies on the thermal, microstructural stability and thermo-physical properties of Super 304HCu, Alloy 740 and Alloy 617 were initiated and a comprehensive high temperature materials property database on Alloy 740 and SS304HCu was created.

Application of Langmuir Probe for laser deposition of thin films

Towards development of quality thin films for sensors, a Langmuir probe was installed in a thin film Laser deposition equipment as a diagnostic tool for getting an insight on the laser produced plasma. As a model study, tungsten and cerium oxide plasma plume were created and its spatio-temporal evolution was investigated. Among other findings, the optimum target-substrate distance for the synthesis of good quality thin films was also found to be 45-75 mm.

Characterisation of ω-phase in a Ti-15%Mo Alloy

The occurrence of ω-(Omega) phase is encountered during the processing of various Ti and Zr related alloys. This is often undesirable as it causes embrittlement. Towards promoting a fundamental understanding of ω-phase, basic study using high resolution electron microscopy and synchrotron X-ray source was carried out to map the finer crystallographic aspects of the ω-phase in a Ti-15%Mo alloy.

FBR - FRONT END FUEL CYCLE

The U-Pu mixed carbide fuel pins for FBTR at Kalpakkam and fuel pins for the full core of PFBR were supplied by BARC. Studies on characterization and thermo-physical property evaluation of U-Pu-Zr alloy have been

initiated for the metallic fuel development programme for future fast breeder reactor. The ternary alloy with target composition of U-23.5%Pu-6%Zr (wt%) was prepared by induction melting and gravity casting route. Experiments were carried out for the determination Solidus/liquidus temperature and other phase transformation temperatures by Differential Thermal Analysis (DTA), axial and radial thermal expansion using a high temperature vertical dilatometer, measurement of thermal diffusivity by laser flash technique and microstructural investigation using optical microscopy.

Direct electrochemical conversion of solid uranium dioxide to uranium metal was carried out at IGCAR. The pellets weighing 100 gram were converted to uranium metal and the conversion efficiency was found to be more than 98%. The efficiency was determined from the hydrogen gas produced in a reaction of the samples with hydrogen bromide.

Enthalpy increment measurements were carried out on U-19wt.%Pu-6wt.%Zr in the temperature range 527–1027°C by inverse drop method using a high temperature differential calorimeter. Thermodynamic functions such as heat capacity, entropy and free energy functions of the U-19wt%Pu-6wt%Zr were computed in the temperature range 15-1527°C. The study provided the first experimental enthalpy increment data and the heat capacity data in the temperature range 527–1027°C for U-19wt% Pu-6 wt% Zr metallic fuel.

Electro refining of U-Pu-Zr alloy in molten LiCl-KCl-$PuCl_3$ electrolyte salt was carried out by galvanostatic and potentiostatic modes. Uranium is also expected to be deposited at liquid cadmium cathode as the electrode potentials for uranium and plutonium at liquid cadmium electrode are similar. Even though the anodic potential was controlled between -1.2 to -1.1V, Zr was found to dissolve in LiCl-KCl melt which was confirmed by cyclic voltammetry. The basic studies on anodic dissolution of U-Pu-Zr alloy for estimation of exchange current density and cathodic polarization at liquid cathodic electrode were also carried out.

The recovery of uranium from mine water samples was successfully demonstrated using macroporous-bifunctional phosphinic acid based organic resin. About 500 litre of mine water sample was processed and the uranium contents were brought to acceptable limits.

A tin oxide based sensor capable of sensing down to 10 ppm of hydrogen in argon was developed and tested successfully in FBTR. Simultaneous calibration of tin oxide and thermal conductivity detector based hydrogen sensor systems for argon cover gas was also carried out in a loop by injecting hydrogen concentrations from 5 to 1000 vppm through sodium.

The hydrogen released during regeneration of a secondary sodium cold trap was monitored, managed and accounted by using electrochemical burner and proton exchange membrane based hydrogen sensor.

FBR- BACK END FUEL CYCLE

Reprocessing of mixed carbide spent fuel of FBTR

Aqueous phase partitioning run in the CORAL extractor Banks

A study was carried out to implement aqueous phase based partitioning of uranium and plutonium in CORAL centrifugal extractor banks to obtain plutonium and uranium products with higher decontamination factors from each other. The results indicated that a decontamination factor of 46 could be obtained for uranium in plutonium products, whereas it was about 10 for plutonium in uranium products and also the significant reduction in the requirement of uranous for partitioning of uranium and plutonium. The Plutonium product met the specification required for further processing in plutonium reconversion. The Uranium product required further purification for making it suitable for table-top handling. This activity had the main task of installing 32 centrifugal extractors remotely using manipulators after fabricating the same. The aqueous partitioning method reduces the waste volume to be handled in the reconversion laboratory as well as ammonium diuranate supernatant to be disposed as low level

waste. This optimized process will be adopted in the reprocessing campaigns of CORAL as well as future plants such as DFRP (Demonstration Fast reactor fuel Reprocessing Plant).

Materials research for Back End Fuel Cycle

Burn up determination

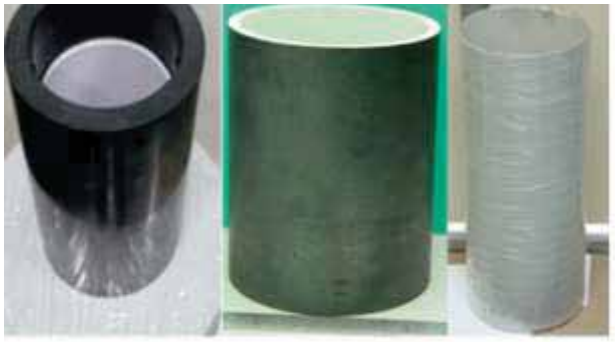
At high burn-up, the composition of the nuclear fuel pellets changes in a non-homogeneous manner within its radius. The spatial profile of burn-up and the information on the re-distribution of fissile and fission product atoms across the pellet are needed. A procedure involving pulsed laser deposition of heavy element (U and Pu) and fission products (Nd, La etc.) from the spent fuel matrix followed by isotopic dilution mass spectrometry, is being adopted to measure the ratio of the heavy element to burn-up monitor in the irradiated fuel, from which burn-up could be determined. Towards this, studies with simulated irradiated fuel pellets were carried out.

Materials Selection for highly corrosive nitric acid applications in spent nuclear fuel reprocessing

Refractory materials such as zirconium and titanium alloys with excellent corrosion resistance in boiling nitric acid are proposed as structural materials for the dissolvers in future spent fuel reprocessing plants. Long-term corrosion evaluation in zircaloy-4 mock-up dissolver with a simulated dissolver solution was carried out. The studies revealed that corrosion rates are of the order of 0.003-0.009 mpy for Zirconium-702, zircaloy-4, autoclaved zircaloy-4 and titanium of commercial purity in as-received and welded conditions after exposure to the boiling liquid phase for 2,500 hours.

Development of high temperature corrosion resistant coating for melting of uranium based metallic fuels and pyrochemical reprocessing applications

It is required to have high temperature corrosion resistant ceramic top coats on metallic and high density graphite substrates for applications related to the melting of uranium and U-Pu, U-Pu-Zr metal fuels and also in pyrochemical reprocessing. As a part of technology development, atmospheric plasma spray and high velocity oxy-fuel coating systems were successfully installed. Using the technique, high density yttria coating was deposited on high density graphite crucibles. The uranium melting experiments confirmed the compatibility of coating in three melting cycles without spallation. The coatings were successfully demonstrated on the inner side of engineering scale high density graphite crucible designed specifically for demonstration facility for metallic fuel fabrication. Simulated copper melting and uranium melting experiments were carried out using these coated crucibles and the yttria coating showed good adhesion behaviour and the uranium metal ingot could be easily removed after the melting run. Yttria stabilized zirconia coating with NiCrAlY bond coat was also developed on Inconel 600 for pyrochemical reprocessing applications.



Yittria coated High Density Graphite and Inconel 600 Crucibles

R&D on Fast Reactor Fuel Reprocessing

Thermal degradation studies of various sets of solutions were completed at 50°C for 400 hours. Values of phase disengagement time and interfacial tension for 30% TiAP-DD/HNO_3 system were found to vary from 85 to 158 seconds and 13.7 to 12.1 mPa respectively after degradation. Thermal degradation of TiAP in n-dodecane was investigated as a function of aqueous phase acidity (2 to 8 M HNO_3) and time (0 to 400 hours) at 40°C. Interfacial tension increased sharply when aqueous phase acidity increased for neat samples as well as degraded samples. Zirconium retention

measurements and FT-IR spectral characterization of the degraded solvent are in progress.

Centrifugal extractors are used as the contactors for solvent extraction in the fast reactor fuel reprocessing in CORAL, each Centrifugal extractor unit consists of a bank of sixteen stages, which are driven by an individual 3-phase squirrel cage induction motor. The process requires that the speed of each motor should be maintained between 3300 and 3700 RPM, irrespective of the load. Measurement of the centrifugal extractors motor speed with a sensor inside the hot cell has many operational difficulties. Also the variable frequency drive used to control the motor does not provide an indication of actual speed of the running motor. In view of the above, speed measurement of centrifugal extractors induction motors in CORAL without any sensor using mathematical methods is needed. A test bench was setup in the laboratory to carry out the testing and simulation of centrifugal extractors induction motor from no load to full load condition with variable frequency drive. During the study, all parameters of the motor like current, voltage, power factor etc. and also parameters like load, actual speed using load cell and proximity switch were observed. The above data was logged using Modbus communication from variable frequency drive into a computer. This data was used to correlate the speed of the motor with an observable parameter like motor current. The correlation developed was found to be applicable within the speed range of 2300-3700 rpm and the maximum error observed within the range was +5%. The indication for the speed was provided in human-machine interface in the Control Room of CORAL. The human-machine interface communicates with the individual variable frequency drives by Modbus protocol. The human-machine interface is a rugged system which provides for programming the display screens, operator inputs through touch screen, real-time computation of speeds and the control actions through ladder language.

The feasibility of aqueous reprocessing of metallic fuels was studied. The dissolution of zirconium containing metallic alloy fuels (2 to10 wt% Zr) was studied in nitric acid media under reflux conditions. An electro-oxidative dissolution technique using cerium as an oxidizing agent was also carried out. These studies have established that U-Pu-Zr based fuels can be dissolved in nitric acid medium for reprocessing applications.

The solubility of various trialkyl phosphates was determined in supercritical carbon dioxide medium. Based on the results, it is inferred that the modified carbon dioxide stream could be employed for recovery of actinides from various matrices.

Advanced alkoxy acetamide reagents were synthesised and demonstrated the single-cycle methods for partitioning of trivalent actindies directly from fast reactor high active waste. In addition, the organo-functionalized inorganic and magnetic materials were developed and demonstrated for magnetic assisted mutual separation of lanthanides and actinides.

Fast Reactor Fuel Cycle Facility

Fast Reactor Fuel Cycle Facility comprising Fuel Reprocessing, Reprocessed Uranium Oxide, Fuel Fabrication, Core Subassembly and Waste Management Plants along with necessary supporting facilities is under construction at Kalpakkam piloted by IGCAR with technical support from BARC and NFC. This comprehensive facility is being built to close the fuel cycle of PFBR and to facilitate its sustained operation. It is co-located with PFBR to eliminate movement of radioactive spent fuel and reconstituted fresh fuel in the public domain.

Excavation work in the nuclear island area is nearing completion with hard rock layers being removed by controlled blasting operations to reach the foundation depth of the various plant buildings. Geotechnical investigations and geological mappings were continued to confirm the seismological designs of the plant building construction and accord clearances for civil construction of the plants. The site for the construction of waste management plant is ready. Construction of a few of the infrastructure buildings such as training centre, administration building, central surveillance, safety and health physics buildings crossed the second floor level and a few others such as canteen building, extensions of stores and workshop reached first floor level. Construction activities also commenced for some of the common services buildings such as diesel

generator and oil storage buildings and centralised water chilling plant.

On the procurement front, several bulk supplies of raw materials such as about 4250 tonnes of pig lead ingots and 3140 tonnes of stainless steel sheets and plates were received at site to be issued as free issue material for fabrication of shielding bricks, process vessels and tanks respectively. Fabrication of standard size glove boxes and fume hoods commenced and a few glove boxes were received at site. Orders were placed for several long delivery high value items such as seamless stainless steel pipes, welded SS pipes, the three different types of Master Slave manipulators and radiation shielding window glass slabs. Procurement actions are underway for process equipment for fuel fabrication plant and a few instruments for the characterization laboratory.

Augmentation of infrastructure of the townships for meeting all the requirements of these additional constructions was continued.



Excavation in the nuclear island area for construction of plant buildings



Training Centre of FRFCF under construction



Administration building under construction

Considerable progress was achieved during the year despite the major constraint of not having adequate manpower and the rate limiting essential requirement of multiple clearances in view of the highest quality and safety standards of such a mega project.

NFC carried out the following work in connection with FRFCF:

Prototype of Remote Helium Leak Testing chamber with automatic door closing system and rollers was designed and developed to do leak test of highly radioactive PFBR blanket pins for FRFCF.

Installation of in house made remote camera based inspection for PFBR fuel sub-assembly at Interim Fuel sub-assembly Storage Building (IFSB) enabled recording of fuel pin numbers, fuel pin position in the sub assembly which eliminated operator dependence and reduced exposure of radiation to operator.

Prototype remote inspection system was designed and developed for length, diameter and wire wrap pitch measurement for active PFBR blanket pins.



Prototype Remote Helium Leak Testing chamber



Installation of in house made remote camera based inspection for PFBR fuel sub-assembly at IFSB

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. The following activities were carried out:

- Equipment layout for RUP Pin Section was finalised after detailed discussions and provided to IGCAR for incorporation into relevant tenders.
- Prototyping activities were initiated for the following:
  - ✦ Automatic Contamination monitoring System: Design was completed and procurement was initiated for bought out items like Alpha Scintillation counter monitors, pneumatic systems and structural items. Specially designed components are being machined in-house.
  - ✦ Shielded Pin Tray (SPT): Design was completed and procurement was initiated for prototype SPT. In house fabrication of Light weight dummy SPT was completed.



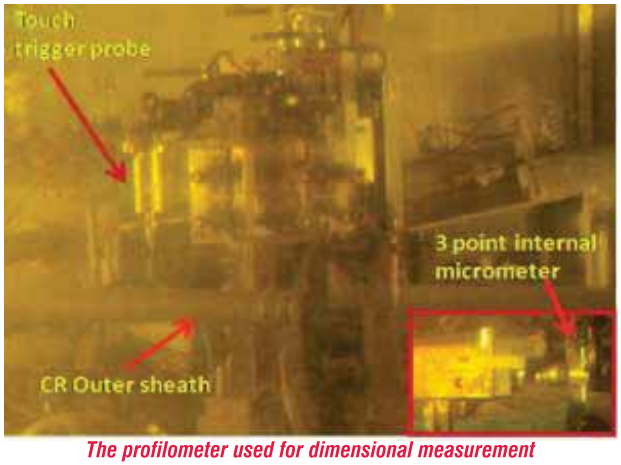
Prototype remote inspection system

- Mock Trial System is being developed for Integrated Top Plug Welding, Buffing and Passivation operations.

REPAIR & INSPECTION TECHNOLOGIES

Remote Metrological Inspection of Control Rod Assembly of FBTR

The post irradiation examination of the control rod assembly of FBTR, with a fluence level of $1.2x10^{23}$ neutron/cm^2 was carried out successfully. Remote dimensional measurements revealed that the control rod exhibited a diametral increase of about 0.1 mm in the foot region, and about 0.3 mm near the bottom end plug and no appreciable increase in the central and top end-plug regions. The



The profilometer used for dimensional measurement of the control rod in hot cell

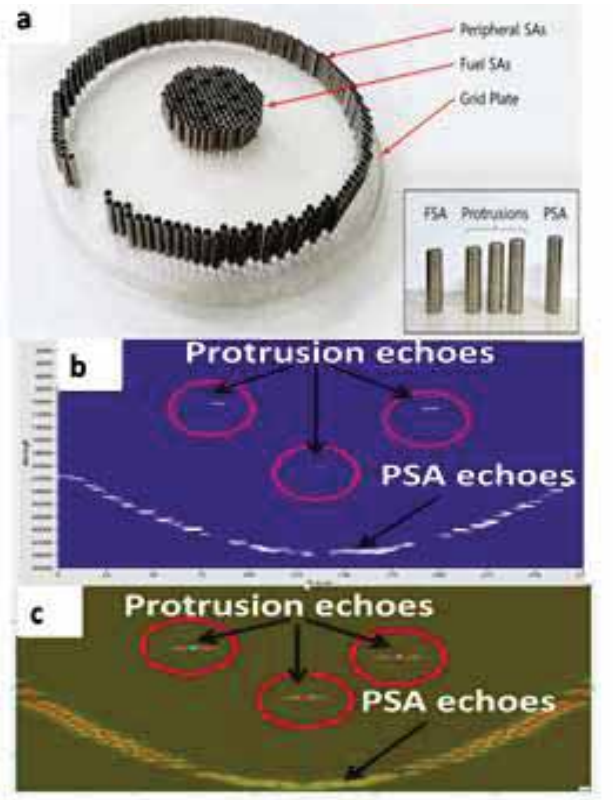
clearance between the control rod body and the stellite overlay on the outer sheath got slightly reduced both in middle and top guide regions.

Development of a sensitive field-worthy remote field eddy current instrument

A highly sensitive remote field eddy current instrument was developed for detecting the spatially localized defects in modified 9Cr-1Mo steam generator tubes of PFBR. The instrument can detect localised defects such as flat bottom holes of 5.0 mm diameter and 30% wall thickness in depth and circumferential notches of 5x2mm x 30% wall thickness depth.

Simulation and 1/10th scale under water experimental simulation for under sodium ultrasonic imaging

During fuel handling operations in PFBR, it is to be ensured that no subassembly protrudes beyond the allowable limit. Towards ensuring this, an ultrasonic methodology was developed based on the drop in the reflection amplitude from the peripheral sub-assemblies in case of a protrusion. Further, simulation and development of a 1/10th scale model of the PFBR core was undertaken to facilitate understanding the under-sodium ultrasonic phenomenon and to simulate various scenarios. Using the immersion transducer and optimized models, the effect of protrusions on the signals obtained in various sectors were studied. The protrusions are clearly seen in both images and they also compare well with those obtained for the core set-up in a 5 metre water tank.



(a) 1/10th model of PFBR core
(b) Experimental B-scan image of 1/10th scaled core with three protrusions at different locations and
(c) B-scan images from simulation with three protrusions at the same locations

CAD-augmented control of a robotic arm for remote tele-operation

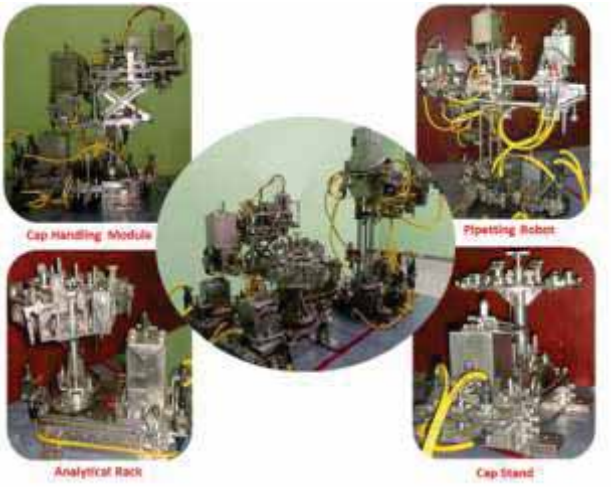
Augmented Reality by computer aided design tools can enhance the control and operation of robots used in nuclear facilities. A complete integrated set-up for CAD-augmented system for remote tele-operation was demonstrated successfully on a planar robotic arm.

Fabrication of mock-up instrumented capsule for detection of in-pile stress rupture in T91 pressurized capsules

A full scale mock-up of the instrumented capsule assembly was designed for determining the in-pile creep rupture behaviour of T91 cladding tubes. All the required components were machined, sub-systems fabricated and final integration by welding was also successfully completed. The capsule is presently being used for out-of-pile tests in laboratory.

Analytical Robotic System for DFRP

Remote sampling and analysis using automation plays an important role in the reprocessing of spent nuclear fuel. Towards this, an Analytical Robotic System, based on modular design approach and disposability was developed for DFRP (Demonstration Fast Reactor fuel Reprocessing Plant) with suitable software and tested successfully on robots.



Analytical Robotic System for DFRP

HEALTH, SAFETY & ENVIRONMENT

Radiological Safety

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD (Thermo Luminescence Dosimeters) personnel monitoring services, covering about 2500 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 800 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for over 150 occupational workers were also carried out.

In-situ/in-house testing of more than 100 HEPA filters was completed. Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated.

Bore well samples, soil samples around

active facilities and other samples for low level counting and determination of radioactivity from different institutions and industries were catered to.

Radon measurements were carried out on natural samples to quantify the environmental radioactivity levels thereby estimating the annual effective dose due to natural background radiation. Indoor radon measurements were also carried out at the residences of DAE Township.

Nuclear counting and calibration facilities were extended to various institutions involved in BRNS projects, researchers and industries in southern region. A special laboratory for bioassay of faecal samples was established.

Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Online Nuclear Emergency Response Decision Support system (ONERS) was developed indigenously and validated.

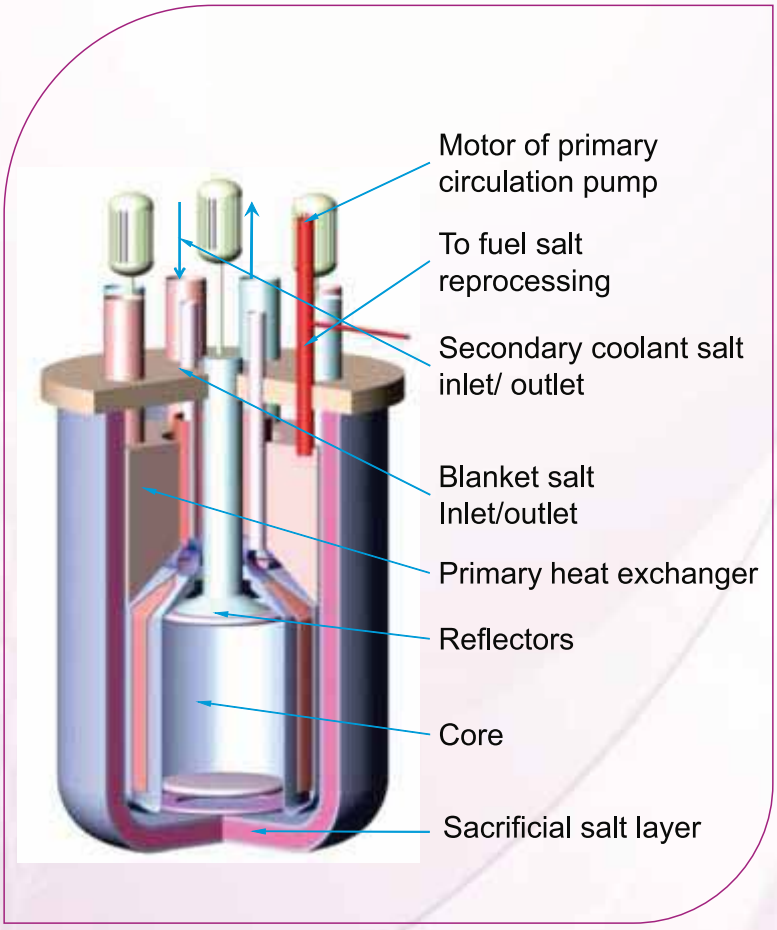
A numerical ocean wave model was implemented for Kalpakkam site for the prediction of extreme waves during stormy events to provide advance warning. Environment, industrial, fire and occupation health awareness programmes were also conducted successfully for IGCAR employees.

CHAPTER-3

NUCLEAR POWER PROGRAMME STAGE-III



AHWR bellows test facility



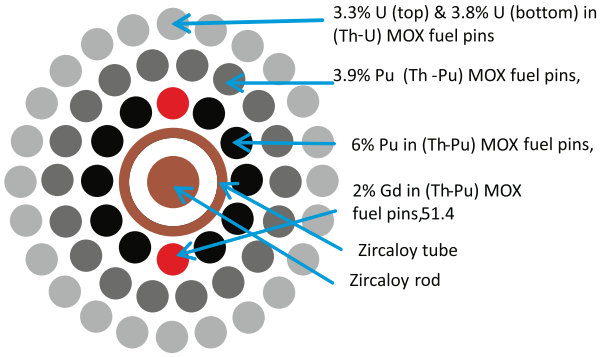
Schematic of Loop-In-Tank type IMSBR

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

The Advanced Heavy Water Reactor (AHWR) equilibrium core cluster having (Th, Pu-U) MOX fuel was re-optimized for better performance. The equilibrium core cluster requires about 1.8 kg of U and 3.1 kg of Pu and after irradiation for 40 GWd/Te, results in 2.2 kg of U and 1.1 kg of Pu. Use of an intermediate cluster of (Th, Pu) MOX fuel makes the transition to equilibrium core in a smooth manner.



Equilibrium core cluster for AHWR

The transition period is about 20 years and after that the core can be refueled with equilibrium core clusters made out of in-situ produced ^{233}U and about 6.2 kg Pu. Two types of initial core clusters containing depleted U and Pu to form (DU, Pu) MOX were designed for the initial core AHWR.



Fuelling machine installed in FMTF At Tarapur



High Temperature PADS Experimental Facility

Fuelling Machine Test Facility (FMTF) is established at R&D Centre Tarapur for testing of full scale prototype Fuelling Machine (FM) in reactor simulated condition. FM along with hydraulic supply system has been installed and hydro-tested.

A Passive Auto Depressurization System (PADS) was developed for faster de-pressurization of main heat transport system to initiate timely injection of cooling water to ensure safety and integrity of the core. Experimental demonstration of PADS for small break LOCA (Loss of Coolant Accident) condition at 70 bar & 285C is in agreement with results of RELAP model of the system.

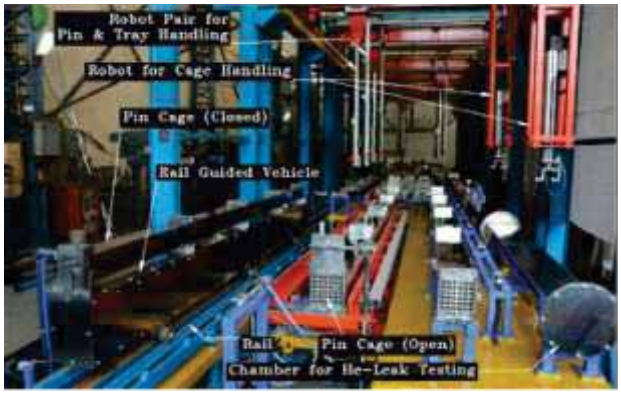
One of the design safety features of AHWR is the detection of occurrence of stagnation channel break through a combination of leak detection using acoustic sensors and low flow in the channel and executing reactor trip. Experiments were performed to validate the adequacy of this safety system in Integral Test Loop (ITL). The acoustic signal due to the stagnation break, simulated by a valve opening was captured by an acoustic emission sensor. Channel power trip was actuated on both low channel flow and acoustic signal together as desired, within seven seconds after occurrence of break.

Seismic risk analysis of AHWR was carried out to look into the possibility of station black out and LOCA type events. For this, seismic event is considered as initiating event and event tree is developed to examine various scenarios.

Seismic initiating event frequency is derived from hazard curve analysis and the seismically induced failure probabilities of systems can be evaluated by developing seismic fault trees. Analyses results are found to meet acceptance criteria.

A mock-up facility is developed and installed at BARC to demonstrate all aspects of fuel fabrication of (Th-^{233}U)O_2 fuel for AHWR, automatically and remotely.

IGCAR also extended support for design validation of the Advanced Heavy Water Reactor. Passive valve actuation bellows made up of SS 316 Ti were tested simulating the reactor operating conditions. The results found that all bellows



Mock-up Facility



Fuel Pin, Tray and Cage



AHWR bellows test facility

completed the required fatigue cycle at high temperature and high pressure conditions with a comfortable margin. Testing was continued to compute the ultimate life.

THORIUM FUEL CYCLE

An inert atmosphere glove box with hydro-fluorination facility for preparation and purification of thorium-based salts has been commissioned. The facility can be utilised for the preparation of pure thorium fluoride and purification of any molten salt systems (Capacity: ½ Kg per batch).



Inert Atmosphere Glove Boxes with hydro-fluorination facility

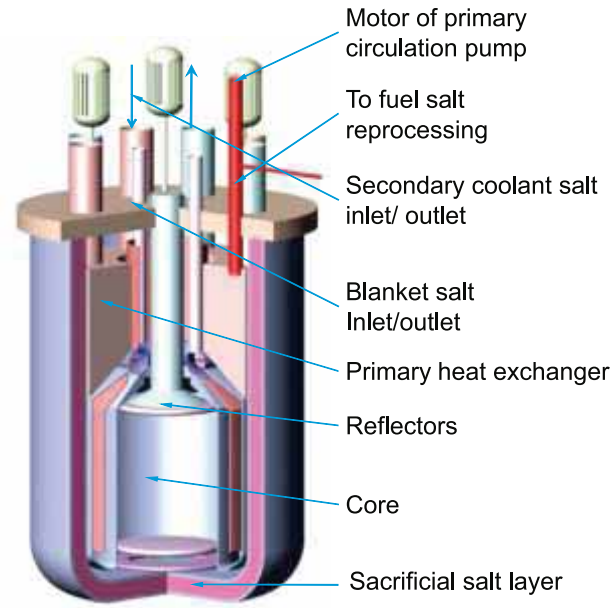
A Laser Induced Breakdown Spectroscopy (LIBS) technique employing Partial Least Squares Regression algorithm for spectral processing was developed for simultaneous characterization of Th, Al, Fe, Cr, Ni, F, and Sr in a simulated waste glass of Power Reactor Thoria Reprocessing Facility (PRTRF) to achieve a precision of 2-5%.

KAlpakkam MINI (KAMINI) Reactor

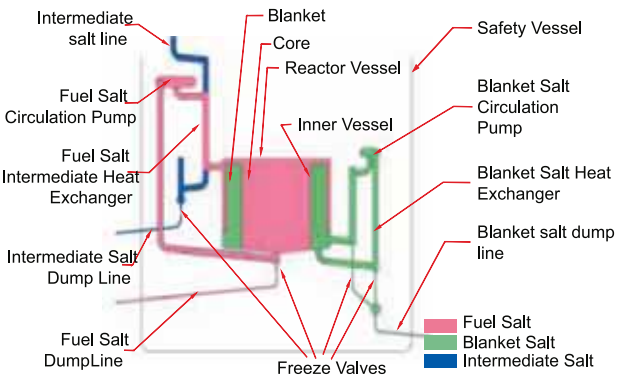
KAMINI reactor was in regular operation upto a maximum power of 30kWt for carrying out neutron radiography and neutron activation analysis. Reactor was operated for neutron radiography of 1700 pyro components for Vikram Sarabhai Space Centre and irradiation of samples from users for activation analysis. In addition, the reactor was used for calibration of high temperature fission chambers of PFBR at 570°C and boron carbide coated detectors at room temperature. Periodic Safety Review document for KAMINI was submitted to the safety authorities. Evaluation of the neutron spectrum at pneumatically operated fast sample transfer system was completed by using neutron induced radioactivity in thin foils and adopting various codes.

OTHER THORIUM REACTOR SYSTEMS

The refueling and removal of molten salt fuel in the 850 MWe Indian Molten Salt Breeder Reactor (IMSBR) has been computed at various burn-ups. Two different design configurations- Loop-In-Tank type and Pool Type have been worked out. The Loop-In-Tank type configuration has been designed considering the need for frequent in-service inspection, ease of component replacement and minimizing the fissile inventory. The Pool Type design



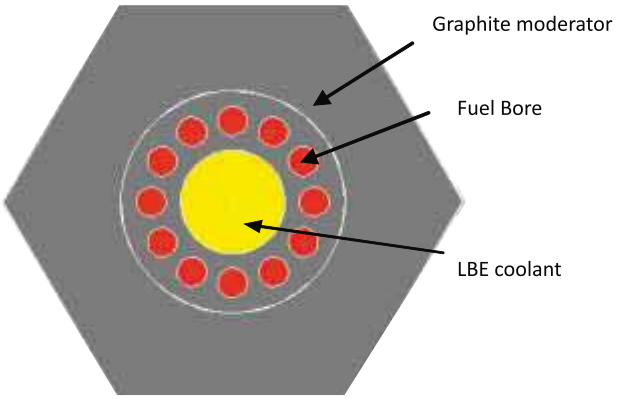
Schematic of Loop-In-Tank type IMSBR



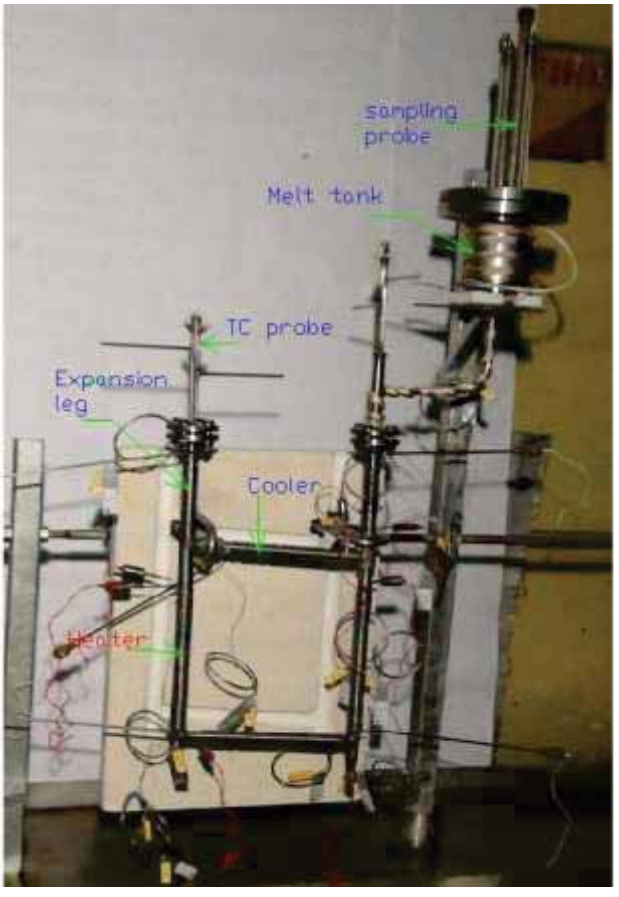
Schematic of Pool Type IMSBR

has been worked out by locating the entire primary fuel circuit inside the reactor vessel, forced circulation with the core inlet and outlet at 600°C and 800°C respectively and natural convection.

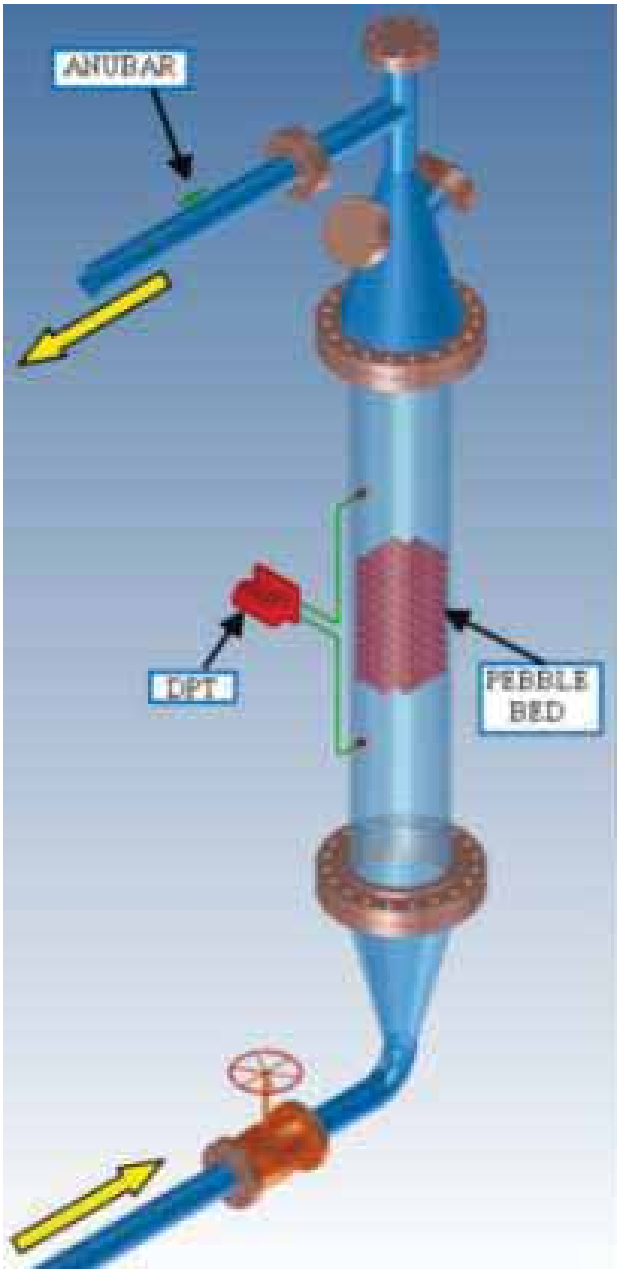
Monte Carlo simulations of LEU fueled, graphite moderated/reflected and Lead Bismuth Eutectic (LBE) cooled core of Compact High Temperature Reactor (CHTR) have been carried out for feasibility and optimization.



Fuel assembly of CHTR



Facility for MSBR thermal hydraulic studies



Isometric view of PBTF

To study the thermal hydraulic behaviour of the molten salts used in MSBR and the compatibility with different structural materials, experimental facilities are set up at BARC and various studies are in progress. A Pebble Bed Test Facility (PBTF) has been setup to study the heat transfer and pressure drop in Indian High Temperature Reactor (IHTR). Six pebbles instrumented with thermocouples are provided with heater for simulating heat generation inside the pebbles.

Due to its high effective thermal conductivity, good isothermal behaviour and self-actuating properties, high temperature heat pipe has potential use in CHTR, HTR and fusion reactor. A high temperature heat pipe has been fabricated in-house with sodium as the working fluid and tested up to 800°C. A number of computer codes have been developed for design and simulation. The results from simulation studies are in good agreement with the experimental results.



Sodium heat pipe

MATERIALS

Beryllium facility at BARC has developed a process for preparation of high purity beryllium oxide and technique for fabrication of rectangular shape high density sintered beryllia ceramic through vacuum hot pressing. These specific shaped beryllia ceramic blocks machined to finished tolerances shall form the stack for use as Reflector and Moderator for upcoming Nuclear Research Facility (upgraded APSARA).



Unfinished sintered beryllia blocks and multi-cavity die for production of beryllia stack

A vitrification process has been developed for the safe disposal of solid waste generated during extraction of Be from its ore by immobilizing the Be value present in waste mud. Vitrification was carried out at 950°C using varying ratios of mud and flux. Leaching experiments carried out for estimating migration of Be from vitrified mass to water has shown an atmospheric leaching rate of 10^{-7} g/cm^2/d, which is close to the leaching rate (10^{-8} g/cm^2/d) of natural occurring beryl ore. The vitrified mass

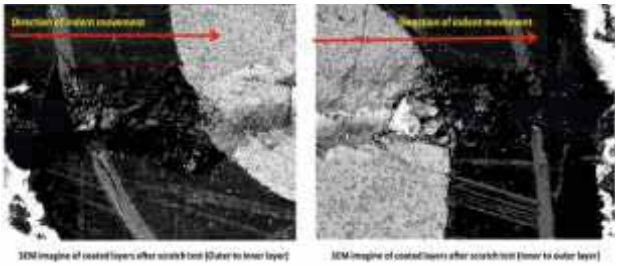


Vitrified beryllium solid waste

showed formation of crystalline phase along with amorphous phase in XRD.

Boron alloy composites (TiCr)B_2+$MoSi_2$ and B_4C+ZrO_2 was developed for control rod material of P-4 facility and shut-off rods of project B-3. (Ti,Cr)B_2 powder was synthesized by the solid state co-carbothermic reduction of Ti and Cr oxides at 1800°C in the presence of boron carbide. Pre-alloyed powder mass was crushed and ground to the desired particle size and hot pressed into pellets. Total requirement of special boron alloy pellets for control rod in the first core of P-4 facility was supplied.

The existing TRISO (TRIstructural ISOtropic) coating facility has been relocated, erected and re-installed with modified gas inlet lines, superior exhaust gas treatment facility and automation of coating status, gas flow monitoring systems and equipped with a re-designed spouted bed CVD reactor and a modified graphite heating element. The integrity of the TRISO coated particles have been established using scratch test conducted along radial direction of a cross sectional in both the directions viz., outer layer to inner layer and inner to outer layer, using constant load of 5 N over a tip of Rockwell diamond indenter having 20 µm diameters. The results establish a good integrity between low



Scratch test of TRISO coated particles



CVD spray coating facility

and high density pyrolytic carbon layers and that the SiC layer acts as a perfect pressure vessel: withstanding pressure from inner layers but failing at relatively lower pressure in the reverse direction. A five times scaled up TRISO coating facility has now been designed after establishing suitable correlations for the reactor hydrodynamics.

A Carbon Vapour Deposition (CVD) spray coating facility assisted with induction heating is designed, fabricated and commissioned for the coating of pyrolytic carbon as well as silicon carbide over all the internal and external surfaces of CHTR fuel tube. The facility has a capability to uniformly coat all the annular holes (13 nos.) and outer surface of CHTR fuel tube of 1 m length and 0.075 m outer diameter.

In house development of tubular fuel tube (dia 75 mm and length 300 mm) made up of graphite and carbon/carbon composite has been carried out.



SiC coated C/C composite



SiC coated graphite component

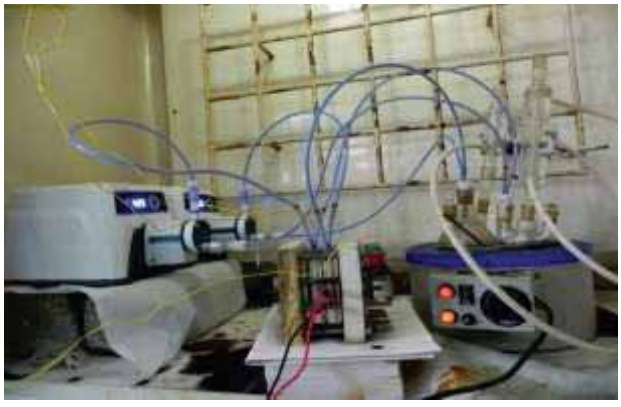
Protective coatings on these materials for application in an oxidizing environment have been deposited by Chemical Vapour Deposition (CVD) method. Simulation of gas-phase behavior in CVD reactor for silicon carbide coating on scale down fuel tube was carried out using computational tool, COMSOL. The characterization of fuel tube after coating has shown that dense silicon carbide was uniformly coated along the tube length and diameter.

HYDROGEN ENERGY

Process demonstrations were conducted at temperatures up to 110°C using in house developed Electro-Electrodialysis (EED) cell. The HI concentration was found to increase substantially, which shall drastically decrease the thermal load of IS process and makes it commercially viable.

Cell module of electrolyser plantHI decomposition studies were carried out upon employing zeolite coated alumina membrane as well as tantalum (Ta) metal coated alumina membrane in the membrane reactor at 500°C with Pt-alumina extrudes as catalyst and more than 90% of one-pass conversion of HI into hydrogen was obtained compared to the reported equilibrium conversion value of 22 %.

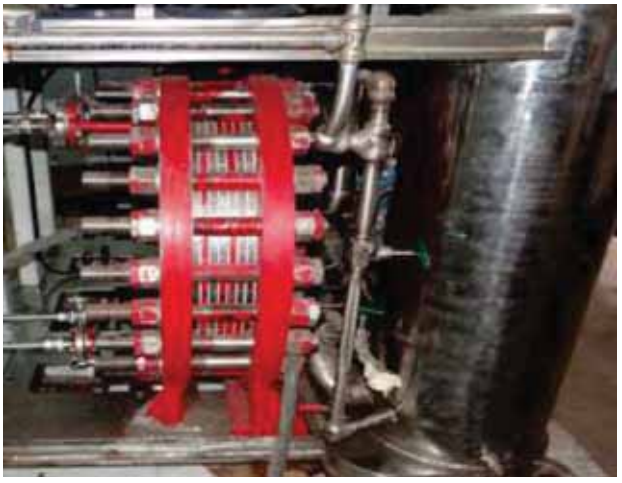
Development & Performance Evaluation of Membranes & Electrolyser module for Alkaline Water Electrolysis is done in lab scale system for feasibility demonstration, intermediate scale for system performance evaluation, prototype scale for scale-up design validation and actual production scale for deployment with desired product purity with 75% energy efficiency has been achieved.



EED process experimental setup



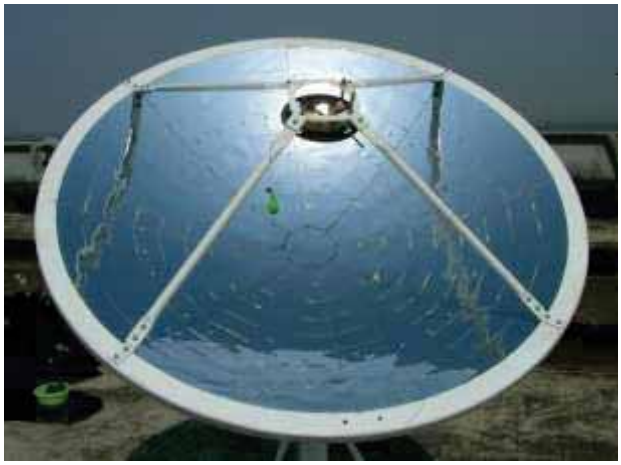
High temperature membrane reactor



Cell module of electrolyser plant

R&D has been carried out in successful application of membranes in Iodine Sulphur (IS) thermo chemical-cycle to overcome the low efficiency of the IS cycle. Ongoing research is dedicated towards application of proton exchange membrane to concentrate HI beyond azeotropic limit through Electro-Electrodialysis (EED) process, hydrogen perm-selective membrane reactor for efficient HI decomposition and to make the IS process thermo-chemically more efficient.

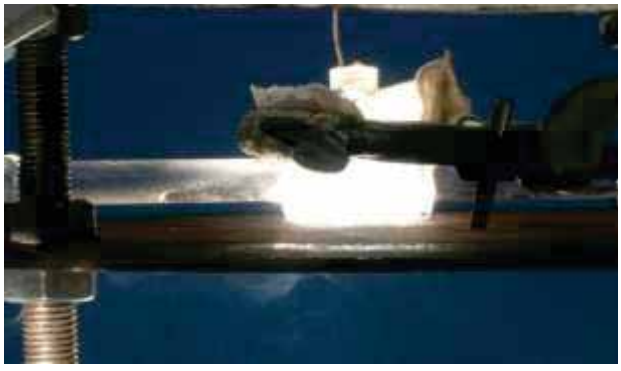
BARC is working on production of hydrogen by water splitting using two-step hybrid sulfur thermo-chemical cycle. The high temperature (1000°C) required for the thermo-chemical cycle is generated using solar energy. For integrated technology development at laboratory scale, a 1.8m dia solar concentrator has been installed to provide 1000°C temperature at the flat plate receiver. Two steps of the hybrid sulfur cycle, i.e., decomposition of sulfuric acid and electrolysis of sulfur dioxide have been demonstrated and an integrated demonstration of solar hydrogen production is underway.



Solar concentrator for laboratory demonstration of solar hydrogen



Hot zone at ~ 1000^{0}C



H_2SO_4 decomposition in the hot zone

MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

Pb-Li alloy prepared in 3-4 kg batch sizes and analyzed for Li composition at different locations showed that Li loading on top was in the hyper-eutectic range, in the central region it was in the eutectic range and there was a fall in Li loading at the bottom of samples. To make uniform composition, Pb-Li alloys produced were homogenized in a skull-melter. A facility was created for Pb-Li alloy preparation on 15 kg scale. Fully equipped inconel reactor with hydraulic movement of cathode assembly for Pb-Li eutectic production by fused salt electrolysis was commissioned. A caustic soda based scrubber to dissolve chlorine upto a flow rate of 8 lpm and lead in the electrolysis process was also tested and commissioned.



Lead lithium production facility

A forced circulation Pb-17Li loop replicating the actual size and design of the Lead Lithium Cooling System (LLCS) of the Indian Test Blanket Module (TBM) is being developed for fusion reactor application. This loop will be a demonstration of self-reliance in the field of Pb-Li technology and provide a common platform for conducting experiments related to component efficiency, material compatibility, fluid flow, Magneto Hydrodynamics (MHD) and instrumentation development for In-TBM. The detailed design of the loop has been completed and validated.

An electromagnetic pump driven loop had been designed, fabricated, installed and operated for 5,000 hr at a Pb-Li flow of 1.2 m/s at 500°C for compatibility studies on Indian-Reduced Activation Ferritic Martensitic Steel (In-RAFMS) with Pb-17Li. Corrosion rate of 49.98 μm/y has been recorded for In-RAFMS sample which is comparatively lower than that for the reference material EUROFER 97 under similar operating conditions. This may have a



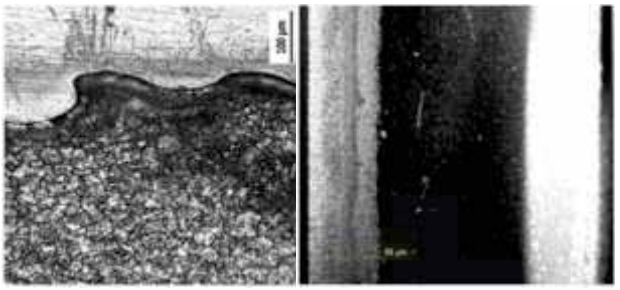
Pb-17Li in the presence of magnetic field

significant implication in the qualification of In-RAFMS for Indian TBM. Another experiment has been started in the above loop where a new set of In-RAFMS samples have been exposed to Pb-17Li in the presence of magnetic field at 500°C. A permanent dipole magnet having a field of 0.5 T has been integrated with the test section of the loop and the loop has been successfully re-commissioned.

The above experiment will provide important information about the effect of magnetic field on the corrosion compatibility of In-RAFMS material in Pb-17Li under simulated condition of Indian LLCB-TBM for ITER.

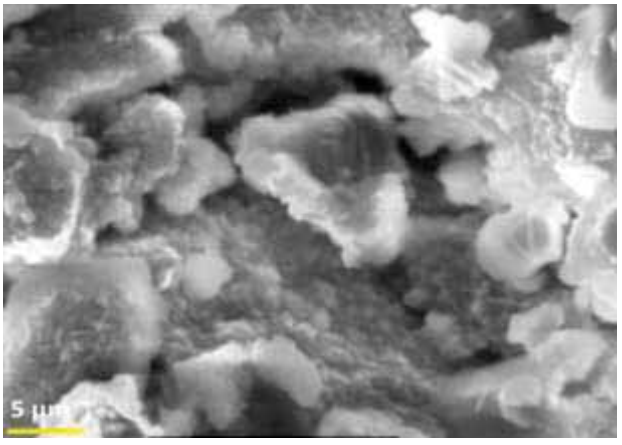


Box type channels



Aluminide coating / RAFMS Alumina coating on channel

Simulated box type channels as per the dimensions of cooling channels of Test Blanket of fusion reactor were designed and fabricated for developing iron aluminide /alumina coating. Iron aluminide coating (100 µm thick) was obtained on Reduced Activation Ferritic Martensitic Steel (RAFMS) by pack cementation. Alumina coating of 15-20 µm thickness was achieved over box type channel by CVD using Aluminum tri-isopropoxide, $Al(C_3H_7O)_3$ as precursor. Coating morphology and composition were studied by SEM-EDS. XRD analysis confirmed the formation of desired -Al_2O_3 phase.

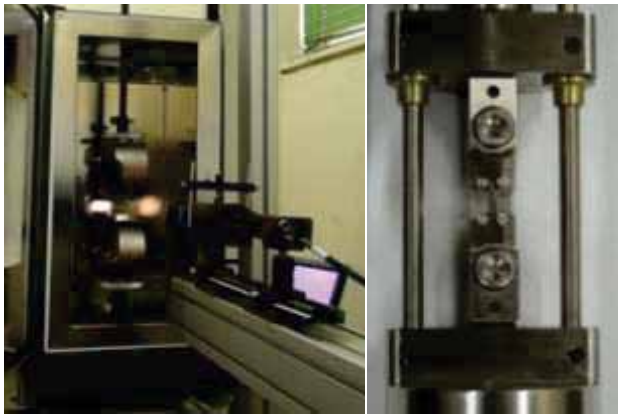


SEM micrographs for orthosilicate with 5% excess Li

About 6 kg of lithium titanate was prepared by solid state reaction of titanium dioxide and lithium carbonate 5%, 10%, 15% and 20% in excess of stoichiometric proportion respectively. Pebbles of size 1.0 mm were sintered at 900°C for 6 hrs. XRD confirmed the formation of multiple phases when excess lithium was used, as shown in Figure for 10% excess Li. Similar behaviour was observed of lithium orthosilicate with excess lithium. Morphological modifications of mesoscopic structure in silicate pebbles with different quantities of excess lithium by SEM reveal the presence of sub-micrometric pores.

This experiment is useful for selection of synthesis procedure for ITER application.

Dissimilar Metal Weld (DMW) joints are used to connect ferritic pressure vessel nozzles or piping to Austenitic Stainless Steel (ASS) piping in AHWR. Several fracture tests on component level DMW joints having through wall circumferential crack was conducted and structural integrity has been demonstrated.



Miniature specimen technology



Fracture Test Setup

A correlation has been developed by finite element analysis to estimate the thickness of disk bend specimen at fracture location from the central deflection during test which is an input to estimate the fracture properties. A facility for preparation of miniature size tensile and fatigue test specimens from scooped out volume has been developed at BARC. The dimensions of miniature specimens were standardised to get comparable results with results of standard tensile test.

CHAPTER-4

ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES AND THEIR APPLICATIONS



Feed cap & End cap assembly



Laser Additive Manufacturing (LAM) in process

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, Special materials and others. These technologies and equipments have many applications in the fields of medicine, industry and research.

Remarkable contributions in the field of radioisotope production and applications of radiation technologies the areas of healthcare, nuclear agriculture, food preservation and industry have been made by the above organisations.

To widen the reach of these technologies for the benefit of common man, DAE has been working in close cooperation with other organizations of the Government of India. The major activities and achievements of DAE organizations during the report period were as follows.

RESEARCH REACTORS

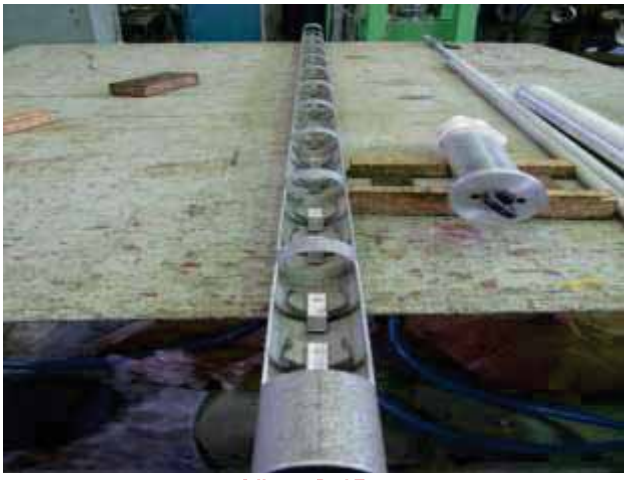
APSARA

Construction for 2 MW upgraded APSARA Reactor is in progress. Civil Construction proceeded as planned. Electrical and Ventilation work has started. Process equipments are in advanced stages of fabrication. Contract for control and instrumentation package has been awarded to M/s. ECIL. Review of the Safety Analysis Report has been completed by the Design Safety Review Committee (DSRC). Review for the process safety report is nearing completion and equipment erection clearance is expected.

DHRUVA

Research reactor Dhruva continued to be the only facility for radioisotope production and served as a national facility for neutron beam research. Dhruva continued to operate at rated power (100 MW) with a high level of safety and the availability factor was about 76%. Reactor logged the highest ever capacity factor of around 61%. About 600 samples were irradiated during the year as per the user requirements. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research. Irradiation of (Th–LEU) MOX AHWR fuel assembly in pile position E-23 continued.

An air cooled Adjuster Rod along with the rod drive mechanism was designed, developed and commissioned in Dhruva for the production of high specific activity Co^{60} for the preparation of tele-therapy source for cancer treatment as an import substitute. Adjuster Rod offers other advantages such as enhancement of flux in self-serve irradiation facility, reduction in linear heat rating of fuel rod,



Adjuster Rod Tray



Adjuster Rod Capsules

enhancement of reactor capacity factor and provides operational flexibility by providing adjustable reactivity load. Adjuster Rod is designed to produce 700 grams of high specific Co^{60} activity after 5 years. ARDM is built with rod continuous position monitoring and also has top and bottom end limit switches.

Top Bulge and Bottom End are the part of the Dhruva reactor Fuel Assembly and serve as biological Shield as well as structural components for hanging the fuel cluster. Manufacturing of Top Bulge (600 Nos) and Bottom End (300 Nos) have been completed. Required number of fuel assemblies, Al shields and SS plugs were fabricated and delivered to Dhruva facilitating its operation up to 100 MW.



Top Bulge



Bottom End Bulge

A dummy DHRUVA cluster containing MS rod was fabricated for flow tube under water cutting trials at DHRUVA. Modified Dhruva clusters were dismantled after flow test, cleaned, inspected, reassembled and delivered for irradiation trials.

Additional two pumps with independent piping and valves have been installed in new underground pump house to augment the existing auxiliary coolant pumps to enhance reactor safety, diversity and higher safety margin against extreme level of flooding (Beyond design basis flood level).

To enhance core reactivity for facilitating reactor operation at high power levels and utilisation, it was proposed to modify the existing fuel assemblies of Dhruva by dividing the core into two zones viz. inner and outer zones having fuel assemblies with different fuel mass, clad thickness and flow area. Two such assemblies have been designed, fabricated and were loaded in pile for test irradiation after getting regulatory clearance. The assemblies were removed after completion of target irradiation. The in pile performance of these assemblies was as intended. Full core loading with such modified assemblies will be carried out in due course of time.

As a part of Dhruva Control & Instrumentation up-gradation, triplicated Trombay Programmable Logic Control (TPLC-32) based Reactor Trip Logic System (RTLS) was installed and commissioned. Grouped local coincidence logic had been implemented in RTLS resulting in enhanced availability and maintainability. Comprehensive diagnosis of hardware and software coupled with information rich Operator Consoles have resulted in precise and crisp analysis of events.

Single channel Start-Up Logic System (SULS) of Dhruva was upgraded with TPLC-32 based triplicated channel Start-Up Logic System. This has resulted in implementing fail safe feature for all interlocks and elimination of large number of relays and wiring leading to better availability, reliability and maintainability.

To facilitate commissioning of RTLS, Emergency Core Cooling System (ECCS) processing circuit was modified to accept Linear Flow Signals in line with RTLS and solid state electronics based Auxiliary Trip (XT) circuit was replaced with relay based logic system. Pneumatic transmitters were replaced with electronics transmitter. Electronics Differential Pressure Indicating Switch (EDPIS) provided for fuel channel flow measurement were configured for analog mode and current output was directly catered to RTLS. Alarm & Trip Units



TPLC-32 based RTLS in Dhruva



Single Channel Start–up Logic System (SULS)

(ATUs) were provided to generate alarm and interlock outputs related to process parameters.

Commissioning of the system was done channel wise during monthly routine shutdowns with few additional days of outage of the reactor thus saving time, energy and effort.

Operation of Heavy Water Upgrading Plant was continued for improvement of Isotopic Purity (IP) of the downgraded heavy water received from Dhruva to maintain Reactor IP. By efficient capacity utilization, additional quantity of downgraded heavy water was processed to meet the requirement of Dhruva.

ACCELERATORS

At BARC, the prompt fission neutron spectra for fast neutron induced fission of ^{238}U were measured at Folded Tandem Ion Accelerator (FOTIA) facility and compared with calculations of nuclear model code EMPIRE. The shape of prompt fission neutron spectra is important for reactor design simulations.

The Pelletron-Linac facility is running round-the-clock and various beams have been delivered through Pelletron and Linac booster to the user requirements. The unambiguous identification of sputter-ejected TaOn - (n=1-6) negative ions was performed via accelerator mass spectrometry technique using Pelletron Accelerator. Silicon Nitride window of 200 nanometer thickness was mounted at the entrance of the segmented anode gas ionization detector and tested for gas pressure up to 100 mbar for carrying out the ^{36}Cl and ^{129}I accelerator mass spectrometry measurements. Field Programmable Gate Array (FPGA) based modular, 24 channel, high speed data acquisition system with a maximum sampling rate of 1G samples/sec and a 4-lane, PCI-express interface card has been indigenously developed.

In thermal ADS system, various noise experiments using techniques such as continuous Feynman-alpha, Rossi-alpha and autocorrelation were carried out to measure neutron decay constant. A new technique of modal analysis was developed for eliminating the contribution of higher harmonics in such system.



Feed cap & End cap assembly

Cryo Module Test System (CMTS) to measure the performance of superconducting RF cavities of 1.3 GHz Cryo module is developed under Indian Institution and Fermi Lab Collaboration (IIFC). CMTS consists of five main assemblies i.e. Feed box, Feed cap, End cap, Transfer line & Support Structure. Various Quality, manufacturing, assembly and testing procedures were prepared and were approved by Fermi Lab., USA. Manufacturing of Feed cap & End cap assembly have been completed and delivered.

Piping installation for Radio Frequency Quadruple (RFQ) and Drift Tube LINAC (DTL) cooling systems of Low Energy High Intensity Proton Accelerator (LEHIPA) at Common Facility Building was completed. The Closed loop operation of RFQ Vane Channels and RFQ Outer Channels cooling system was carried out.



RFQ Cooling system Distribution Piping Headers

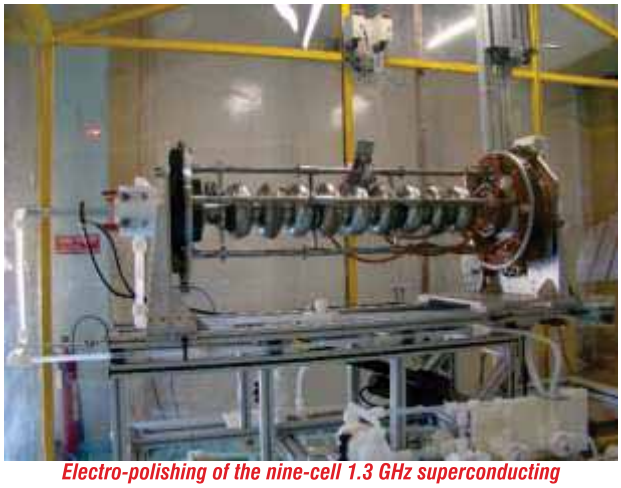


DTL Cooling system Headers



DTL Cooling System Pumps

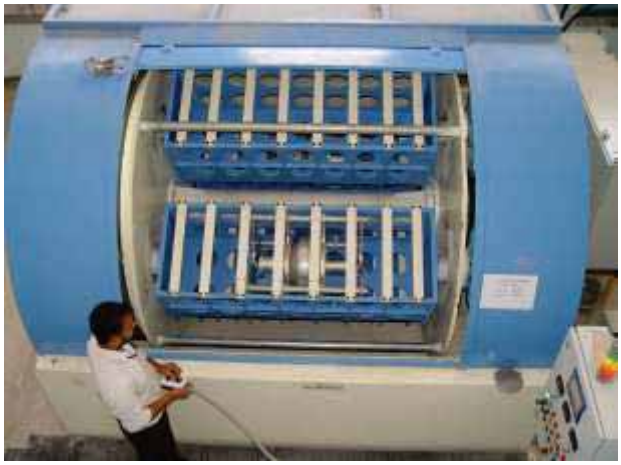
A facility for processing of multi-cell 1.3 GHz Superconducting Radio Frequency (SCRF) cavities has been set up at RRCAT. Using this facility a nine-cell 1.3 GHz SCRF cavity has been fabricated and is undergoing processing using in-house developed facilities. Processing of the cavity is being carried out using a standard recipe followed at international lab. The cavity has been electro-polished to remove an average of 50 micron material from equator region and high pressure rinsed using ultra-pure water at 120 bar. The cavity is now ready for the second stage polishing and will be tested at 2 K for required performance in terms of quality factor and accelerating gradient.



Electro-polishing of the nine-cell 1.3 GHz superconducting radio-frequency cavity

A semi-automatic cavity tuning machine has been designed and developed for the RF resonating frequency and field flatness correction of a multi-cell 1.3 GHz SCRF cavity. The tuning machine has motor driven tuning jaws, cavity mounting system and bead pull measurement system. A tuning methodology to tune a multi-cell cavity has been developed and trials have been carried out on a nine-cell 1.3 GHz cavity.

A centrifugal barrel polishing machine has been indigenously designed and developed for polishing of the internal surface of multi-cell SCRF cavities. The machine has a provision to simultaneously polish 4 numbers of five-cell 650 MHz SCRF cavities in four barrels.



Centrifugal barrel polishing machine loaded with single-cell 650 MHz cavity

RRCAT had developed an innovative laser welding technique for fabrication of SCRF cavities. A 1.3 GHz test cavity was welded using this technique and had demonstrated performance matching international standards. A Japanese patent was granted for this procedure. This technique has been used now to fabricate a single-cell 650 MHz SCRF cavity which is much larger in size. Development of multi-cell cavities at 650 MHz is essential for building a high intensity pulse proton linac which will be used



The 650 MHz laser-welded SCRF cavity

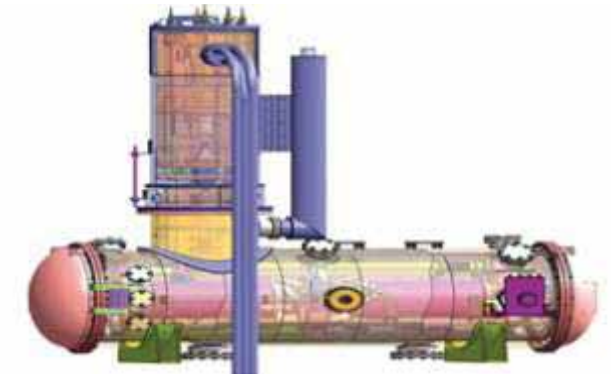


Indigenously developed helium liquefier of 35 litre/hr capacity

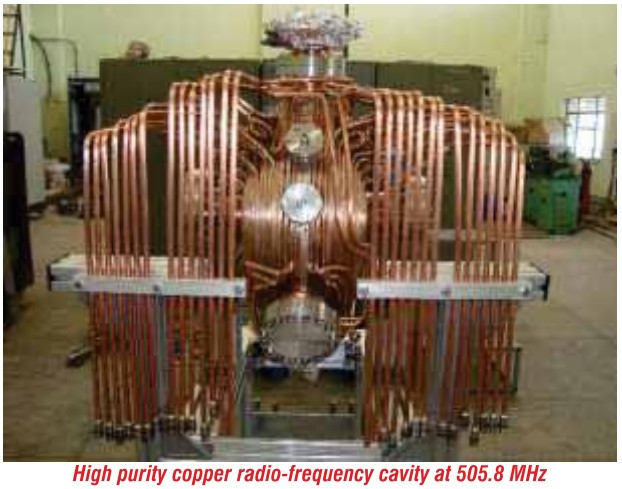
in the long term Indian Spallation Neutron Source (ISNS) programme.

Helium liquefaction using a completely indigenous system was first achieved at RRCAT in 2010. The system was based on reciprocating type expansion engine and used cross counter flow type heat exchangers. This system has now been upgraded with the development of new reciprocating type cryogenic expansion engines with larger refrigeration capacity and state of the art brazed aluminium plate fin heat exchangers with high heat transfer rate and efficiency. High efficiency brazed aluminium plate fin heat exchangers manufactured in the country have been successfully deployed in a helium liquefaction system for the first time. The upgraded system produces more than 35 litres of liquid helium per hour.

A horizontal test cryostat has been designed under the Indian Institutions-Fermilab Collaboration (IIFC) for testing two 650 MHz "dressed" SCRF cavities at 2K in a single testing cycle. This cryostat will be the third such system in the world and will be used to test 5-cell 650 MHz SCRF cavities in CW / pulsed regime being developed at RRCAT. The design has been reviewed and approved by international experts. The following picture shows the finalized 3-D model of the horizontal test cryostat.



3-D model of the horizontal test cryostat



High purity copper radio-frequency cavity at 505.8 MHz with copper cooling coils

A bell-shaped tuneable oxygen-free copper radio-frequency (RF) cavity and high power input coupler operating at 505.8 MHz for Indus-2 has been indigenously designed, fabricated and tested. The RF cavity half shells, ports and cooling tubes are joined using precision fixtures by four stage vacuum brazing process. To keep Higher Order Modes (HOM) within safe limits, extensive water cooling is provided on the cavity body, ports and coupler parts to get a temperature stability within ± 0.1°C. The cavity achieved an ultimate vacuum of $5x10^{-10}$ mbar after baking and cool down. High power testing of RF

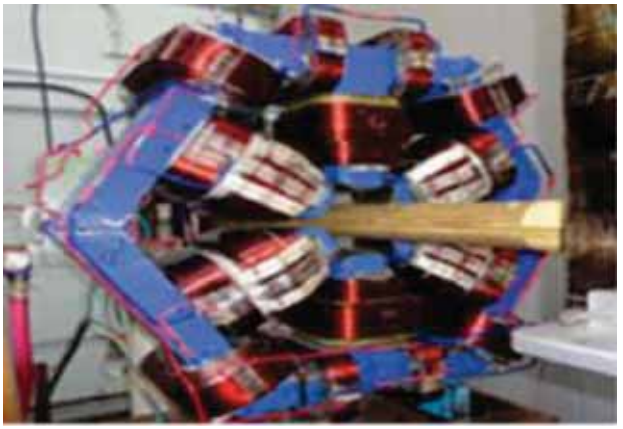
cavity was carried up to 33 kW net average RF power meeting the consistent operational requirements of Indus-2. During the entire testing no significant multipacting, arcing or oscillations were observed.

All four RF stations of Indus-2 have been now upgraded with Field Programmable Gate Array (FPGA) based digital Low Level RF (LLRF) control system. After replacing the analog LLRF systems with digital LLRF systems, feedback control parameters were optimized in all four stations to achieve phase stability of better than 0.5° and amplitude stability of better than 0.5%. Also, feedback loop bandwidth was optimized for all four stations to accumulate the beam at injection energy and successfully ramping the energy to achieve stored beam of more than 200 mA at 2.5 GeV. Development of the Digital Low Level RF (DLLRF) system involves use of latest technologies of digital signal processing, RF signal processing and fast feedback control systems.



Digital LLRF systems installed with four RF stations in Indus-2

All the different types of magnets required in the Indus synchrotron sources have been developed in-house. In a continuing effort to further improve the performance, prototype harmonic sextupole magnets and low coupling impedance kicker magnets for Indus-2 have been developed. Harmonic sextupole magnets are required to suppress the non-linearity induced by the existing chromatic sextupole magnets and thereby to improve the dynamic aperture in Indus-2 storage ring. A prototype magnet with low carbon steel core has been developed and characterized for integrated magnetic field strength and quality. The overall physical length is kept within 250 mm to accommodate it in the existing available space in the beam direction of Indus-2. Infrastructure for magnet testing has been augmented by



Prototype harmonic sextupole magnet for Indus-2



Low coupling impedance kicker magnet for Indus-2

development of pulsed type MH loop tracer system for characterization of high energy permanent magnets and a stretched wire system for the measurement of magnetic field integrals of planar undulators. A spin wave measurement set up has been developed to measure power handling capability of ferrites and garnets for development of high power (100 kW) CW ferrite circulators at RRCAT.



The 10 MeV industrial linac. The linear accelerating structure, focusing magnetic elements and the beam scanner can be seen

A 10 MeV electron linac suitable for operation under industrial conditions has been developed with mostly indigenous design and component manufacturing. Its supervisory control system facilitates remote operation of the linac from a control room and ensures personnel safety, fail safe and reliable operation. At present, the developed linac has delivered a beam power of 4.2 kW and has been tested for a continuous running of more than 90 hours.

Development of an Infra-Red Free Electron Laser (IR-FEL) designed to lase in a wavelength range as 15-50 μm using a 15-25 MeV electron beam from an injector linac and a 2.5 m long pure permanent magnet undulator with 50 mm period has been completed. This FEL employs an indigenously developed injector linac system with employing a 476 MHz sub-harmonic pre-buncher and two S-band two Plane Wave Transformer (PWT) linac structures developed in-house. The main challenge in this PWT linac assembly was precision machining followed by precision brazing to ensure UHV leak tightness and precision spacing of the copper disks. A low level S-Band LLRF system has been designed and developed for phase and amplitude stabilization of microwave power to be fed to injector linac of IRFEL. The electron beam transport line magnets and the vacuum beam line for the IR-FEL have been built in-house, tested off-line and installed in the IR-FEL setup. Design vacuum has been achieved in the complete vacuum beam line. A vacuum system has been designed, fabricated and tested for the 14 meter, variable cross-section beam transport line.



The plane wave transformer linac for the infra-red free electron laser.



The 60 m long shielded tunnel showing the free electron laser being assembled in place

The system is able to maintain the required vacuum level of better than $3x10^{-8}$ mbar throughout the line. Commissioning and testing of individual sub-systems of the IR-FEL is presently in an advanced stage.

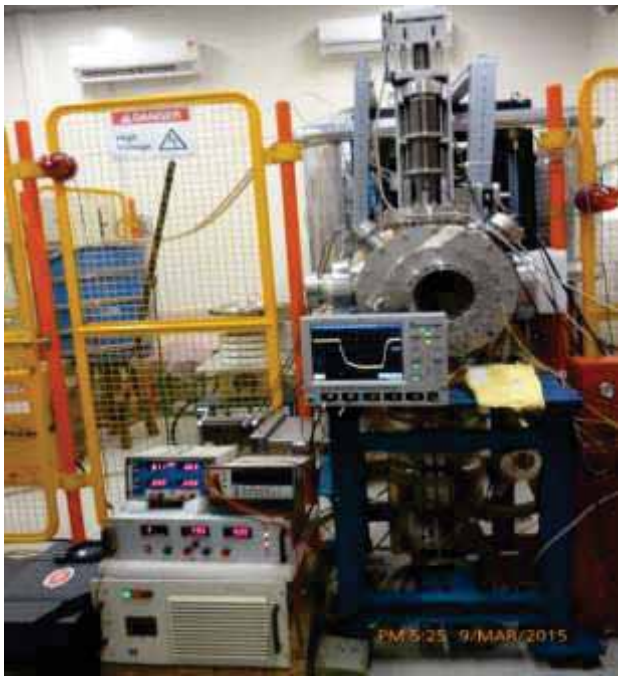
An indigenously built hydrocarbon-free ultraclean cold walled controlled atmosphere brazing furnace has been installed to facilitate brazing of dissimilar metal transition joints and copper-to-copper joints for accelerator components. The furnace has demonstrated a fast pump down time of less than an hour, an ultimate vacuum of 5×10^{-7} mbar and a temperature uniformity of ± 5°C. It can also operate in dynamic argon partial pressure of 0.5 mbar. Apart from fulfilling the brazing requirements of various accelerator projects, this ultraclean furnace environment has also facilitated development of new brazing recipes for joining of niobium and copper to austenitic stainless steels.



The controlled atmosphere brazing furnace

The physics design of Low Energy Beam Transport (LEBT) line and Medium Energy Beam Transport (MEBT) line for the injector linac has been completed. The LEBT matches and transports the beam from the ion source to the entrance of Radio Frequency Quadrupole (RFQ), MEBT matches and transports the beam from the exit of RFQ to the entrance of Single Spoke Resonator (SSR). The electromagnetic design and beam dynamics studies have been completed for three families of single spoke resonators to accelerate the beam in three different ranges of beam energy.

A multicusp type H^- ion source has been developed for high current H^- injector linac. The developed multicusp filament based H^- ion source has been operated up to 50 keV energy with extraction of 6 mA H^- ion current, in pulsed mode with 0.5 ms pulse duration and 2 Hz repetition rate.



Filament based multicusp H^- ion source



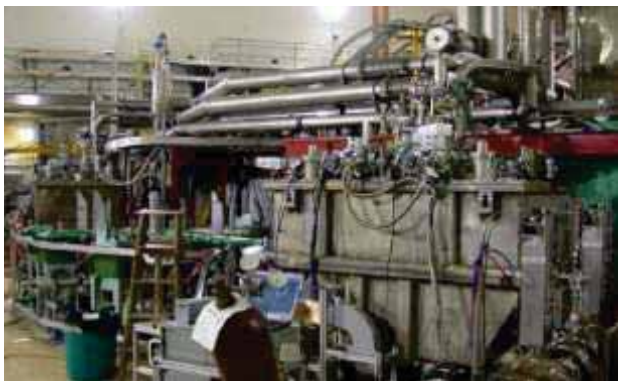
Alumina ceramic chamber with titanium end flanges for injection kicker magnets

A prototype high purity alumina ceramic chamber with titanium end flanges was designed and developed. Such chambers with a thin metallic coating are required for injection kickers magnets in order to avoid shielding of a fast-changing kicker field, minimize eddy current heating, and to carry beam-induced image current.

Developing and testing of 10 MeV superconducting Electron linac.

At VECC, a 10 MeV injector based on 1.3 GHz superconducting RF technology is being developed in collaboration with TRIUMF (TRI University Meson Factory) Canada. This injector forms front end of the 50 MeV electron linac (e-Linac) photo-fission driver for the ANURIB (Advance National facility for Unstable and Rare Isotope Beams) facility. Two Injector Cryo-Modules (ICM), one for each institute, are being jointly built and will be tested at TRIUMF. The ICM houses one 9-cell Bita=1, 1.3 GHz niobium elliptical cavity operated at 2K at an acceleration gradient of 10 MV/m.

The first ICM has been assembled and its first beam tests were conducted at TRIUMF. 10 μA Electron beam was accelerated up to 10 MeV through the ICM and thereafter in an Acceleration Cryo Module (ACM) with one cavity reaching final energy of 23 MeV. The second ICM, which is meant for VECC, has been fabricated and is being assembled at TRIUMF. The testing is scheduled at TRIUMF in early 2016. VECC scientists are participating in the assembly as well as tests of the ICMs.



The Injector Cryo-module during testing at TRIUMF



e-Linac test area showing electron gun & LEBT line

Apart from the ICM, the Injector comprises a 300 kV electron gun and Low Energy Beam Transport (LEBT) line which are being developed by Indian industry. A test area has been set-up at VECC Salt Lake campus for initial tests of the Injector.

Design of rod-type high current proton radio frequency quadrupole accelerator for ANURIB project at VECC

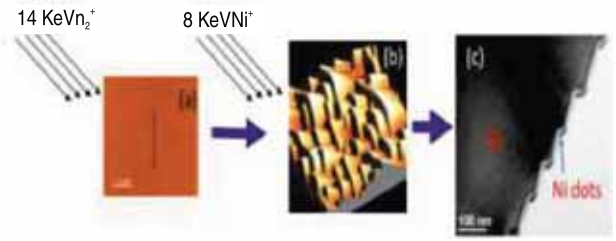
A high current rod type RFQ accelerating protons to 1 MeV has been envisaged as the injector to 50 MeV proton driver for the ANURIB facility. This would be used to produce p-rich radioactive nuclei complementing the n-rich nuclei production via the photo fission route. Rod type structure has been chosen owing to ease of machining and well separated dangerous dipole modes appearing in vane type structures. RFQ with optimized physical parameters should be able to accelerate 5 mA beam to 1 MeV with minimum loss within a viable length from machining point of view. While designing, special emphasis has been given in analyzing the space charge induced effects and avoiding beam instabilities. With the optimized parameters the RFQ beam dynamics have been carried out using TOUTATIS code with corroborative study using another particle tracking code GPT. The optimized RFQ has a 3.41 m long RFQ accelerating proton beam of current 5 mA from 50 KeV to 1 MeV with transverse efficiency of more than 99% and longitudinal efficiency of more than 86% (within ± 0.09 MeV) for beam current upto 15 mA. The beam dynamical study ensures that for the designed RFQ particle – core effect is not predominant. No significant halo developed in the output beam even after introducing 50% mismatch factor in input beam.

Theoretical calculation of yields of neutron-rich nuclei by actinide photofission in the giant dipole resonance region

The aim at the ANURIB facility is to produce neutron-rich radioactive ion beams by photo-fission of actinide target. Nuclear structure properties of neutron-rich nuclei are of prime importance in understanding r-process nucleo-synthesis of elements. This study was aimed at estimating the yield of n-rich nuclei in photo-fission of 238-uranium at nuclear excitation energies that covers the entire giant dipole resonance region. A comparative analysis of the behavior of the symmetric and asymmetric modes of photon-induced fission as a function of the average excitation energy of the fissioning nucleus is performed. The mass distributions for photofission fragments are obtained. The integrated yield as well as charge distribution of photofission products is determined. Thus, the production cross sections of neutron-rich nuclei are calculated and their exoticity (neutron richness) is explored in comparison to the nuclei produced by rapid neutron capture process in nucleosynthesis.

Magnetic dot and channel formation by site specific Ni ion implantation

Fast and large area nano dot formation of magnetic materials in minimum processing steps is one of the big efforts underway due to its vast applications in nano scale electronic and magnetic storage device fabrication. A simple but unique cost effective technique for large area isolated nano dot formation has been developed. It has been shown that by exploiting the geometrical shape of pre-fabricated triangular structures and resulting local ion impact angle, keV energy broad Ni ion could be implanted to form isolated dot patterns without the need of any resist, mask, focused ion or electron beam and multistep processing. It has been shown that Ni^+ ions bombardment on Si surface at an ion incidence angle of 70^0 with respect to the surface normal generates three dimensional saw tooth like structure on the entire beam exposed area. A Ni beam of 10 keV is implanted on such pre-fabricated patterned Si surface at same (70^0) angle. This resulted in a self-organized isolated Ni dot patterns on the entire beam exposed area.



Nickel nano-dot formation by shadow implantation. (a) Atomic Force Microscope (AFM) topography of smooth and clean Si(100) surface (b) AFM of triangular nano-structures formed by nitrogen ion beam bombardment, (c) cross-sectional view by Transmission Electron Microscope (TEM)

Development of experimental set-up & starting a new R&D programme on Graphene layer formation by carbon ion implantation

A programme on graphene layer formation by implantation of low energy carbon ion beams on deposited or implanted Ni layer has been initiated. An experimental arrangement for this purpose in the UHV chamber of the RIB material science beam line has been made. Ni layer could be formed by both implantation and vapor deposition on a substrate. For direct deposition of Ni layer on the Si substrate an arrangement is developed with an e-beam evaporator. For nickel layer formation by implantation, higher intensity (micro amps) Ni beam is developed from the ECR ion source by Metal Ions from Volatile Compounds (MIVOC) technique. Carbon beam is extracted from the same ion beam system for implantation into the deposited or implanted Ni layer. In an experiment, a buried layer of Ni is formed just below the Si surface by 10 keV Ni^+ ion implantation at normal incidence with a fluence of 1×10^{17} ions/cm^2. Carbon ions of energy 5 keV an implanted within the buried Ni layer. Atomic Force Microscopy study on the surface shows an interesting surface morphology with hole structures surrounded by debris. Cross sectional Transmission Electron Microscopy (TEM) study detects the buried 10 nm thick Ni layer just below the Si surface Formation of graphene by control annealing of this system is underway.

Development of stable and radioactive beams in ECR ion source

Development and acceleration of higher intensity stable Ni ion and radioactive ^{111}In ion beams using the ECR ion source have been performed. Ni beam of micro amps current was developed by Metal Ions from Volatile Compounds (MIVOC) technique using the 2.5 GHz ECR ion source. The same ion beam was developed last year by sputtering of a Ni ball and a beam current 100 nA was achieved. Higher current was required for isolated buried Ni dot formation in a nonmagnetic matrix. Nickelocene, a chemical compound containing Ni is utilized this time. The compound was kept at a separate chamber which is connected to the ECR chamber. An ECR plasma is formed by carrier nitrogen or Argon gas. The relatively high vapour pressure of Nickelocene at room temperature causes it to diffuses into the ECR chamber. The compound is dissociated and elements are ionized in the ion source. The ions were extracted and mass spectrum of Ni isotopes were recorded. The beam current of ^{58}Ni on target was from 250 nA to 1 μA through a 6 mm aperture.

Stable ^{115}In and radioactive ^{111}In beams were also developed using the same ECR ion source. ^{115}In beam was developed to optimize the ion beam system for acceleration of radioactive ^{111}In beam. Radioactive ^{111}In has a half-life of 2.8 days and is used as a radioactive probe in biology and materials science research.

For radioactive indium beams, ^{111}In isotopes were first produced by bombarding natural silver target with 30 MeV, 1 μA alpha particle beam from the K-130 cyclotron. After radio-chemical separation, about 500 micro-curie ^{111}In chloride was deposited on an aluminum electrode and inserted in the plasma chamber of the 2.4 GHz ECR ion-source of the RIB facility. Indium ions were produced in the ECR by the sputtering technique and extracted from the ion-source. Isotopically separated and a pure ^{111}In beam was implanted in Si and Au target with an integrated dose of $2x10^9$ atoms.

Design and development of a 3 axis magnetic field measurement facility using Hall probe

A precise 3 axis drive system has been designed and developed to move a magnetic hall probe in a precise manner with accurate positioning in 3D space and measure the magnetic field. The drive of each axis has linear guide and zero backlash ball screw combination to achieve accurate

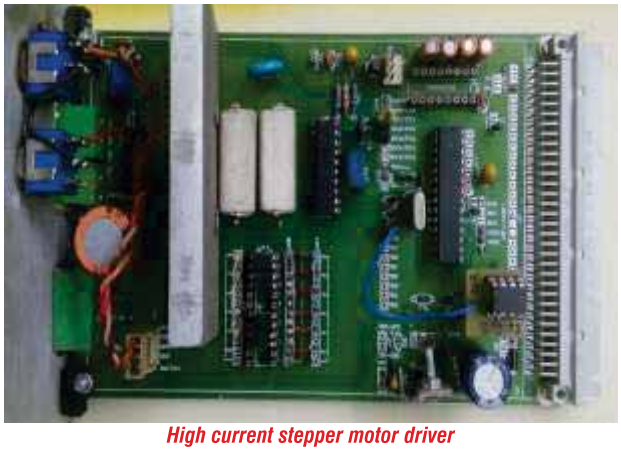


3 Axis magnetic field measurement machine

movement of the hall probe with positional repeatability of +/- 0.2 micron / 50 mm. The drive system is mounted on a granite surface having flatness tolerance of 9.5 micron and flatness deviation of less than 3.5 micron over an area of 250 mm x 250 mm. It will have capacity to measure magnetic field in a volume of 1500 mm X 1300 mm X 150 mm for a single setting. The positional accuracy of hall probe in 3D is better than 0.2 mm for the whole volume. This facility can be used for accurate magnetic field mapping of big dipole magnets, solenoids, etc.

The control hardware of the mapper system comprises stepper motors, motor controller and driver cards for X, Y and Z movements, optical encoders, encoder read-out cards and a hall sensor based magnetometer. The stepper motors are driven by in-house developed microcontroller based card having PWM based current control. The optical encoders are interfaced with in-house developed microcontroller based encoder read-out system. An LCD displays the absolute position of the probe with reference to predefined zero using position of limit switches and index pulse. All these modules communicate with a LABVIEW based GUI through a serial device server.

A Hall sensor based magnetometer with four ranges (0.1 - 3 T), precision of 100 µT (1 Gauss), and an accuracy of ±1% is used for field measurement. Its small size enables 3-axis field measurements in small gaps of magnets too. A microscopic 3-axis active volume provides accurate measurements even in strong gradients. The spinning-current techniques used in the sensor minimize offset as well as the Planar Hall Effect.



High current stepper motor driver

Lab view based GUI (Graphics User Interface) using touch-screen control has been developed in-house for 3D surface scan and point wise measurement. Lab view is chosen for its Rich GUI features (like Knobs, 2D and 3D graphs etc), easy interfacing with Magnetometer (THM1176 by Metrolab) and compatibility with Windows-8 OS. The 3D scanning with specified step-sizes is performed by availing inputs from 'origin', 'destination' and 'step-size' controls of the GUI.

Accelerators Development of single-cell, 650 MHZ, ß=0.61 niobium SRF cavity

The research and development activities on 650 MHZ, ß=0.61, superconducting RF cavity has been going on at VECC under Indian Institutions Fermilab Collaboration (IIFC). On successful completion of the design of single-cell 650 MHZ, ß=0.61, superconducting RF (SRF) linac cavity, fabrication of prototype aluminium cavity and also single-cell niobium cavity was taken up.

The cavity half-cells have been formed from ultra-pure niobium sheet (600 mm. x 600 mm.) with 4 mm. thickness, using our die-punch assembly already made in-house. Also, two beam pipes (with 96 mm. inner diameter and 110 mm. length) have been rolled from the same 4 mm. thick niobium sheet. The end flanges have been fabricated from 25 mm. thick Nb-55%Ti alloy. The necessary fixtures for electron beam welding are designed, related engineering drawings are prepared and fabricated. Before starting electron beam welding, all parts for the cavity have been thoroughly cleaned with acid. In the first step, two half cells were successfully welded



Cavity half-cells along with fixtures being put inside EBW machine for equator welding (left), Single-cell niobium cavity after EBW (right)



VNA testing of 1-cell Nb cavity (left), Vacuum leak rate checking of 1-cell Nb cavity by MSLD (middle), MSLD done at LN_2 temperature (right)

at the equator region and also separately the rolled beam pipes were welded by using Electron Beam Welding machine at IUAC, New Delhi. In second step, the iris portions of the single-cell cavity and the corresponding beam pipe ends were properly machined. The Nb-Ti end flanges were welded to the corresponding beam pipe ends. The joints between the iris and the other end of the beam pipe have been Electron Beam Welded (EBW) and the final single-cell cavity has been fabricated.

LASER TECHNOLOGY

A fiber coupled pulsed Nd:YAG laser providing pulses of 20 kW peak power has been developed at RRCAT specifically for laser welding of up to 4 mm thick niobium superconducting radio-frequency (SCRF) cavities. The pulse duration can be varied from 2 to 60 ms and pulse repetition rate from 1 to 100 Hz. This laser system has been equipped with two time shared fiber optic ports of 600 micron core diameter, one for full depth welding of niobium SCRF cavities and another for surface smoothening to achieve good quality weld joint with minimum heat affected zone, distortions and shrinkage. The laser delivers an average power of 1 kW.



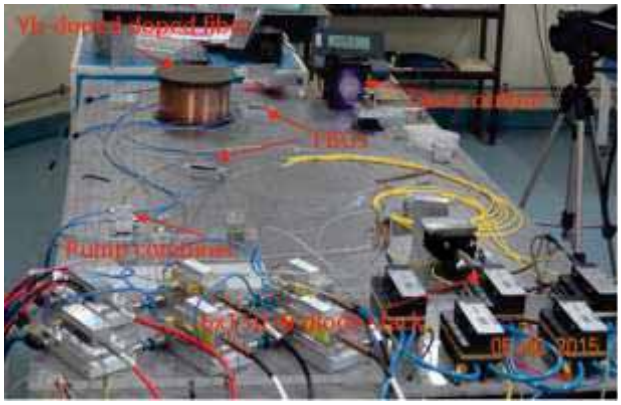
The 20 kW peak power Nd:YAG laser for welding of Superconducting Radio Frequency cavities

A pulsed Nd:YAG laser of a 10 kW peak power average power with dual port fiber optic beam delivery has been developed for remote dismantling of irradiated fuel subassemblies of the Prototype Fast Breeder Reactor (PFBR) in hot cell at IGCAR. It provides pulses with duration variable in the range of 2 to 40 ms and repetition rate in the range of 1 to 100 Hz. Laser system parameters has been optimized for cutting of hexagonal fuel subassemblies of 3 mm thickness in the presence of slippery and pyrophoric sodium at a radiation level of about 10^6 rad/hr.



10 kW peak power fiber coupled pulsed Nd:YAG laser for IGCAR

An Yb-doped CW fiber laser of 400 W output power has been developed using a single oscillator. The all-fiber integration involved minimization of splice joint loss of various fiber components, fiber coupled pump diodes and recoating of these joints to reduce losses. This has led to a high optical-to-optical conversion efficiency of 71%. Laser output is emitted from a 20 micron core diameter of Yb-doped fiber with a nearly-Gaussian beam profile (M^2 1.04). A diode side-pumped Continuous Wave (CW) Nd:YAG laser of output power 1 kW operating at 1060 nm wavelength has also been developed. The laser has a double pump head resonator and each pump head is



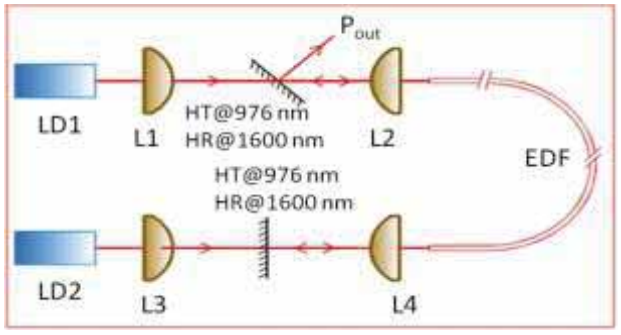
400 W all-fiber Yb-doped CW fiber laser



1 kW CW Nd:YAG laser

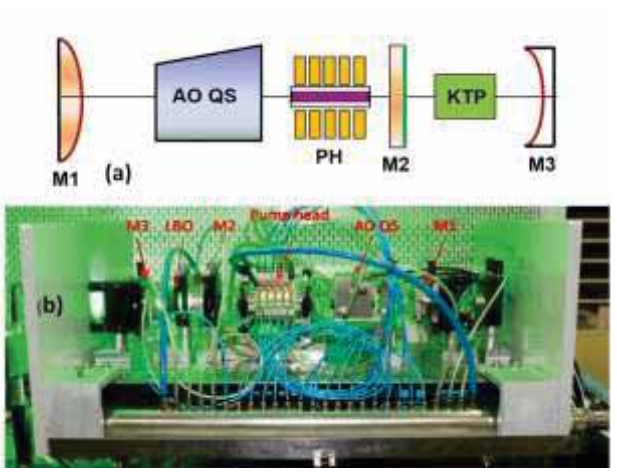
made to accommodate 27 diodes of 80 W power each. The output is coupled to a fiber of 400 micron diameter. Both these lasers are useful for material processing applications.

An Er-doped fiber laser emitting at the eye-safe wavelength of 1600 nm has been developed. It uses a large mode-area Er-doped fiber pumped by a 976 nm diode laser and has a CW output power of 25 W. Due to large quantum defect of 39% between the pump and lasing wavelengths, a water cooled heat sink for the fiber had to be designed to enable laser operation at such a high output power.



A schematic view of 25 W Er-doped CW fiber laser

A user-friendly engineered version of Diode Pumped Solid State (DPSS) green laser operating at 532 nm has been developed. The laser delivers 40W of average power at 6.25 kHz repetition rate with less



(a) Schematic of the diode-pumped solid-state green laser
(b) Internal layout of the engineered model

than 40 ns of pulse duration, and has control and safety features suitable for remote operation. The laser was continuously operated for 15 hours and output power, pulse timing jitter and pointing beam stability of the green beam was measured and found to be satisfactory. Two such engineered models of DPSS green lasers have been delivered to BARC and successfully installed there.

A wide aperture (30 mm inter-electrode separation) XeCl excimer laser at λ= 308 nm capable has been developed. The laser cavity has been designed for high pointing stability and high tolerance for misalignment (50 mrad). The laser is suitable for material processing applications.

Testing and quality control parameters and procedures have been evolved for the Nd-doped phosphate laser glass indigenously developed in collaboration with CGCRI, Kolkata. Performance of such glass rods has been studied by using them in the high power laser chain at RRCAT and the quality is found to be of international standards. The quality



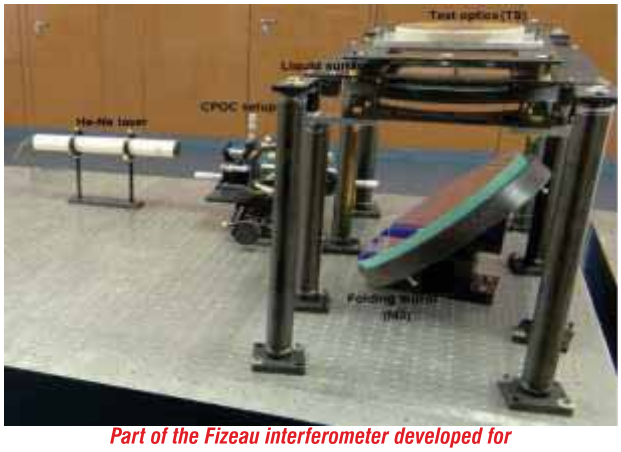
Wide aperture xenon chloride excimer laser



A typical Nd:glass slab and a 40 mm diameter, 310 mm long Nd:glass rod made from a similar slab

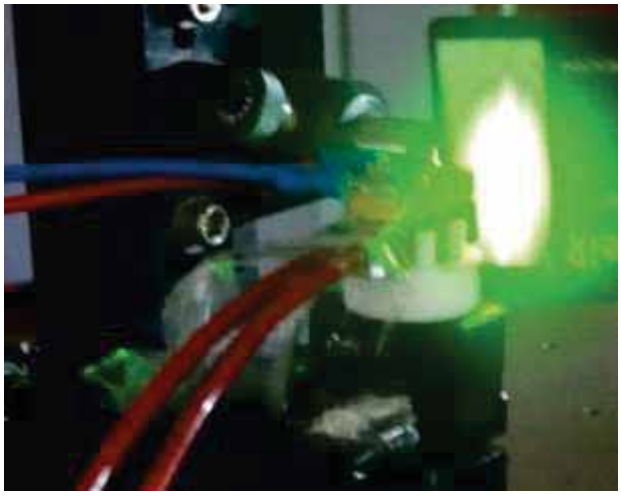
control of the laser glass rods has been done by measuring several spectroscopic and physical properties of the laser glass like refractive index, non-linear refractive index, Abbe number, stimulated emission cross section, fluorescence peak, fluorescence lifetime, and attenuation coefficient at 1053 nm and 3000 cm^{-1}. These quality control procedures will enable the study of batch by batch production performance of the laser glass fabrication process technology in future.

A large beam diameter (250 mm) Fizeau interferometer has been developed for surface quality testing of polished large laser amplifier discs. Liquid paraffin is used as the optical reference flat surface. This interferometer was successfully tested for surface flatness of a 200 mm diameter polished optical window with a flatness of λ/6 at 633 nm.

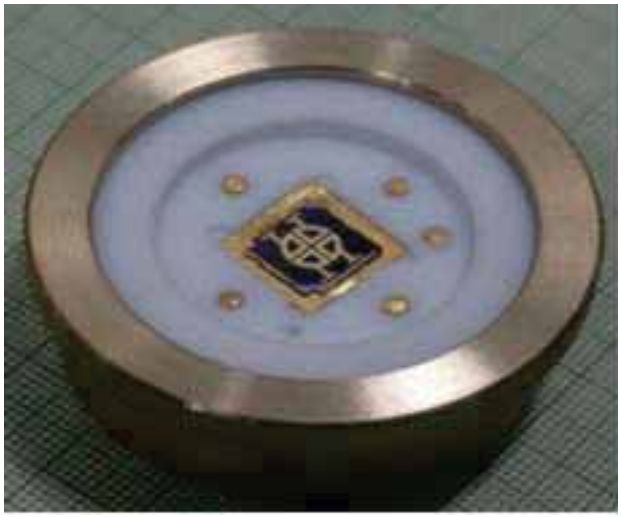


Part of the Fizeau interferometer developed for testing of large diameter optics

Photonic devices based on GaAs and InP semiconductors have been fabricated. These include laser diode arrays operating at 980nm with 23.5 W peak power under pulsed operation and 3 W CW



The diode array laser and its output on a fluorescent screen



Radiation hard GaAs based quadrant detector

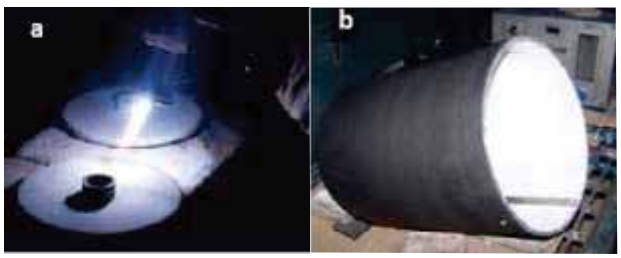
power, GaAs based radiation hard (100 kGy for gamma rays) quadrant detectors operating in the wavelength range of 200-900 nm and a novel gold/semiconductor hybrid detector that can simultaneously measure the degree of circular polarization and intensity of a laser beam.

At BARC, Laser surface processing was carried out and self-assembled micro-conical surface structures of varying height and tip diameter have been generated on Stainless Steel (SS) surface by nanosecond (ns) pulsed laser and Femtosecond (fs) laser irradiation for enhanced field emission and induced hydrophobicity. Field emission study on the nanosecond laser surface structured electrodes has shown low turn on field (for 10 $\mu A/cm^2$ emission current) of 7.5 V/μm and enhanced field emission efficiency. These can serve as potential candidates for cold electron emitting electrodes. Femtosecond

laser treated SS samples turned hydrophobic in nature with measured contact angles ranging between 140 to 150 degrees. Further studies on the corrosion resistance of such fs laser treated SS samples are in progress.

Laser surface treatment of bio-active glass (Hench 45S5) has demonstrated improved bio-compatibility when immersed in Simulated Body Fluid (SBF) during in-vitro tests. Growth of Hydroxyapatite (HAP) layer on laser treated samples was both rapid and of higher crystallinity in comparison to untreated bio-glass surfaces. Studies demonstrate laser surface treatment as a potential technique to achieve improved and faster bio-integration of BG implants.

Plasma Spray coatings of ceramics find significant application as thermal barrier and corrosion resistant coatings in nuclear fuel fabrication technology. Plasma spray based Yttria was deposited on Molybdenum trays used in synthesis of Uranium Silicide and Uranium inter metallic fuels. User groups confirmed superior performance of these Yttria coated components in terms of prolonged operation life in comparison to conventional slurry powder coating.



Plasma Spray coatings of Yttria on: (left) Molybdenum Trays for synthesizing Uranium Silicide, (right) graphite crucible

Microwave Atmospheric Pressure Plasma Jet (APPJ) is a portable plasma device which operates at atmospheric pressure and can be used for the specific application of actinide decontamination. A three-electrode APPJ has been designed and fabricated and performance tested for its use in actinide decontamination.



(a) Single electrode and (b) Multi-electrode APPJ

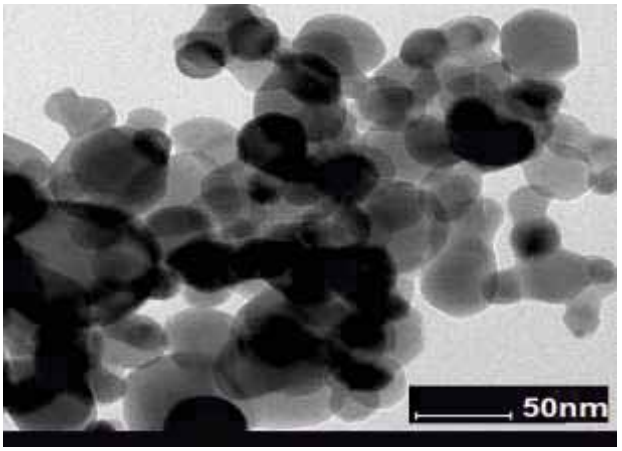
Hafnium cathode non-transferred arc long jet large volume air plasma torch has been developed at the power rating of 20-30 kW. Low-level radioactive waste gasification by the developed torch has been demonstrated. High pressure radio frequency thermal plasma reactor for the synthesis of refractory nano-particles (Y_2O_3) is developed and operated for the first time. Various studies such as thermodynamic and transport properties, primary inputs for any numerical simulation, understanding and



Long jet large volume non-transferred arc DC air plasma torch



Low-level radioactive waste using gasification



Synthesized Y_2O_3 particles

interpretation of experimental data etc. were carried out for nitrogen plasma in the temperature range 300 to 50,000 K under thermal and chemical non-equilibrium.

Photo excitation dynamics in a three-step photo ionization of atomic uranium was investigated using time-resolved two-color three-photon (λ1 + 2λ2) and delayed three-color three-photon (λ1 + λ2+ λ3) photo ionization signals in an atomic beam of uranium coupled to a high resolution time-of-flight mass spectrometer using three tunable pulsed dye lasers. Dependence of both the signals on the second-step laser photon fluence is studied. Photo excitation and photo ionization cross-sections at many values of the second-step laser wavelength were measured.

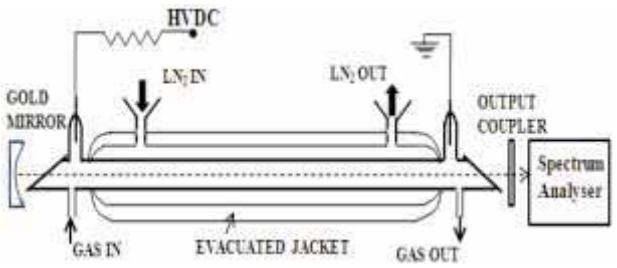
A significant increase in average power of dye lasers was realized through simultaneous excitation of dye gain medium using temporally synchronized and spatially combined Copper Vapour Laser (CVL) and Diode Pumped Solid State Green Laser (DPSSGL) outputs. Addition of more rugged and efficient DPSSGLs (from RRCAT) in the existing pump pool at BARC and efficient coupling of pump beams to the dye cells using optical fiber delivery is in progress to substantially increase the powers of dye lasers for the process.

A high repetition rate (5 Khz), widely tunable (500-650 nm) Optical Parametric Oscillator (OPO) operation (15 % efficiency) was achieved using a constructed OPO system comprising type 1 BBO non-linear crystal, excited with 3rd harmonic (355 nm) output of a commercial DPSSL.

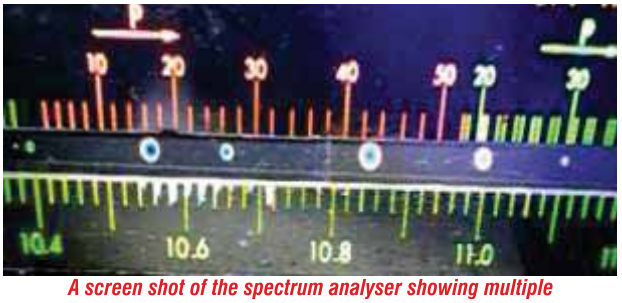
Photonic Crystals (PhC) were fabricated via self-assembly route using nano-spheres of polystyrene (PS). These PhC were then impregnated with fluorescent dye pairs working in Donor-Acceptor (D-A) mode. Influence of Photonic crystal on Fluorescence Resonance Energy Transfer Efficiency between Laser Dyes was investigated.

In case of Rhodamine-B (D) and Rhodamine-800(A) dyes embedded in a colloidal photonic crystal, energy transfer efficiency between the two dyes increased by 3 times in photonic crystal environment in comparison to a dye mixture solution. Such PhC based micro-cavity lasers not only provide wavelength tunable coherent radiation but can also serve as a versatile cost effective promising light source for use in large size laser displays.

The emission spectrum of a liq.N_2 cooled CW-CO_2 laser revealed intense lasing on many transitions that cannot originate from the conventional CO_2 laser gain medium suggesting that these are arising from the ro-vibrational transitions of van der Waal's clusters of CO_2 molecules making this the first ever report on the operation of a cluster laser. The prospect of tunable emission across a wide spectral range, a consequence of diversity and spectral richness of cluster lasers due to the presence of multiple active species, makes this finding very significant.



Schematic diagram of the liq.N_2 cooled cw-CO_2 laser



A screen shot of the spectrum analyser showing multiple frequency emission from the clusters

A Process laser system was designed and installed with three dye laser chains in MOPA (Master Oscillator Power Amplifier) configuration at BARC. Three multi-mode dye laser oscillators were set up to generate the laser beams with required precision wavelengths. A pump laser system was set-up with 24 CVLs in MOPA configuration. The CVL MOPA output is transported and distributed for pumping the dye laser MOPAs. An auto-synchronization technology was developed for synchronizing the CVLs under software control for optimizing the MOPA output power. The temporal jitter, drift and Electro-Magnetic Interference (EMI) in the CVLs

were reduced to a large extent by electrical and electronic modifications carried out in the laser Pulse Generator Units (PGUs). Dye laser wavelength locking systems for three dye laser MOPAs were developed for precision tuning and locking of laser wavelengths. Three combined dye laser beams of high power were generated and delivered with proper temporal pulse synchronization, beam spot spatial overlap, matched beam divergence, spot size and shape. Transportation of high power CVL pump laser beams through optical fibers without thermally induced damage was achieved and demonstrated by under-water coupling of laser beams to the fibers immersed in water. A high power CVL pump beam was delivered to a dye laser oscillator through the optical fiber and efficient lasing from the dye laser was demonstrated.

Selective vibrational excitation of $S^{32}F_6$ molecules in a supersonic jet of SF_6-Ar binary gas mixture by an appropriately focused CW CO_2 laser emission on 10P(16) line resulted in enrichment of $S^{34}F_6$ in the central stream that was effectively skimmed by a skimmer. Separation factors exceeding 2 were obtained under optimized conditions. The efficiency of the process exhibited a monotonic increase with reducing molar concentration of SF6 in the gas mixture, and showed a maximal behavior with stagnation pressure.



Experimental arrangement used for enrichment and estimation of sulphur enrichment in SF6-Ar binary gas jet

A novel method for the estimation of the relative concentration of the isotopes in the enriched central stream of SF_6-Ar jet following laser irradiation has been evolved. This method exploits the selective absorption of the emission of CO_2 laser on 10P (36) and 10P (20) lines by $S^{34}F_6$ and $S^{32}F_6$ respectively

A facility for the time resolved Raman spectroscopy of dynamically shocked material has been developed the study of materials behavior under dynamic loading. The effect of shock pressure on vibrational modes and dynamical changes at different delay times for Poly Tetra Fluro Ethylene (PTFE), Polystyrene, Polyvinyl Toluene (PVT) and Carbon Tetrachloride (CCl_4) etc. were studied.

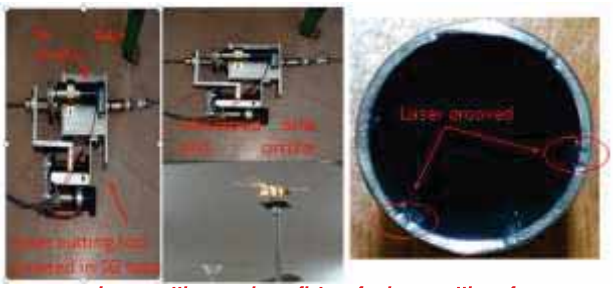
The power levels of the Nd : glass laser have been upgraded and a measurement technique viz. Frequency Resolved Optical Gating (FROG) for ultra-short pulses has been set up. The clusters in the supersonic gas jet have been characterized by determining the mean size and density of clusters, by Rayleigh scattering and Mach-Zehnder Interferometer.



Photograph of FROG setup

Laser Applications

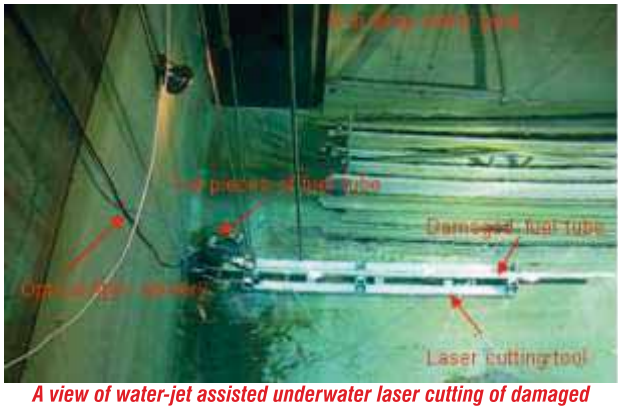
In some of the nuclear power reactors such as that at Kaiga Generating Station-4 (KGS-4) there is a problem of over rolling of Steam Generator (SG) tubes in tube sheet. In such cases the removal of leaky SG tubes by mechanical pull out requires very high load strength. A laser based axial grooving technique has been developed by RRCAT for KGS-4 reactor to reduce the pull out strength of over-rolled SG tubes to a value below 2 ton for tubes which earlier required 5 ton of pull out strength. This procedure has been qualified at KGS-4 and will be



Laser cutting mock up, fixture for laser cutting of SG tube and laser grooved sample of SG tube

deployed for removal of leaky SG tubes during the next biennial shutdown of KGS-4.

An in-house developed remotely operated water-jet assisted underwater laser cutting technology was deployed for cutting of damaged portion of 12 numbers of highly radioactive spent fuel assemblies. The aluminium fuel assemblies (2.5 mm thick and 4 m length) were stored at the bottom of a 5 m deep water column at the spent fuel storage bay of the Dhruva reactor complex. Using the laser cutting technique these were salvaged successfully for reprocessing without any airborne activity and with a very small radiation dose of 600 mR.



A view of water-jet assisted underwater laser cutting of damaged fuel tubes in spent fuel storage bay of Dhruva reactor complex

Quasi-mono-energetic acceleration of ions has been demonstrated at RRCAT from the interaction of intense, ultra-short laser pulses with specially designed targets. The targets consists of a few nanometers thick coating of gold followed by a top coating of few tens of nanometer thick carbon layer, on an aluminium (Al), silicon or Mylar substrate surface. The results showed that the all the gold ion of different charged species created by the plasma got confined to a narrow energy range. Computer simulations for the above target geometry also corroborate the experimental results.



A view of underwater laser cutting tool for pressure tube stubs

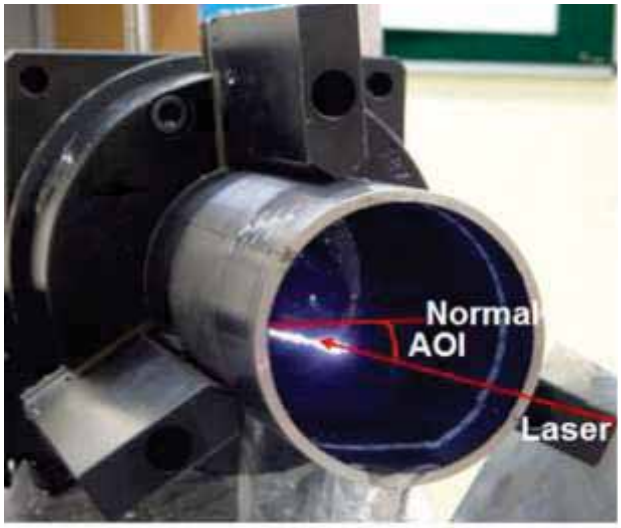


Laser cutting mock-up of bellow lip after cutting of outboard end-fitting

A collimated beam of fast electrons has been generated by laser-solid interaction at grazing incidence. The divergence (FWHM) of the electron beam was measured to be 9.8° and 5.3° in the horizontal and vertical directions, respectively. The energy of the electron beam was in the range 300 keV to 1 MeV.

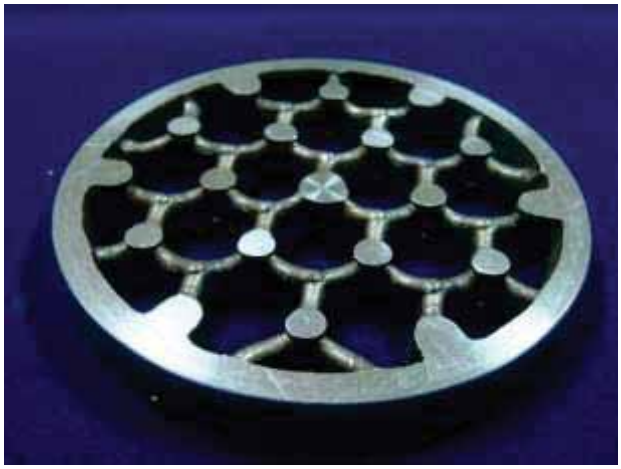
A laser shock peening technique was developed to inhibit stress corrosion cracking. Results on tubular SS304L components showed that the surface area affected by stress corrosion cracking reduced from 25% to less than 2% after peening.

A Laser Additive Manufacturing (LAM) system comprising a 2 kW fiber laser, twin powder feeder and a 5-axes CNC workstation has been used for fabrication of nuclear components not possible to manufacture by conventional methods. In PFBR, regulating the flow distribution of liquid sodium as per the power level is required to remove fission heat. Honey-comb geometry orifice is one such permanent pressure dropping device used in the foot of the PFBR core sub-assembly. It has a complex structure with several hubs and ribs joining each other. Orifices fabricated with conventional precision fabrication methods have yielded a limited success



Oblique laser peening set up


Laser Additive Manufacturing (LAM) in process


A stainless steel orifice plate for the fast breeder reactor fabricated by LAM

and better dimensional control and surface finish is desired. Hence, LAM of these orifices was taken up. The following picture shows the fabricated structure. After metrological evaluation, the orifices have been provided to IGCAR for further tests.

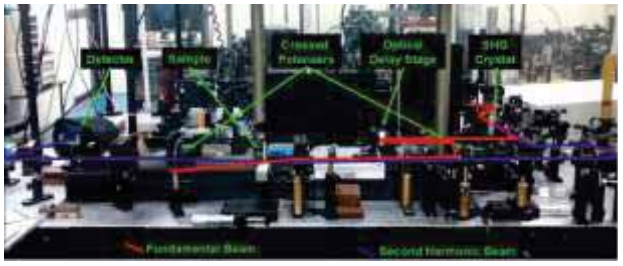
A prototype machine vision based computerized inspection system has been designed and developed for quality assurance of the fuel pellets used in Pressurized Heavy Water Reactors (PHWR). It can inspect cylindrical surface of eight pellets in three seconds and each end face in 400 msec. The system is able to detect and categorize various surface defects like pits, chips and cracks. This setup was qualified at Nuclear Fuel Complex for characterization of various surface defects. NFC is developing the pellet handling mechanism.


The line camera system for fuel pellet inspection

At RRCAT, an in-house developed copper vapour laser based Fiber Bragg Grating (FBG) inscription setup has been used to fabricate distributed temperature sensor with four FBGs in a single fiber for temperature measurement upto 500^{0}C.



Fiber Bragg Grating setup



Femtosecond two-colour Kerr gate setup

A two-colour femtosecond optical Kerr gate setup has been developed which can be used for sub-picosecond measurement of non-degenerate Kerr nonlinearity as well as transient photoluminescence of materials for ultrafast opto-electronic devices. The nonlinear material is gated by a 100 femtosecond laser pump pulse and probed by its second harmonic. This technique allows measurement of the magnitude, rise time as well as decay time of the Kerr nonlinearity of the material over a range of wavelengths allowed by the laser tunability (690-1040 nm in the present case). With CS_2 as the nonlinear material, a gating time as short as 350 fs has been obtained.

The trapping of laser-cooled ^{87}Rb atoms in a toroidal geometry has been demonstrated using a RF-dressed quadrupole magnetic trap formed by superposing a strong Radio Frequency (RF) field on a quadrupole trap. This RF-dressed quadrupole trap has minimum of the potential away from the quadrupole trap centre on a circular path which facilitates the trapping in the toroidal geometry. Cold atom trapping in toroidal geometry has applications in the study of coherence, super-fluidity, Josephson oscillations, realization of atom gyroscope etc. The experiments were performed using a double Magneto Optical Trap (MOT) setup. The cold atoms in the second MOT were loaded in the RF-dressed toroidal trap by applying a RF field of appropriate frequency and power. The number of atoms trapped in the toroidal trap was typically 1.3×10^5 with a temperature of 40 μK.

SPECIAL MATERIALS

Augmented Light Metal Plant (ALM) was commissioned in BARC and regular production commenced to cater to the light metal requirements of the Department. Development of alumina column for the gas chromatographic separation and analysis of hydrogen isotopes was completed.

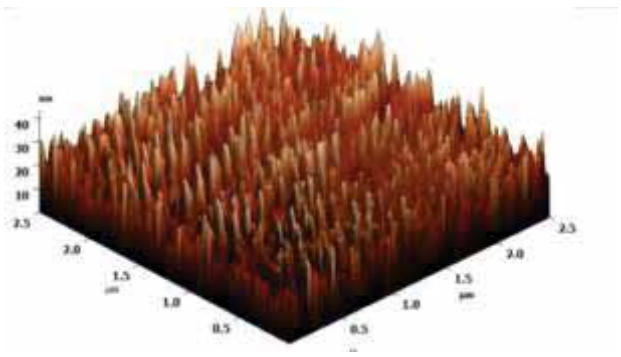
ADVANCED TECHNOLOGIES

A technique for characterizing deeply curved aspheric optical surfaces has been developed at BARC using the in-house built Time Domain-Optical Coherence Tomography (TD-OCT) setup. It is useful for simultaneous measurements of 3-D surface profile and the refractive index of nearly hemispherical asphere lens. The method has an accuracy of ±0.012 mm in shape measurements and ±0.002 in refractive index. This non-contact measurement technique can determine the radius of curvature, conic constant and aspheric coefficients from the 3D shape measurements and has many advantages over the conventional laser interferometric techniques such as ease of alignment and non-requirement of complex aspheric standards and can be extended to profile and index measurements for non-regular surfaces such as free form surface optics.

A Glancing Angle Deposition (GLAD) system was developed for synthesis of novel photonic structures. GLAD system uses an



GLAD assembly



AFM images of HfO_2 nano structures

asymmetric pulse DC-RF magnetron sputtering for thin film layer deposition over substrates at glancing angles (>850) by suitably designed substrate holder with rotation facility. Using this system columnar nanostructures of HfO_2 was grown on glass and silicon substrates for developing sculptured thin film layer with tailored optical properties.

A mass spectrometer for analysis of isotopic ratio of hydrogen in gaseous state has been developed and supplied to RRCAT. Thermal Ionisation Mass Spectrometer (TIMS) for precise isotope ratio measurement in solids and Process Gas Mass Spectrometers for isotopic ratio analysis in gases have been developed and tested.



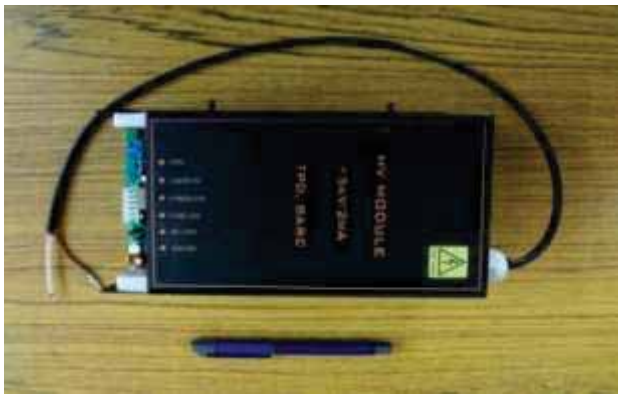
D/H Mass Spectrometer



Process Gas Mass Spectrometer

Technology of Quadrupole Mass Spectrometer (QMS) was transferred to M/S ECIL for the development of QMS based Hydrogen and Steam Concentration Measurement System (HSCMS) for NPCIL.

Compact +/- 5 kV, 2 mA high voltage modules operating with 24 V dc supply was developed for precision analytical instruments. An improved and compact SMPS based power supply was developed for sputter ion pumps (140 litres/sec) and the technical knowhow transferred to a private company. A universal vacuum gauge based on a combination of Pirani and hot cathode ionization gauge was developed for pressure measurement from atmosphere to 10^{-10} Torr. A battery based miniature neutron generator using penning ion source providing $5x10^6$ n/s for applications in oil logging, uranium mining etc. has been developed.



Compact high voltage power supply



Sputter ion pump power supply



Universal vacuum gauge

For the Low Energy High Intensity Proton Accelerator (LEHIPA) being built in BARC, the 100 kV, 25 A High Voltage Power Supply required to power the 1.2 MW klystron of RFQ section is installed and commissioned. This indigenously developed power supply was successfully operated up to 65kV.

An advanced version (Mark-II) of large volume Calorimeter was developed. The instrument offers improved sensitivity and higher throughput for assay of Special Nuclear Materials.



Regulated High Voltage Power Supply for LEHIPA



Calorimeter for assay of special nuclear materials

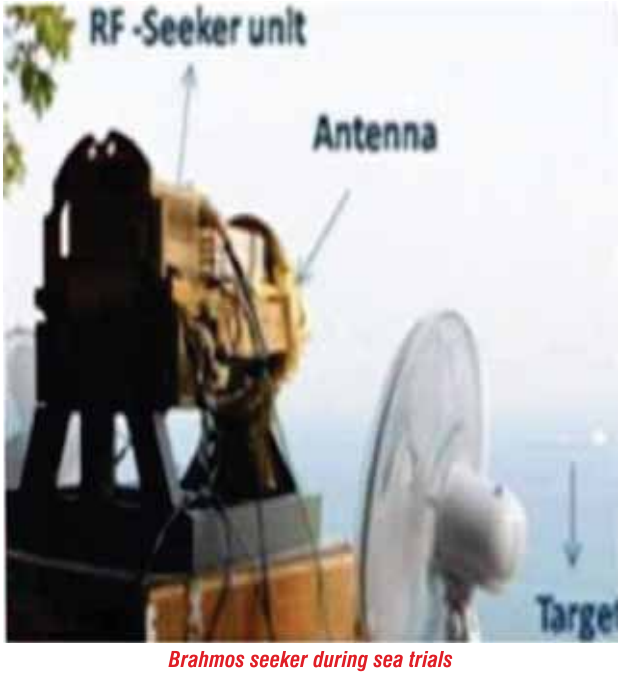
A modular and scalable compact neutron diffractometer data acquisition system catering to eight Position-Sensitive-Detectors was developed for UGC-DAE CSR. It was installed in Dhruva for material structure study. An indigenous Vertical Radiometry System has been designed, developed and commissioned in AFD, BARC for fuel pin characterization during fabrication process. The system is used to quantify and qualify the variation in the linear fissile material density in the fuel pins over its full length.



Data Acquisition System for Neutron Diffractometer



Vertical Radiometry System

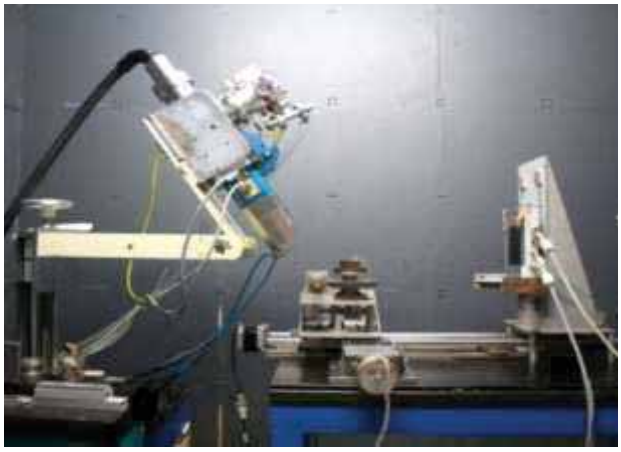


Brahmos seeker during sea trials

Continuing the collaborative development of Active Radar Seeker with ECIL, the seeker was set up on the shore to track ships at sea in range and angle. This was the first successful tracking of a sea target by the seeker validating integrated functioning of all major subsystems.



Miniature Neutron Generator



X-ray micro imaging facility

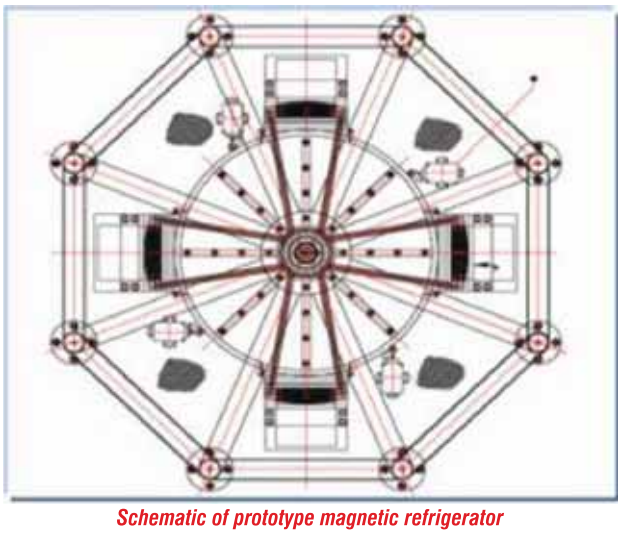


Photograph of the detector

A Peripheral Pulse Analyzer to study physiological variables for the purpose of disease characterization has been developed. It features yielding of Heart Rate Variability, Pulse Morphology and Cardiac Output Variability / Peripheral Blood Flow Variability from a single data acquisition session of the patient. The technology is available for transfer to industry.

X-ray micro-imaging facility using laboratory based micro focus source and high resolution X-ray detector was setup to meet applications such as micro-radiography, phase contrast imaging and micro-tomography. This system can provide image resolution of 5 microns.

A 2-proportional counting chamber was developed for precise activity measurement of large area - coated sources and installed at BARC for calibration of national primary standard for reference coated sources. The counting system, based on a multiwire proportional counter and gas flow arrangement, is useful for measurement of absolute emission rate from - coated sources. A coated source is mounted within the sensitive volume of the detector, thus a windowless design and large sensitive area enables efficient counting of emissions in~ 2 solid angle. A suitable provision for frequent manual loading, unloading of source samples is possible. These accurately calibrated sources are further used to calibrate efficiency of hand–foot, floor contamination monitors and are used in checking radioactive spillage at various nuclear facilities.



Schematic of prototype magnetic refrigerator

Magnetic entropy change across magnetic phase transition can be used for magnetic refrigeration. A significant amount of research on this topic has been carried out at BARC. A Prototype Magnetic Refrigerator test Set-up with rotating high-magnetocaloric effect materials under magnetic field has been designed.

A permeation barrier coating based on iron aluminide/alumina compositions was developed for cylindrical AISI 316 steel vessels used in the transportation and storage of tritium. The inner surfaces of the storage modules were coated with a 25-30 μm thick barrier layer by the pack aluminizing process and subsequently heated under vacuum to remove entrapped gaseous impurities. The permeation barrier coatings of about ten modules have been achieved this year.

Cold Crucible Induction Melter (CCIM) was set up for making of complex ceramic materials. Zirconia and zirconates were produced using this facility for departmental applications.



(a) Cold Crucible Induction melter (b) fused ceramic ingot and (c) finished powder



Indigenous seismic switch



Turbine failure of NSPCL

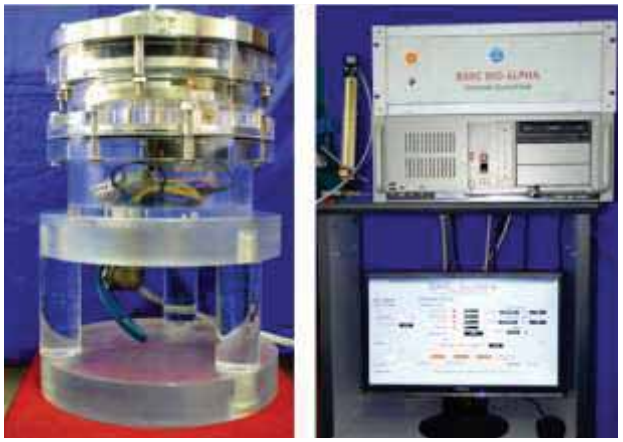
A seismic switch with Fail-safe and online testability features which can trigger on detection of earthquake has been designed

Long blades in low pressure turbines are prone to steam induced vibrations at different power and operating conditions. Using BARC technology, a recent failure in a 250 MWe turbine operated by NTPC Sail Power Corporation Ltd (NSPCL) was predicted. The exercise helped in validating the robust technology developed for direct application in power plants of all type.

A radiation ageing test facility (Gamma Chamber) having a dose rate of 0.1 Mrad/hr has been installed in Common Facility Building of BARC. It has a compact self-shielded cobalt-60 gamma irradiator and better control on gamma radiation dose rates during the irradiation.

Development of Indian Cargo Scanner for non-intrusive inspection and exercise control on sensitive scan data was initiated. Imaging performance experimentation using 6 MeV LINAC as x-ray source established the feasibility of technology. The performance of the system is very close to that of commercial systems of international standards. Full scale demonstration and product development of Portal and Gantry type cargo scanners is in progress.

A novel α-irradiator (BARC BioAlpha), first of its kind in the world, with advanced features such as high speed shutter (1/30 sec), Variable exposure time (1 sec to 99 min), uniform & collimated exposure through inter-locked system at set parameters and high safety features has been developed. It can irradiate cells under sterile culture conditions with 4.8 MeV α-particles will be very useful in generating data for simulation of the optimum conditions for cancer therapy.



BARC BioAlpha

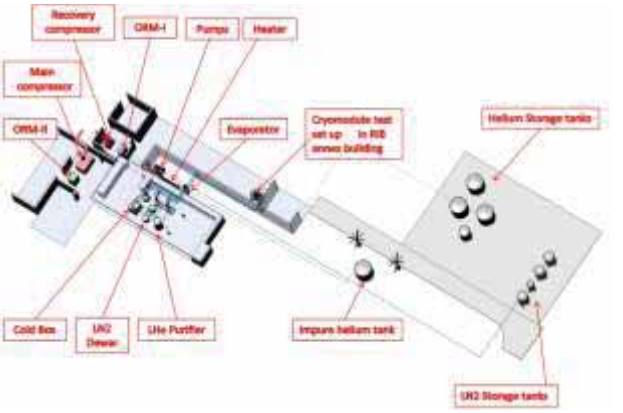
A micro-flow processor for automated processing of immunostained tissues or hybridization of slides/membranes has been developed and tested. A low-cost, cold plasma-based electroporation system has been developed and demonstrated to transform bacteria (E. coli) with simplified protocols. This system, useful for the preparation of genetically modified organisms and introduction of DNA/ drugs into cells, is under patenting process.



Cold plasma-based electroporator

Cryogenics

A cryogenic system is being set-up for the superconducting electron and heavy-ion linacs at VECC. It consists of cryogen distribution lines for liquid helium and liquid nitrogen, sub-atmospheric vacuum jacketed lines for helium, warm helium lines between the helium buffer tanks and compressors, and a 500 watt helium liquefier. A layout of the cryogenic system is shown in the figure. The design of the cryogenic system has been finalized. The helium plant has been ordered. The cryogenic system and He Liquefier will be initially installed at VECC's Salt Lake campus and utilized for the tests of 10 MeV injector.



Cryogenic distribution system for superconducting linacs at VECC

Robotics

A robot based frameless stereotactic system is developed by BARC which has accuracy and patient comfort level comparable to frame based system. It automates the frameless stereotaxy using a high precision robot (Parallel Mechanism based Robot). A 4 DOF (Degrees of Freedom) Surgical Coordinate Measuring Mechanism (SCMM), a 6 DOF Parallel Kinematic Mechanism (6D-PKM) based robot and the visualization display to aid the



A 6D-PKM based robot developed for frameless stereotactic neurosurgery



Frameless stereotactic neurosurgery using SCMM and high precision robot

surgeon during neurosurgery are the major components of the system. After completion of laboratory evaluation, it is under trial runs in hospitals.

Special Programmes

Basic models of FZ crystal puller and CVD polysilicon bulk crystal grower have been developed at BARC. FZ Model is based on melt zone magneto hydrodynamics to predict temperature profile of the system. CVD model is based on hydrodynamics as well as kinetics of the polysilicon deposition to predict temperature and velocity profile of the reactor. Silicon wafer processing & characterization equipments like Slicing, Hall Effect measurement instruments are installed & commissioned.



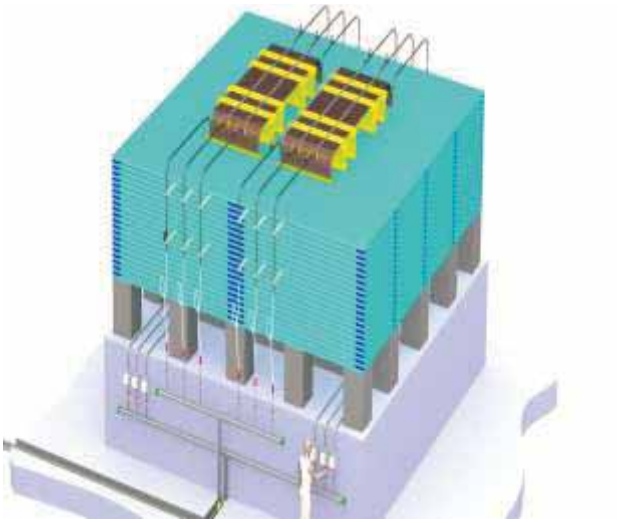
Wafer slicing machine



Hall effect measurement system

Design and assembly details of very large size water cooled coil for prototype of ICAL magnet for INO project.

For the upcoming INO project, three large magnets, each of size L=16m, W=16m, H=15m will be used for the INO Calorimeter (ICAL). For the hands-on experience of working on such a huge size of ICAL magnet, it has been proposed to fabricate a scaled down model which is called Prototype magnet. It is planned that the prototype magnet will also follow the similar assembly procedure as the actual magnet by using similar copper conductor. The dimensions of the prototype magnet is L=8m, W=8m, H=2.1m and will contain 21 layers of Iron plates weighing around 680 Ton of Iron.



Prototype Magnet coming up at Madurai

The design job has been completed as per the requirement input provided by the magnet simulation group at BARC.

Relevant R&D works have been performed at VECC before freezing the design, which includes fabrication of Glass epoxy spacers, water cooling systems and development of brazing procedures by using Induction heating. This is a new concept to perform induction brazing followed by on-line testing of the brazing quality. Water cooled copper conductor of cross section 30 mm x30mm with 17mm bore is finally selected to use for prototype and actual magnet. The conductors are already procured and development activities such as bending, machining, making brazing joints etc. have been under progress.



Brazing of 5 Nos. of copper conductors and their Test Set-up for Resistance measurement as well as leak detections of the joints by using hydraulic and pneumatic scheme



Glass Epoxy Spacers for anchoring the coils in the base

The photographs shows an idea about the development undertaken in VECC on this project.

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.



Isotope processing



^{125}I seeds production



Radioactive sources

At BARC, around 4 kCi activity of radioisotopes (^{131}I, ^{99}Mo, ^{153}Sm, ^{177}Lu, ^{32}P etc) have been chemically processed and 991 laboratory reference sources, 93 custom-made sources 214 Nos. of ^{125}I brachytherapy seeds and 250 numbers of TRODAT-1 and HYNICTOC freeze dried kits were produced and supplied to BRIT for supply to hospitals.

At RAPPKOFF, Kota, total activity of ^{60}Co which was processed during the year was about 63.52PBq (1717 KCi). Safe handling, transportation of adjuster rods from various reactors were transported to RAPPKOFF, Kota for processing of Cobalt-60 and subsequently transported for fabrication of sources at Mumbai and the necessary documentation of the records were performed.

^{60}Co Teletherapy sources (CTS) are prepared using indigenous pellets recovered after cutting 09 pellet capsules. This is the first time we have successfully fabricated more than 200 RAM CTS using indigenous ^{60}Co pellets. Machine and procedure for cutting of pellet capsules, recovery of pellets and filling of pellets in inner CTS containers is developed at RAPPKOFF, Kota and duly endorsed by various regulatory committees of AERB.

AGRICULTURE

Crop Improvement

The Trombay Groundnut varieties TG 79 and TG 80 entered for evaluation in Indian Council of Agricultural Research (ICAR) trials all over the country. TG 60, TG 68, TG 70, TG 73, TG 74 TG 75, TG 76, TG 78, TG 79 and TG 80 were evaluated at

different Agricultural Universities and Research Centres across the country. Black gram selections TU-67 and TU-41 have been promoted from Initial Varietal Trial (IVT) to advanced varietal trial (AVT-I) whereas five black gram selections TU-22 (Kharif), TU-13 (Rabi), TU-42, TU-43 (Rice fallow) and TU-44 (spring) were entered in the IVT trials of All India Coordinated Research Project on Mungbean, Urudbean, Lentil, Lathyrus, Rajmash and Pea (MULLaRP) of ICAR. Cowpea selection TC-901 has been promoted from AVT-I to AVT-2 (summer season)' TC-140 has been promoted from IVT to AVT-1 (summer season) and TC150 was entered in IVT (Kharif season) in National Network Project on Arid Legumes of ICAR.

In breeder seed programme, 340 quintals breeder seed of Trombay groundnut varieties were produced from BARC, Gauribidanur and from contract farming and distributed to 19 seed agencies in Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu and West Bengal.

Groundnut contains bioactive compounds like phenolics and flavonoids which determine its antioxidative activity. Genetic mapping and Quantitative Trait Locus (QTL) analysis revealed five QTLs for total flavonoid content, four QTLs for DPPH (Diphenyl-1-Picryl Hydrazyl) radical scavenging activity and a single QTL for total phenolic content in six linkage groups.

Mungbean TMB-163 entered in the IVT (summer and spring seasons) of All India Coordinated varietal trials of ICAR. Mutant LSM-1 was tested in MULLaRP trials for summer and spring and identified as multiple disease resistant genotype for yellow mosaic disease and leaf curl virus. Study conducted in 94 mungbean genotypes revealed that high Phytic Acid (PA) in seed as well as seedling is associated with resistance reaction to diseases like YMD and bruchid.

Seed multiplication of black gram released varieties, TAU-1, TAU-2, TPU-4, TU94-2 and TU-40 was done. 70 accessions of chickpea were analyzed for iron and zinc content to obtain the second season data. Genotypes having consistently high zinc across two seasons were identified.

A set of 92 diverse cowpea genotypes were serologically screened for resistance against CABM virus using DAS-ELISA and sap inoculation techniques and a rating scale was developed to classify the cowpea genotypes. Breeder seed production of pigeon pea variety TT401 was undertaken at Trombay and Visakhapatnam.

Trombay Mustard genotypes (5 nos.) were promoted to Multi-location Yield Trial (MYT). TM106 has shown the potential to release during 2016-17. 13 TM genotypes are undergoing IVT evaluation.

A total of 96 soybean genotypes collected from different regions of India were screened with 22 soybean Simple Sequence Repeat (SSR) markers and 20 SSR markers were found polymorphic among the soybean genotypes. Hundred soybean germplasm lines were screened to determine the genetic variation in starch content using rapid iodine-starch reaction colorimetric method. Ten soybean germplasm lines were identified showing variability for high starch content.

Advanced wheat breeding lines were evaluated at ARS, Niphad, Dr. PDKV, Akola & IARI-RS, Wellington for rust resistance, quality and thermo tolerance.

Indian Agriculture Research Institute, Regional Station (IARI RS), Wellington, collaborated with BARC for improvement of Dicoccum wheat. A gel-free protocol has been developed for rapid assessment of single band DNA markers and to expedite selection of desired traits in wheat plants. It reduces the cost (by 22%) and time of analyses of DNA markers.

Rice selection, BARCKKV 13 was found superior in Maharashtra in AVT - 1 and promoted to AVT - II. BARC KKV 18 entered into AVT- I. Four rice selections with high yielding and salt tolerance put into Maharashtra State Rice Salinity Trials under IVT.

The Giant Cavendish radiation induced semi-dwarf mutant suckers selected from the trials conducted at NPCIL, Kaiga is used for initiating the shoot tip cultures for multiplication of the lines. The evaluation for their performance is in progress. Multiple shoot cultures of one elite banana variety Karibale Monthan was established from floral apex

cultures. The progress of banana tissue culture production in the labs established with the help of BARC for Mahabeej Biotech Centre, Nagpur, JalaSRI, Jalgaon, and RHRDF, Pandhrapur established was monitored and the problems faced by them has been resolved.

Transgenic banana plants overexpressing MusaNAC68 were raised and different putative transgenic lines were confirmed by Polymerized Chain Reaction (PCR) and Southern blot analysis. Analysis of transgenic line suggested that MusaNAC68 is a stress responsive gene in banana and is involved in salinity and drought tolerance.

For increasing the iron content in banana, transgenic plants were regenerated with OsNAS1. 100 lines each of Grand Naine and Rasthali were regenerated after transformation of embryogenic cells and confirmed their transgenic nature by PCR analysis.



Bold seeded hybrid TSH-13 showing high seed weight of 7.9 g/100 seeds as against control plants (3.5g/100 seeds). Pigeon pea seeds are shown for the comparison.

About 148 new indigenous and exotic germplasm lines of sorghum were evaluated for their synchronous flowering, seed set and potential to be used in the hybrid development. Fifteen sorghum hybrids were generated through hand emasculation and pollination technique and TSH-12 recorded highest mean grain yield and TSH-13 recorded highest seed weight.

Biopesticide formulations based on B. sphaericus and B. thuringiensis were mass produced and multi location field trials for evaluation were undertaken in collaboration with PDKV, Akola and RAU, Raichur under BARC-MoU to test efficacy of Bt biopesticide. Biopesticide technology based on B. thuringiensis subsp. kenyae isolate HD-549 is under technology transfer.

Waste samples received from Biosludge and digested sludge was evaluated for its composition to study its suitability for processing in Nisargruna Biogas plant. Biogas manure has very good potential for increasing fertility and productivity of soil. A small scale basket based technology for degradation of household biodegradable waste in-situ has been developed by BARC and scaling up of the starter culture for biodegradation to popularize the technology is in progress.

Studies on influence of soil bioaugmentation with Providencia rettgeri on Cd uptake in Brassica juncea and influence on phosphatase activity of soil were initiated.

Association between redox based regulation of miRNA and hormone homeostasis under salt tolerance in brassica has been demonstrated which will help to develop strategies to enhance crop productivity in salt-affected areas.

The studies on radiation-polymerized cryogels (rpCryogel) was extended for designing of biocompatible macroporous matrices for biological applications using 2-Hydroxyethyl Methacrylate (HEMA) and Polyethylene Glycol Diacrylate (PEGDA). Optimum concentration of HEMA to PEGDA was found to be 2:1 ratio and the synthesis of cryogel was established with two stage cryogenic temperatures with an optimum irradiation dose of 1.5 kGy.

Protocol for the preparation of biomass for the uptake of U and suitable color reagent for its detection was established.

RAPD (30) and SRAP (30) based markers were used to study the genetic variability in sugarcane mutant lines. RAPD markers showed very less variability in the mutant lines whereas four SRAP primer combinations showed variation as compared to parent.

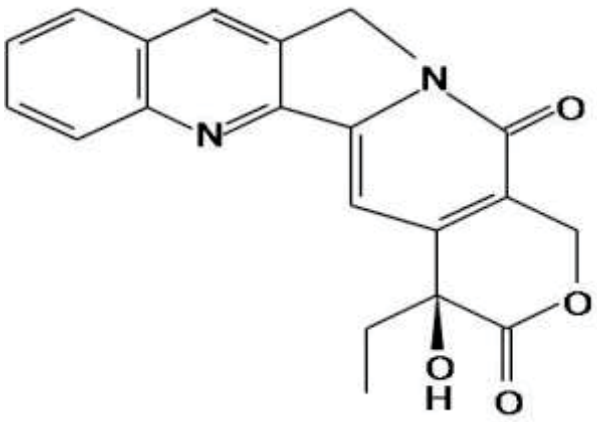
A study was carried out to understand the effect of constant (high and low) and progressive exposure to salt (NaCl) stress in two varieties of sugarcane using salinity stress related molecular and other markers under constant and progressive imposition of salt stress.

Whole genome of a "P" strain of Trichoderma virens was sequenced, analyzed and compared with that of a "Q" strain. A critical comparative analysis revealed the presence of a novel, non-ribosomal peptide synthetase gene cluster in "P" strain, which is absent in the "Q" strain. A purely organic, seed dressing biofungicide formulation of an improved Trichoderma virens mutant strain was developed.

Investigations on the indigenous medicinal plant Ophiorrhiza were pursued for the production of the Camptotheca alkaloids for use in cancer therapy. Biotechnological approaches such as plant tissue and organ cultures were established and mass cultivated and were used for the extraction and isolation of bioactive constituents. Camptothecin, were identified from these cultures and were isolated. The high yields of camptothecin 0.056 % dry weight in tissue cultures of Ophiorrhiza were highly significant for the production of this alkaloid through tissue cultures. The parent plant contains only 0.001-0.002 % dry weight of camptothecin. The technology titled "A Rapid, continuous and a renewable method for production of the anticancer drug Camptothecin" was transferred to three parties. Further work on Ophiorrhiza is being pursued and studies are focused to characterize other known and unknown products from the cultures. Attempts are also made to promote and augment alkaloid synthesis in these cultures by suitable manipulations in the nutrient parameters.



Ophiorrhiza sp. Plant tissue cultures



Camptothecin- an anticancer drug

FOOD PROCESSING

Complete dose mapping of Food Package Irradiator (FPI) after replenishment of source was carried out using Fricke / Ceric Cerous dosimetry system. Lithium borophosphate and Lithium borate glass systems were synthesized by solid state route in collaboration with GAMD, BARC for Thermo Luminescent (TL) study of food irradiation dosimetry. A linear dose response of integral TL was measured in both the cases. Lithium borate system with Dysprosium (Dy^{3+}) dopant showed further improvement in dosimetric properties. TL characteristics of lead aluminosilicate glass with Pr3+ dopant were also studied to assess dose response and TL emission.

The potential of using irradiated Onion Scales (OS) as a source of natural food additive was evaluated. Studies revealed that an irradiation dose of 6 kGy was found to be optimum for enhancing the extractability of bioactive compounds and prevent fungal contamination. The irradiated OS extract had increased antioxidant activity and antibacterial activity against both gram positive and negative organisms. OSE prepared from irradiated samples was encapsulated in alginate beads for its better utility and stability. These beads could withstand the gastric conditions, retained their antioxidant activity, minimized lipid peroxidation and inhibited bacteria in minced chicken meat suggesting that encapsulation of bioactive OS extract in alginate beads is a viable method for use in food industry.

Ratanjot (Arnebia nobilis) Extract (RE) had the highest antioxidant potential and showed excellent antibacterial activity against gram positive microorganisms.

Extraction studies of bioactive compounds from Alphonso and Badam mango peels showed both peel extracts had high phenolic, flavonoids, tannins and total carotenoid content and exhibited very good antioxidant and antibacterial activity against gram positive S aureus and B cereus suggesting that mango peel by-product have potential for its use as natural ingredient in the formulation of functional foods.

Leaves of Amaranthus tricolor are rich in phenolic compounds and betalains having antioxidant properties. Pectin beads containing Amaranthus leaf extract was shown to be used as a natural food additive with bioactive properties.

Utility of gamma radiation to depolymerise alginate and improvement of functionalities of radiation induced oligomer was investigated. Irradiation of alginate solution resulted in dose dependent increase in antioxidant activities.

Antimutagenic bioactive from honey was identified as abscisic acid, and that from spinach as ethoxy substituted phylloquinone derivative.

Methods were standardized for the preparation of Ready to Eat (RTE), shelf stable mutton masala using gamma radiation. Results showed that radiation processed samples are microbiologically safe and sensorily acceptable upto 6 months of storage at ambient temperature.

Microbiologically safe Ready-to-eat (RTE) mung bean sprouts were developed using combination treatment with 200 ppm sodium hypochlorite and 12 kGy dose of gamma radiation. Complete elimination of microbial load and insignificant effect on the sensory qualities was observed, even during storage at 4°C up to 12 days.

A procedure was standardized for ready to bake chapattis by radiation processing at 1 kGy dose and heating at 80^{0}C for 15 minutes in water bath. It could be stored at 4^{0}C up to 2 months. The chapattis were microbiologically safe and well accepted. Pressure cooked Rajma packed in multilayer pouches and irradiated at 4 kGy dose and heat treated at 80^{0}C for 15 minutes in water bath was shelf stable for 6 months at room temperature.

For ready to eat lemon rice, a dose of 5 kGy was sufficient for preservation at ambient temperature for one month. However, further storage did not keep the microbiological quality of the samples. Samples processed at 7.5 and 10 kGy exhibited overall acceptability > 70%. A preliminary work for standardizing the preparation protocol for tamarind rice was carried out.

Different combination of sprouts, vegetables and fruits were tested for an ideal health drink for special target group. Mung sprout with orange combination and carrot, banana and apple combination were selected for further optimization. Combination treatment of microwave and radiation was used to ensure the microbiologically safe drink.

An enrichment medium was developed to enrich low number of Salmonella from food samples. Extensive field test was carried out and the developed medium could recover Salmonella from significantly more samples than conventional medium.

Gooseberry powder was extracted with 70% ethanol and the extract high in bioactive compounds and Vitamin C was blended with Polyvinyl Alcohol (PVA) and chitosan to prepare composite packaging films. Addition of extract increased the absorbance in the UV region. The film had good antioxidant and anti-microbial activities.

Significant increase in the D_{10} values of carrot-associated biofilm cells as compared to planktonic and glass-associated biofilm cells of S. flexneri was observed.

Procedures for preparing guar gum films with additives such as FYNOL and EPOXY were optimized. Films incorporated with 0.5 % Fynol or Epoxy demonstrated higher percent elongation (40 %) as compared with control (20 %). No significant effect of these additives was seen on the tensile strength of films.

Silver nanoparticles synthesized using mint extract were found to be bactericidal against E. coli, S. aureus, B. cereus and P. aeruginosa. Copper nanoparticles were incorporated in PVA films to develop active antimicrobial films. Packed inoculum studies performed confirm the potential of active PVA

films in extension of shelf life and microbiological quality of meat in chilled storage. Composite film using gum acacia and PVA was developed for food applications. Results suggest sorbitol was best plasticizer to reduce the water vapor transmission rate for these biopolymer films.

Various concentrations (0.5 - 4.0 %) of aqueous methanolic extract of sabja seeds were used for preparation of Silver Nanoparticles (SNPs). 1% Aqueous methanol extract of the seeds resulted in formation of SNPs.

The study of antibiotic susceptibility patterns has been suggested for assessing the safety of strains for use as probiotic bacteria in foods.

A carboxypeptidases and prolidases from different organisms were characterized for the substrate preference in order to check for their preference towards bulkier hydrophobic amino acids and proline containing dipeptides, respectively. The enzymes were further characterized for structure function relationship.

About 57 samples of various food samples were irradiated in Food Package Irradiator. Dosimetry was carried out regularly. 45KCi Co-60 source was loaded in the racks of Food Package Irradiator successfully as part of replenishment programme of Co-60 source.

An experiment carried out to find the energy savings by storing potatoes in refrigerator after irradiation at 15°C, and without irradiation at 4°C showed that storing at 15°C post irradiation instead of 4°C results in energy savings of about 52% in case of potatoes.

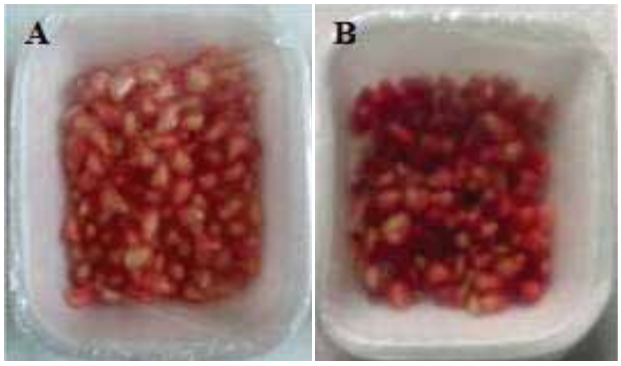
The starch properties such as water absorption, solubility, light transmittance, syneresis and gelatinization viscosity were evaluated in wheat and chickpea, irradiated at the doses 1.0, 10.0, 20.0 and 30.0 kGy.

An in vitro study was carried out to compare the extent of the starch digestibility present in various combinations of cereals and legumes types and in different proportions in a given cereal and legume mixture. Further studies regarding the efficacy of different types of legumes and their proportion with cereal mainly rice in reducing the starch digestibility are in progress. The evaluation of antioxidant properties and Angiotensin Converting Enzyme (ACE) inhibitory activity in green gram, horse gram, lentil, chickpea, cowpea, black pea and white pea were carried out per se as well as after subjecting them to different processing conditions and In Vitro Protein Digestion (IVPD). it was concluded that unprocessed legumes could be a better source of nutraceutical compounds.

Improvement and modification of litchi preservation technology was effected by replacing hydrochloric acid treatment with tartaric acid doing away with the ascorbic acid treatment making the process more cost effective. Cheaper agro-produce for xanthan production using fermenter was optimized and the process was developed. Process and Recipe of Ambient Prolonged Storable Meal 'Stuffed Baked Food (SBF)' Ethnically Called 'Litti' for Natural Calamities and Other Target Groups was developed and these technologies will be transferred to private domain soon for further commercial exploitation.

Effect of gamma irradiation on the volatile constituents in three varieties of kidney beans (Kashmiri red, Sharmili and Chitra) was studied using solid phase micro extraction. To confirm the contribution of key odorants to the aroma quality of kidney beans, Aroma Extraction Dilution Analysis (AEDA) was also performed using steam distillates. Their content was found to vary among the different varieties studied with the highest content in Kashmiri and lowest in Sharmili. An increase in the content of the key odorants except guaicol was noted during radiation processing at all the doses investigated. However, beyond a dose of 5 kGy the increased content of these compounds resulted in a lower acceptability of the beans.

Pomegranate arils were packed in polystyrene trays (75g), stored at 12 °C for 10 days and the FT-IR data of the juice were correlated with the total log cfu of bacteria (Total Viable Count-TVC) and Yeast & Mold count (Y & M) everyday up to 10 d using partial least square regression model. A close agreement between actual and predicted values of TVC and Y&M was observed from the data obtained from FTIR. Multiple Layer Perception (MLP) was



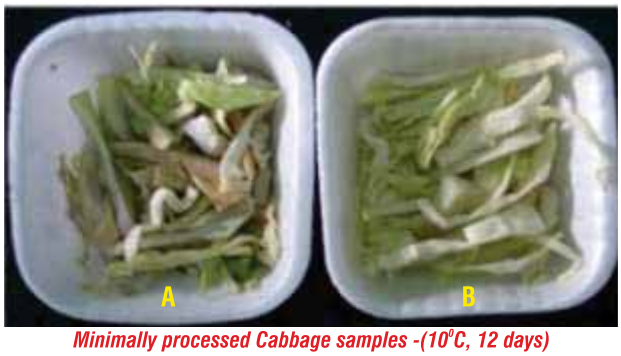
Minimally processed pomegranate samples (10°C, 8 days) packed in A. Edible film B. Cling film

developed from FTIR spectral data that could be employed for prediction of microbial load in ready-to-use pomegranate arils.

The aroma isolate of pumpkin obtained by Simultaneous Distillation Extraction (SDE) and Solid Phase Micro Extraction (SPME) were subjected to GC–Olfactometry (GC–O) based on detection frequency (olfactometry global analysis) to characterize odor active compounds of the pumpkin. 6Z-nonenal and 2E, 6Z-nonadienal possessing melon and cucumber type aroma were identified as major compounds responsible for the characteristic aroma of the vegetable. Radiation processing (1 kGy) enhanced the shelf-life of its Ready to Cook (RTC) product, without significantly affecting the key odorants indicating maintenance of overall flavor quality.

Glycosidic aroma precursors of cauliflower were extracted using Solid Phase Extraction (SPE) and hydrolyzed with pectinase enzyme. The first report on the occurrence of glycosidically bound aroma compounds in cauliflower was found. Studies on the effect of radiation processing and storage on these precursors and its impact on the vegetable quality are under progress. Seven phenolic compounds (gallic, syringic, chlorgenic, vanillic, caffeic, m-coumaric acid and catechin) were identified in RTC cauliflower florets. At a radiation dose of 2 kGy that resulted in improved shelf-life up to 21 d, significant increase (36-38%) in the content of catechin, vanillic acid and caffeic acid and reduction in the gallic (47%) and syringic acid (15%) was noted. No significant effect was observed in other phenolic constituents.

Glucosinolates were identified as their corresponding free isothiocyanates or nitriles by GC/MS (Gas Chromatography-Mass Spectrometry). Studies on the effect of radiation processing and storage on glucosinolate and isothiocyanates in RTC cauliflower are in progress.



Minimally processed Cabbage samples -(10°C, 12 days) A. Control B. AITC treated

An MOU with Institute of Chemical Technology (ICT), Mumbai was signed for the transfer of technology know-how of "Oxocatalysed Polyolefin Packaging Films for Environmental Degradation". Technology for preparation of radiation processed guar gum as a dietary fiber is ready for transfer to the prospective entrepreneurs.



Partially (radiation) hydrolysed guar gum for application as dietary fiber

Radiation Procession Services

Radiation Processing Plant (RPP), Vashi

Radiation Processing Plant, (RPP) Vashi has provided gamma radiation processing services for Spices, Ayurvedic raw material, healthcare products and pet feed etc. to 259 customers from all over the country. Fourteen new customers for Spice, Ayurvedic raw material and pet feed were registered with the facility during last 12 months.

During the year, till December 2015 2933 MT of spices and other products were processed against the annual target of 4000 MT earning revenue generation of ₹ 2.67 Crores against the annual target of ₹ 3.50 Crores. During next four months, facility is expected to process approximately 1200 MT of various products realizing revenue of approximately ₹ 1.20 Crores.

Facility has received re-certification for ISO-9001:2008 (Quality Management Systems) for three more years. Surveillance Audit for ISO-22000:2005 (Food Safety Management Systems) was carried out by certifying agency and found in full compliance with standard's requirements.

BRIT fetched revenue of ₹36.63 Lakhs as additional revenue from Gamma Radiation Processing Services (GRPS) related products and services such as supply of dosimeters in 91 consignments.



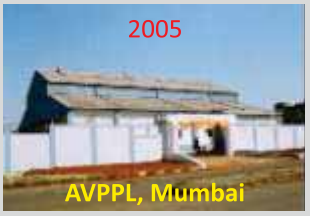
Spices for gamma irradiation

The QA activities at RPP included acquiring of NABL accreditation for Dosimeter calibration Laboratory,RPP Vashi; Export of 2000 Nos. of Ceric-Cerous dosimeters to Atomic Energy Agency, Srilanka; supply of 1 Lakh Ceric-Cerous dosimeters to various private irradiators for low, medium and high absorbed dose measurement in radiation processed medical and food products; Commissioning dosimetry was carried out at M/S Aligned Industries, Haryana for Medical and Pet feed products; Re-commissioning dosimetry was carried out for 4 plants namely M/S Gujarat Agro Industries Corporation Ltd (GAICL), M/S Agrosurg Industries (India) Ltd.,Vasai, M/S Organic Green Foods Pvt. Ltd.,Kolkata,

OPERATING RADIATION PROCESSING PLANTS

Under MoU (with BRIT)



















Plants Under Operation - 14
Products : Medical, Food, Allied Products
Total Rated Capacity - 16800 kCi
Plants Under Construction - 2
Plants Under Planning - 9











M/S Gamma Agro Medical Processing Pvt Ltd, Telangana for Gamma Radiation processing of food and medical products and Dose rate certification of Cesium-137 based Blood Irradiator to be supplied to Jankalyan Raktapedhi, Pune was carried out.

New MoU for Radiation Processing Plants in Private Sector

A MoU was signed with Avantee Mega Food Park Pvt. Ltd. for a setting up of Radiation Processing Plant at Indore on July 14, 2015 for radiation processing of food and medical products. Another MoU was signed with Electro Magnetic Industries for a setting up of Radiation Processing Plant at Sinnaur, Distt. Vadodara, Gujarat on July 25, 2015 for radiation processing of food and medical products. A MoU was also signed with Apollo Agro Industries Ltd. for a setting up of Radiation Processing Plant at Gujarat on October 20, 2015 for radiation processing of food and medical products.

Consultancy was obtained for commissioning Radiation Processing Plant for processing food and medical products by M/s Aligned Industries Pvt. Ltd. at Dharuhera, Haryana.

Four more Radiation Processing Plants (RPPs) under MoU with BRIT have been commissioned during the report period. The total operational Radiation Processing Plants (RPPs) under MoU with BRIT has gone upto fourteen.

HEALTH

Radioisotope based formulations, techniques and equipment are widely used in the diagnosis and treatment of various diseases. BARC, BRIT, RRCAT and VECC are major contributors in this field.

Radioisotopes are produced, processed and technologies are developed at Trombay for varied applications in the medical field. BARC's Radiation Medicine Centre, a premier centre in the field of radio-diagnosis and radiotherapy in Mumbai, is a regional referral centre of the World Health Organization (WHO) for South East Asia.

BRIT produces and supplies radio-pharmaceuticals for diagnosis and treatment of diseases, teletherapy and brachytherapy sources, radioisotope based kits, various instruments, and radio processing services. Jonaki Laboratory at Hyderabad produces and supplies P-32 labelled nucleotides for research in biology, biotechnology and drug discovery. Jonaki also markets S-35 labelled amino acids produced by labelled compounds at Vashi.

Radioisotopes for medical applications are also manufactured at VECC. The Regional Radiation Medicine Centre in Kolkata meets the radio-diagnostic and radiotherapy requirements of the eastern region of the country.

Radiopharmaceuticals

Radiopharmaceuticals meant for in-vivo use are 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.

BRIT continued the regular, uninterrupted, production and supply of radiopharmaceuticals all over India. BRIT has developed new production processes and capabilities towards increasing the production capacity and quality of products which has enabled RPhP to enhance production frequency, production volumes and regularize the production of new products introduced during previous years.

Approximately 561Ci of $Na^{131}I$ and over 22,500 consignments is processed, formulated and supplied to various nuclear medicine hospitals all over India in the form of solution and capsules. These are used for diagnosis and therapy of thyroid disorders.

Thyroid cancer treatment with large dose $Na^{131}I$ capsules is one of the major challenges and towards this; milestone production of 7Ci per batch of radioiodine was achieved. Denominations of 25mCi, 50mCi, 100mCi and 125mCi capsules were produced and supplied for the thyroid cancer treatment.

Approval for regular operation of New ^{131}I capsules production facility hot cells for 10Ci batch of radioiodine, have been granted by AERB.

The revenue generated from the sale of $Na^{131}I$ based radiopharmaceuticals alone is of the tune of ₹ 8.4 Crores upto 31st December, 2015.

About 2500 consignments containing nearly 26.5Ci of ready-to-use radiopharmaceuticals of ^{131}I-mIBG, ^{32}P, ^{153}Sm and ^{177}Lu in the injectable form were supplied to various nuclear medicine hospitals all over India. ^{131}I-mIBG (both, diagnostic and therapeutic) is used for neuroendocrine cancers, while ^{153}Sm-EDTMP and ^{177}Lu-EDTMP injections are used for bone pain palliation. Sale of all other therapeutic radiopharmaceuticals has resulted in the revenue collection of more than ₹ 30 Lakhs upto December 2015.



^{131} I Sodium Iodide therapeutic capsule production facility at RPL, BRIT

Total number of therapeutic treatments based on supplies is estimated to be more than 40,000 patients. This includes therapeutic doses of $Na^{131}I$ for the treatment of thyroid cancer and hyperthyroidism.

During the year, more than 75,000 cold kits for formulation of ^{99}mTc radiopharmaceuticals (15 Products; BRIT Code-TCK) is processed, lyophilized and supplied to various nuclear medicine hospitals all over India generating the revenue of ₹4.5 Crores



TCK Cold Kits Production Facility

. Manufacturing facility for 'Kits for Preparation of ^{99m}Tc radiopharmaceutical injection (Cold kits)' has been accredited and certified for "cGMP-Good Manufacturing Practices-Pharma Products" (in accordance with WHO requirements) by United Registrar of Systems Certification (56022/B/0001/NA/Endt 9, June, 2015).

Nearly, 250 Ci of ^{99}Mo in the form of Sodium Molybdate solution for solvent extraction generator has been supplied. Approximately 378 Ci of ^{99}Mo in the form of Sodium Molybdate is processed and supplied in form of ^{99}Mo-^{99m}Tc Gel Generator (46 generators) and 400 Ci of ^{99}Mo (1200 generators) alumina column generator (COLTECH) whereby BRIT earned a revenue of ₹4.05 Crores.

More than 2,28,245 in-vivo diagnostic investigations are estimated to have been carried out this year with varied diagnostic radiopharmaceuticals. The major one being, ^{99m}Tc based cold kits and ^{99}Mo-^{99m}Tc generator systems.



"COLTECH" generator Production facility

Approval for regular operation of new 99Mo-^{99m}Tc column generator (COLTECH) production facility hot cells for 10Ci batch has been granted by AERB.

The Medical Cyclotron Facility (MCF), Parel, located in the basement of Tata Memorial Annexe Building, continued supplying about 133 consignments of PET radiopharmaceuticals such as ^{18}F- FDG, ^{18}F-FLT, ^{18}F-NaF and ^{18}F- FMISO to various hospitals in and around Mumbai accounting for nearly 240Ci of radioactivity and generating the revenue of ₹ 3.75 Crores during the year 2015-16 upto December 2015. Approximately 14500 patients benefitted with PET investigations in the reported year.

The Medical Cyclotron Facility (MCF) was extensively used for the production of ^{18}F and its conversion to ^{18}F-Radiopharmaceuticals was carried

out. 296 Ci of ^{18}F-FDG, 44 Ci of ^{18}F-NaF, FLT and FMISO as required, were prepared and supplied to 11 nuclear medicine centres including RMC, BARC and Tata Memorial Hospital. The MCF had a turnover of about ₹ 5.5 Crores.

Safety analysis of the Medical Cyclotron facility under construction at Kolkata was carried out to demonstrate compliance with regulatory stipulations and ensure safety of the public and environment. Source term for normal operations, Anticipated Operational Occurrences (AOOs) & postulated accident is established and corresponding doses to public is computed.

More than 50,000 analysis for TSH, T4, fT4, Thyroglobulin and Anti Michrosomal Antibodies (AMA) were carried out using in-house developed kits and kits from BRIT. 142 Ci of $^{99m}TcO_4^-$ was extracted from ^{99}Mo and various ^{99m}Tc-radiopharmaceuticals were prepared for diagnostic studies. ^{68}Ga- DOTA-peptides was prepared and supplied for diagnostic scans. 50 Ci of ^{177}Lu- DOTA-TATE was prepared for neuroendocrine tumour therapy.

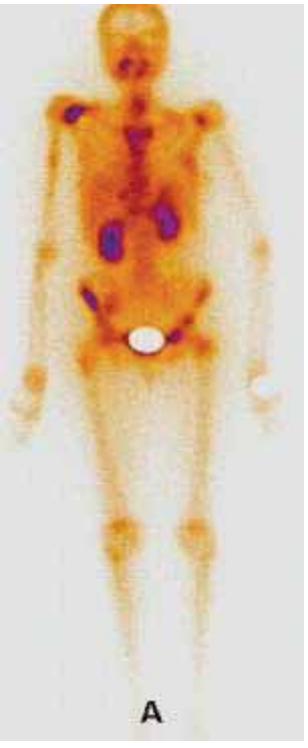
More than 12,000 patients were benefitted (of which 7106 were new patients) from nuclear medicine diagnosis and therapy for various ailments involving thyroid, heart, bone, kidney, lungs, GI tract, hematology, etc. Radioiodine (^{131}I) therapy (30–250 mCi) was administered to 826 thyroid cancer patients. 260 thyrotoxic patients requiring low-dose radioiodine therapy were treated. 333 patients with neuro endocrine tumors were treated with ^{177}Lu-DOTA-TATE. Therapy with ^{131}I- MIBG was administered for Neuroblastoma and ^{153}Sm-EDTMP and ^{177}Lu-EDTMP therapy was given to patients with bone metastases. Large dose ^{131}I diagnostic scans were done in 1031 patients of thyroid cancer. The Scintigraphy and PET-CT performed nearly 12,000 diagnostic scans, including over 3300 PET/CT scans, over 2000 cardiac rest and stress scans in this period. Other scans included renal, bone, thyroid, parathyroid and other specialty scans.

Facility for indigenous sourcing of expensive and clinically relevant peptides such as DOTA-TATE, HYNIC-TOC, cyclic-RGD, etc., using solid phase peptide synthesis has been developed. Single-vial kits are formulated for preparation of the radiopharmaceuticals DOTA-TATE (indigenously synthesized) for ^{68}Ga-DOTA-TATE; PSMA-11 (Prostate specific membrane antigen) for ^{68}Ga-PSMA-11 and HEDP (Hydoxy Ethylene Diphosphonate) for ^{188}Re-HEDP.

A two-vial kit for the preparation of ^{188}ReN-DEDTC/lipiodol (DEDTC–diethyl dithiocarbamates) for inoperable liver cancer as a cost-effective alternative of imported ^{90}Y-based products was developed. Wet chemistry protocol for the preparation of patient doses of the ^{177}Lu-labeled Trastuzumab and Rituximab, monoclonal antibody-based radio-immune therapeutics for non-Hodgkins Lymphoma and breast cancer respectively, and ^{177}Lu-labeled PSMA-617 for prostate cancer was finalized.



^{68}Ga-PSMA-11: PET-CT scan of patient with prostate cancer



^{188}Re-HEDP scinti-scan of patient with metastatic bone cancer

Radiation technology equipment

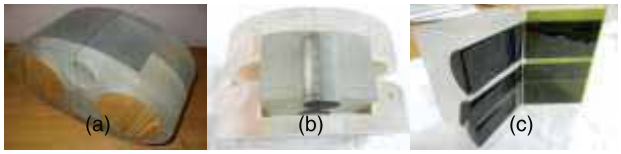
Bhabhatron and Imagin machines

During the year, six units of 'Bhabhatron' have been commissioned, taking the total number of operating units to 36. One unit at ACTREC has been

integrated with multi-leaf collimator, which is aimed at superior conformity. Six units of Radiotherapy Simulator 'Imagin' have been installed taking the total number of operating units of 'Imagin' to 10. One unit each of 'Bhabhatron' and 'Imagin' were gifted to Mongolia during the honorable Prime Minister's visit.

Postal Dosimetry Audit Phantom and Methods

Postal Dosimetry Audit Phantom and Methods for intensity modulated radiotherapy was developed. An elliptical shape anatomy specific (thoracic region) phantom which contains lung and bone equivalent inserts has been fabricated. The phantom has option of measuring planner dose using radio chromic film and point dose using TL/OSL dosimeters. The trial dosimetry audit has been carried out at a few hospitals in the country using this phantom.



Photographs of anatomy specific postal IMRT dosimetry audit phantom (a) Assembled IMRT Audit Phantom (b) Showing removal of Part B containing Planning Target Volume, Organ at Risk and Detectors (c) Showing locations of TLDs and radiochromic Film for point and planar dose verification.



First ^{137}Cs based Blood Irradiator is manufactured

Radiography Camera ROLI-2 & 3

Supply of 81 new indigenous radiography camera model ROLI-2 and model ROLI-3, and servicing and inspection of BRIT manufactured as well as imported ROLI cameras were the highlights during the report period. Apart from the above, production of 50 nos each of ROLI-2 and ROLI-3 cameras were carried out. Total revenue from the sales of radiography cameras and its services amounted to ₹ 3.03 Crores.

Gamma Chamber 5000

Two units of GC 5000 were loaded with 14000Ci each of ^{60}Co and transported to Indian Institute of Horticulture, Bengaluru and University of Bengaluru. These Gamma Chambers are kept ready for despatch, waiting for site clearance. Decommissioning of two units of GC 900, one at Inter University Accelerator, New Delhi and the other at University of Pune was carried out during the reported period.

Radio Diagnostic & Treatment Services

A total number of about 4000 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits to serve about 3,57,700 in-vitro investigations were supplied to various hospitals, research centers and immunoassay laboratories throughout India. The revenue earned by BRIT from the sale of RIA and IRMA kits for the year 2015 is about ₹ 0.71 Crores.

Regional centres at Delhi, Bengaluru, Jonaki, Hyderabad, Dibrugarh & Kolkata, continued the services of ready-to-use-radiopharmaceuticals to surrounding nuclear medicine hospitals, labelled compounds and radio analytical 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. The total revenue collected from all these services amounted to be ₹ 10.77 Crores.

At the Regional Centres for Radiopharmaceuticals (RCR), Kolkata, the revised new TCM-AUTOSOLEX module is in use with success at RRMC, VECC, Thakurpukur, Kolkata in association with technical support from RCR. The revised new TCM-AUTOSOLEX module at RMC, BARC for centralized radiopharmacy is in use. Patient studies have been started using pertechnetate and Radiopharmaceuticals using ^{99}Tc from autosolex. 750mCi Molybdenum batch have been used and the operation was found to be successful. The TCM-AUTOSOLEX module at BRIT, Mumbai is under evaluation stage for installation at

RCR, Hyderabad (Jonaki). Technical support was given to install the software and running the chemical processing steps. The chemical processing unit of the AUTOSOLEX module has been manufactured at BRIT, Mumbai in association with technical support from RCR, Kolkata. A new unit of TCM-Autosolex module at regional centre, Kolkata has been installed for future up-gradation. IAEA training programme has been conducted at BRIT, Mumbai with this AOTOSOLEX module. About 362 cold kits (having sale value of ₹ 9.3 lakh) were sold during the year in nuclear medicine centre at Kolkata.

Regional centre BRIT, Dibrugarh located at Assam Medical College & Hospital is rendering RIA and IRMA diagnostic services for the benefit of patients of the entire North-Eastern region. The Radiopharmaceutical products produced and supplied by BRIT, Vashi complex are extensively used by the RC, Dibrugarh for the diagnosis & investigation of various diseases. More than 7000 patients of the region avail the services from this centre. The revenue collected from RCR, Dibrugarh till November 2015 is around ₹7.0 Lakhs. ₹ 11 Lakhs as the total revenue for the year 2015-16 is expected to be collected.

The Regional Centre, BRIT, Bengaluru supplied 80mCi of ready-to-use ^{99m}Tc-pertechnatate and 1119 TCK cold kits were sold through retail outlet and door delivery for the preparation of ^{99m}Tc-radiopharmaceuticals to nearby nuclear medicine centres. Gamma irradiation services were provided for 2500 blood bags. Also, radio analytical 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. The total revenue generated from the services of RCR, Bengaluru amounted to ₹12.06 Lakhs during the year.

Regional Centre for Radiopharmaceuticals, Delhi continued to supply clinical grade ready to use ^{99m}Tc-radiopharmaceuticals in compliance with GMP and RPC for diagnostic nuclear medicine centres in Delhi and NCR regions. Total revenue of ₹ 21.78 Lakhs was collected by RCR, Delhi till December 2015.

Irradiation of Enriched ^{100}Mo for ^{99m}Tc production in VEC cyclotron and determination of radionuclidic purity of the cyclotron produced ^{99m}Tc

Enriched ^{100}Mo target as pellets (548 mg and 549 mg) were irradiated in VEC cyclotron with 18 MeV, 3μA proton beam for 2h and 3h duration. The obtained experimental yield of ^{99m}Tc were 33.7mCi and 46.9mCi respectively (monitored in dose calibrator). Irradiated ^{100}Mo target pellets were dissolved in 6.5 ml hydrogen peroxide and the basicity of the solution was maintained with 3M $(NH_4)_2CO_3$. Each set of pellet dissolved solution was fractioned in 5 sets. Separation of ^{99m}Tc from ^{100}Mo target was achieved by MEK (Methyl Ethyl Ketone) solvent extraction and Dowex-HNO_3 method (in AUTODOWNA module). Recovery yield of ^{99m}Tc from MEK solvent extraction was >90 % (n=6) and from Dowex-HNO_3 method >80% (n=4). Physicochemical quality control tests of all the separated ^{99m}Tc fractions were performed and it was found that all are within the specified limit.

Radionuclidic Purity (RNP) of final pertechnatate solution separated from enriched ^{100}Mo solution by MEK solvent extraction and Dowex-HNO_3 method was evaluated. For that, the decayed pertechnetate samples were counted in HPGe detector for overnight. It was found that RNP of pertechnatate samples were greater than 99.9% even at 24h after the separation. The level of different Tc radionuclides produced along with ^{99m}Tc are analysed.

The final report for 3 years IAEA Co-ordinated research project on direct production of ^{99m}Tc in cyclotron has been prepared and presented the same at IAEA'S final research coordination meeting on "Accelerator Based Alternatives to Non-heu production of MO-99/TC-99M" meeting at IAEA, Vienna during 22-26 June 2015.

Production feasibility of ^{89}Zr from ^{nat}Y and subsequent radiochemical separation of ^{89}Zr from the target matrix

The emerging PET radioisotope, ^{89}Zr with 3.27d half-life and decays by positron emission and by electron capture is suitable for tumor diagnostics,

tumor therapy and also for investigation of bio-kinetics of antibodies. This isotope can be produced from natural yttrium which has 100% abundance. To standardize the separation of ^{89}Zr from Y, some radiotracer of yttrium is required. Therefore, natY foil of 100µm thickness and weighing 69mg was irradiated in VEC cyclotron with 18 MeV, 1.3µA proton beam for 37h duration for production of ^{88}Y (half-life 106 d), ^{88}Zr (half-life 83 d) and ^{89}Zr. The experimental yield of ^{89}Zr, ^{88}Zr, ^{88}Y were 37mCi, 2.6mCi and 0.27mCi at EOB respectively. Natural Yttrium foil of 100µm thickness and weighing 72mg was irradiated in VEC cyclotron with 12 MeV, 1µA proton beam for 22h duration for production of pure ^{89}Zr. At this energy, the production yield of ^{89}Zr was 6.3mCi at EOB and no other isotopes of Zr and Y were found. Dissolution of irradiated ^{nat}Y targets were carried out in Conc. HCl (12M). The radiochemical separation of ^{89}Zr from irradiated Y target has been done with cation exchange, anion exchange chromatography.

Elution of the ^{68}Ge-^{68}Ga generator (G-8) & Post Purification of Ga-68

The new ^{68}Ge-^{68}Ga generator (G-8) prepared from ^{68}Ge produced by irradiation of Ga target with proton beam was evaluated by daily elution for more than 300 days. Average elution efficiency of the column was found to remain constant at about 58%. A new method of purification of the primary eluate from the generator was standardized using a cation exchange resin. In the optimized method of purification the average yield of purified ^{68}Ga has been around 84%, pH 6-7. Breakthrough of Ge-68 before and after purification were 0.046 and 0.00031 respectively. The process chemistry has been semi-automated.



Semi-automated ^{68}Ga-post purification process system

A new method of direct Separation of ^{68}Ge from bulk Ga using SnO_2 column useful for in situ formulation of ^{68}Ge/^{68}Ga generator: Devoid of using Solvent Extraction process using Toluene

^{68}Ge-Ga target dissolved solution at 1M HCl was directly loaded on a fresh SnO_2 column (mesh size 150-200) was used for the preparation of ^{68}Ge/^{68}Ga generator. The advantage of this method is that no separate solvent extraction is required for the isolation of ^{68}Ge from the Ga target matrix. Then the column was washed with 500 ml 1N HCl to wash trace amount of inactive Ga. All the fractions including the load solution were monitored in HPGe detector to assess the retention of ^{68}Ge in the column. It was found that >99% of loaded ^{68}Ge has been retained in the column. Since Ga is inactive here, the estimation of Ga in the wash solution and in the load solution has been performed colorimetrically with chromazural-S reagent following the same protocol applied for determination of aluminum. It was found that most of the Ga has came out during loading of ^{68}Ge and the level of Ga decreased in the successive washing and it was very close to standard solution 10µg/ml. The Elution Efficiency of ^{68}Ga was 48% from the SnO_2 column with respect to loaded ^{68}Ge activity as determined by HPGe detector. Percentage of loaded ^{68}Ge activity broke through the column was 0.204 (n=7). This breakthrough is little higher as compared to the earlier column (G-8) prepared @ 0.1M Hcl.

Synthesis of cross linked chitosan for preparation of ^{99}Mo/^{99m}Tc generator

The cross-linked chitosan is an emerging potential adsorbent matrix having large adsorption capacity for many metal ions, which can be extended to the preparation of ^{99}Mo/^{99m}Tc generator from low specific activity ^{99}Mo. The precursors for this cross-linked chitosan are Chitosan and glutaraldehyde. The cross-linked mass was separated from the solution and washed thoroughly with deionized water until the pH of the effluent solution was 7. Characterization of

the synthesized cross linked chitosan has been carried out with X-ray diffraction method.

Labelled Compounds and Diagnostic Kits

During the year, Labelled Compounds Programme of BRIT continued the supply of more than 7900 sources of Tritium Filled Self-luminous (TFS) sources of various sizes and shapes for defence establishments along with the custom synthesis & supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products. The revenue earned was about ₹ 80 Lakhs. It is estimated to supply about 25,000 nos. of additional TFS sources by March 2016.



View of Renovated Labelled Compounds Laboratory at BRIT, Vashi Complex

Regional Centre of BRIT, Hyderabad (Jonaki) supplied ready-to-use $^{99m}TcO_4$- (Pertechnatate) and ^{99m}Tc-Radiopharmaceuticals through their retail outlet to the nuclear medicine centres of Andhra Pradesh. It also continued to supply ^{32}P labelled nucleotides and a few molecular biology kits and enzymes for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research. It markets ^{35}S-labelled amino acids products produced at BRIT, Vashi Complex. Total revenue earned by RCR, Hyderabad is Rs. 68.7 Lakhs upto December 2015.

Radio Analysis

Radioanalytical Laboratory (RAL) continued to carry out the measurement and certification of radioactivity content in commodities such as food items for human & animal consumption, water samples, environmental samples, steel and other miscellaneous items. Generally, food items are monitored for the presence of ^{137}Cs & ^{134}Cs. Water



Radioanalytical Laboratory

samples are routinely analyzed for gross alpha/gross beta, uranium, ^{226}Ra and ^{228}Ra content, depending upon the requirement. ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K contents are measured and certified in environmental samples such as coal, fly ash, soil rock phosphate, gypsum etc. Steel samples are generally tested for the presence of ^{60}Co contamination. Steel survey at factory sites and warehouses is carried out to monitor the surface radiation dose. Since April 2015, RAL has carried out more than 3000 tests on export/domestic commodities and 900 tests on water samples (gross alpha, gross beta ^{226}Ra & ^{228}Ra).

In addition to above, one steel survey was conducted for certification of surface radiation dose and 27 food samples imported from Japan were also analyzed and certified.

Setting up of additional Radioanalytical Laboratory at BRIT Project House, Deonar is completed during the year.

Radioanalytical Laboratory Services both at Vashi Complex and RCR, Bengaluru, together performed approximately 3737 analyses of food and water samples for the presence of radioactivity and BRIT earned a revenue of ₹ 0.98 Crores during the report period.

Radiation Sterilization Plant for Medical Products (ISOMED)

ISOMED facility engaged in contract gamma radiation processing services for terminal sterilization of the medical products has processed 5120 Cubic mtrs of products earning a revenue of ₹ 2.29 Crores. It is expected to generate a total revenue of ₹ 3.47 Crores by the end of the financial year 2015-2016.

First of a kind, Integrated System Of Computer Aided Dosimetry (ISOCAD) which has been an innovative endeavour for providing counterfeit proof, computerized dose measurement system for the gamma irradiators has been gaining wide popularity in the country. ISOCAD has till now been successfully installed in six gamma irradiators and is expected to be commissioned for four more irradiators by the end of the current financial year.

Another Graphic User Interfaced innovative application, viz, ISODIMM (Interactive Software of Drawing Interfaced Maintenance Management) has been designed, tested and successfully commissioned at the facility for the Gamma Irradiators. ISODIMM facilitates computerized engineering drawing associated centralized database management system for the System, Structure and Components of the facility.

Gamma Radiation Indicator Buttons were developed indigenously as an import substitute for the qualitative indication of the low and medium range gamma radiation dose delivered to the products. These buttons would provide "Made in India" technological solution to the gamma irradiators in the country.

New Projects

DAE Medical Cyclotron Project: Radiopharmaceutical Facility

Civil construction work is in the final stage of completion. Work on HVAC, electrical work, LCW system etc. are completed. It is expected that the installation of the Medical Cyclotron will start by June 2016.

Indigenous HDR Brachytherapy Equipment (IHDR)

Purchase Order for "Development of suitable TPS for IHDR-KARKNIDON" released and development work has commenced. Implementation of the necessary action based on the feedback of cold trials of 2 units which were supplied to TMH & ACTREC was carried out during the period. Two numbers of Ir-192 miniature source assemblies were made but source holder did not sustain the trials. Subsequently, new design of SS source holder was finalized in consultation with DRHR/BARC and given for manufacturing in CDM by DRHR. Cold trials of five units at BRIT were continued for generation of record towards reliability studies. Improved design of PEEK moulded ovoid & SS applicator made & tested.

Setting up of Fission based ^{99}Mo Production Facility

This project consists of setting up of a State-of-the Art GMP compliant facility capable of producing 300Ci (6 day pre-calibrated) /week ^{99}Mo, utilizing LEU targets. The scope includes commissioning of set of modern hot cells equipped with manipulators, in cell equipments, radiation surveillance instrumentation and data logging system, special AC & ventilation system, waste management equipments, civil construction of building and setting up of world class quality control labs, modern security system, construction of new building at approved site in ISOMED Complex, BRIT near South Gate BARC, etc.

The work of construction of new RCC boundary wall for the complex, new security watch tower is over and installation of new security and surveillance equipment is ongoing. The work on civil construction of laboratory building is nearing completion. The work on installation of facilities for waste management, electrical supply, water supply etc. is progressing.

The procurement of the production plant on turnkey basis is progressing. During the year, the procurement vide Purchase order in favour of M/s INVAP, Argentina for design, fabrication, supply, installation and commissioning of facility was cleared after negotiations and discussions. Work on design and fabrication of LEU targets for irradiation in Dhruva is in progress at BARC.

Advanced Facilities for Radiopharmaceuticals Production

The project scope comprises building Advanced Radiopharmaceutical Manufacturing and testing facility for new generation Radiopharmaceuticals with radioisotopes using ^{90}Y, ^{177}Lu, ^{89}Sr, ^{131}I, ^{32}P, ^{153}Sm. etc . Also the present production capacity of radiopharmaceuticals and

services from RPL, Navi Mumbai and Jonaki Hyderabad would be enhanced under this project.

New Effluent Treatment plant, as per requirement of Maharashtra Pollution control Board and Navi Mumbai Municipal Corporation, of capacity 150CMD for BRIT, BARC-Vashi complex commissioned is operational.



The Effluent Treatment plant

Site clearance work for construction of new laboratory space at first floor over RPL extension building is in progress and re-routing of the return ventilation air duct, which was laid on the terrace of the RPL extension building, completed.



Roof Top View



Ground View

New Laboratory Space Construction

State-of-the-art analytical equipment installed and commissioned during the year are HPGe detector, Laser-Uranium analyser, dose calibrators, Mass spectrometer at RPL Vashi and electrophoresis, real time PCR and Alpha-Beta counting system at JONAKI, Hyderabad.



Mass Spectrometer in RPL

New Pharmaceuticals services room has been set up for preparing Water for Injection (WFI), Sterile and pyrogen free glassware, equipment, glass vial etc. which are used in production and important primary containers for all radiopharmaceutical products.



New facility for Pharmaceutical services

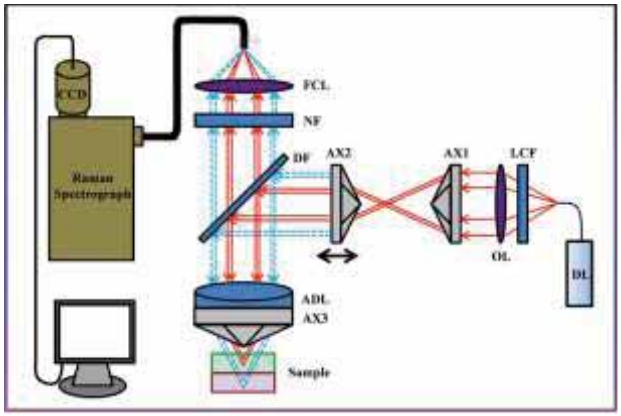
Technology Development for Radiation Technology Equipment

Specifications for I-125 seed manufacturing plant have been finalized. Old canteen building of BRIT has been demolished and construction of new building has been started. Equipment such as X-ray based low dose irradiator, Co-60 camera, source changer have been developed.

Biomedical Applications

Cone-shell Raman spectroscopy for depth-sensitive measurements in layered tissue

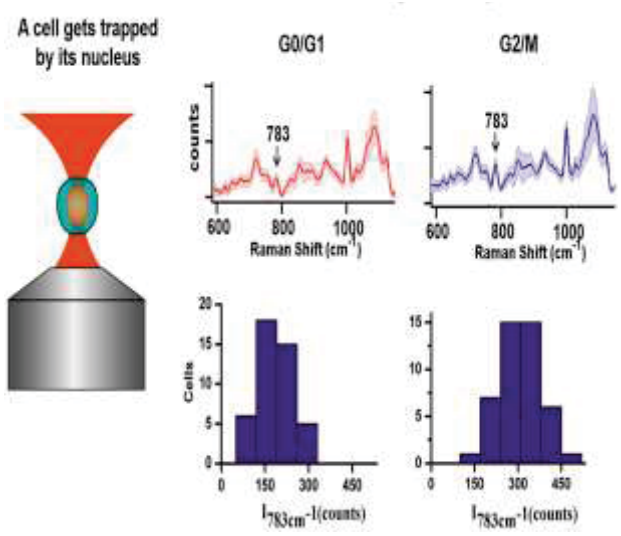
A Raman spectroscopic system based on the technique of Cone Shell Raman Spectroscopy (CSRS) was developed for non-contact, depth-sensitive measurement of layered biological tissue. The system uses a 785 nm diode laser and three identical axicons for Raman excitation of the target sample in the form of a hollow conic section. The performance of the CSRS system was evaluated by measuring the depth-sensitive Raman spectra from a layered non-biological phantom made of paraffin and acetaminophen and also from a chicken tibia with muscle tissue (thickness 2.5 mm) on its top. The results demonstrated the ability of the CSRS system to recover Raman spectra of layers located at depths of 2-3 mm beneath the surface.



Experimental setup for the cone-shell Raman spectroscopy system

Raman optical tweezers for cell cycle analysis

The potential of Raman optical tweezers for label free cell cycle analysis has been demonstrated on human colon adenocarcinoma (Colo-205) cells in different phases of the cell cycle. It was shown that the DNA Raman band at 783 cm^{-1} can provide information about the DNA. The results of the studies showed the utility of Raman optical tweezers for label free cell cycle analysis.



Raman spectra of optically trapped cells in different stages of cell cycle

Alternative Applications of Heavy Water

Realizing the potential requirements of Oxygen-18 (^{18}O) having application in nuclear medicine and bio-chemical research, HWB has successfully accomplished technology development for enrichment of ^{18}O at HWP, Tuticorin. The industrial



^{18}O Plant at HWP, Manuguru

scale facility for ^{18}O production plant has been commissioned at HWP, Manuguru. All columns have been successfully operated with DM water. Nuclear grade heavy water was charged and is under enrichment in coupled condition since July 2015.

Considering the immense potential of application of Deuterium and heavy water in life sciences, pharmaceuticals and technology areas, HWB has put in place an action plan to facilitate and nurture R&D activities in this area. Many Indian companies and government institutions like Indian Council of Agricultural Research (ICAR), Indian Veterinary Research Institute (IVRI), Institute of Plasma Research (IPR), Tata Institute of Fundamental Research (TIFR) etc., have shown their interest in this area and HWB has supplied small quantities of heavy water to support their R&D jobs.

As part of the developmental activities on non-nuclear uses of Heavy Water, methods for synthesizing deuterated NMR solvents viz. Acetone-d6, Acetonitrile-d3, Chloroform-d and Dimethyl Sulfoxide-d6 have been developed at laboratory scale. All these chemicals were synthesized at HWP, Baroda laboratory and got certified by M S University, Vadodara for use as NMR solvent. Experimental Method was established for removal of Dichloromethane impurity from Chloroform (AR Grade). Process optimization has also been done to minimize the consumption of Heavy Water used for synthesizing these molecules. As part of MoU signed

between HWB & BRIT, BRIT has already started marketing these solvents to various reputed research institutes in the country. KOD was also prepared and sent to BARC Vishakhapatnam during this period.

Cancer Diagnostics and Treatment Services

The Tata Memorial Centre (TMC) is a Grant-in-Aid institution of the Department of Atomic Energy, Government of India. It functions through its three Centers, viz., Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC), and Centre for Cancer Epidemiology (CCE). The mandate of the Centre is "Service, Research & Education in Cancer". The hospital registers approximately 50,000 new patients annually, from within and neighbouring countries. The treatment to these patients is facilitated through eleven Disease Management Groups (DMG). During the period, TMC acquired around 140 equipments which included the procurement of various equipments viz Accessories for Robotic Surgery, CT injection system, Local Accessories for rigid Tranchescope & Bronchoscope set, Haemodynamic Monitor,17 FR Cystoscope, Tissue Processor, Video Colonoscope STD accessories, Freeze Drier Martin Christ Model Alpha, Image Analyser System with Microscope, camera & accessories, Fluorescence based fully Automated SSP Analyzer 2 KVA, Pediatric Bronchoscope, Operating Resectoscope Set (TEO), Microtomes, etc., Laryngoscope with carrier, Spirometer portable, Image analyser system with microscope, Double dome LED OT light, Electrohydraulic OT table, Real Time PCR system, Cystoscopy Telescope 30º set. Procurement of laboratory equipment viz. Blood Collection Monitor TCM, CMOS Microscope Camera, 17 FR Cystoscope, Telescope, etc. was also done.

Medical Oncology Information System (MOIS) software is implemented for Breast and GI Disease Management Groups. Introduced smart card services for all services and all categories of patients. Browser based Software implemented for Admission /Discharge/Transfer & Operation Theatre. Refinement carried out in Diagnostic Information System & Radiology Information System.

Installation of major equipments like Surface Plasmon Resonance System, refrigerated shaker Incubators, Tabletop Centrifuges, Inverted Microscope, Thermal Cycler, Water Purification System, Micro plate Reader, Gel Documentation System, Real Time PCR Machine etc. required for basic research labs was completed. Other assorted equipments like vortex mixer, Dry bath, Digital CO_2 analyser, Gradient Thermal Cycler, vacuum pumps etc. were procured and installed.

Screening of women population for breast, uterine, cervix and oral cavity cancers were continued in Ghatia village. Screening camps of 786 women from project clusters viz. Trombay, Payalipada, PMGP colony, Maharashtra Nagar, I (slums), Ghatia village, Initialed follow-up visits for women referred but not attended to TMH and for malignant & pre-cancerous lesions from project clusters namely Mohite Patil Nagar, PMGP colony, Lallubhai compound & Ghatia Village. Household survey was continued for screening of eligible women for breast, uterine, cervix and oral cavity cancers.

Award of construction work to M/s Hindustan Construction Co. Ltd. through DCSEM for construction of 100 bedded cancer hospital at Aganampudi village, Visakhapatnam, Andhra Pradesh was given for the establishment of Cancer hospital in Andhra Pradesh. Construction work has commenced. Procurement of surgical equipments and consumable required for OPD activities were continued. Registries work continued as envisaged.

More than 1000 patients have been registered so far and got the benefits. OPD activities and registries functioned as envisaged. Hematology, Cyto-Pathology, Histo-Pathology & Molecular Biology Labs were initiated and are operational. Palliative care services including Hospice care initiated and are operational.

Approval has been received from DAE for award of purchase order for procurement of Hadron Beam Therapy equipment from M/s ION Beam Application, SA, Belgium. Approval has been obtained from DAE for shifting of site for Hadron Therapy equipment to ACTREC campus. Work regarding obtaining statutory clearance is in progress for the construction of Women & Children Cancer Wing.

For the Cancer Hospital in Chandigarh, work order has been issued to M/s DDF consultant services Ltd. as EPC consultant for short listing of agencies for construction. OPD, day care, radiotherapy and surgical services have commenced. Around 1000 patients have registered so far for treatment. CT Scan / Simulator and Cobalt equipment have been commissioned for treatment of Patients. CT Surgical block, CT scan / Simulator and laboratory, Chemotherapy & sales of drugs have also been initiated.

Clinical Research Secretariat (CRS) and Department of Atomic Energy Clinical Trials unit (DAE-CTC) has continued to play a key role in facilitating research in the field of oncology at the Hospital. CRS is involved in conducting numerous trials including Investigator initiated, pharma sponsored, collaborative studies (International and National) and the thesis of postgraduate students. The mandate of CRS includes promoting clinical research, conducting training programs, ensures scientific and ethical conducts of clinical trials through education of researchers and trial-coordinators and propagates practice of evidence based medicine across the country.

The number of patients referred to and registered at ACTREC has increased over the years. The Clinical Research Centre (CRC) and Hospital of the Centre has a total of 111 beds, including 80 in the ward, 10 in ICU and recovery, 6 in the bone marrow transplant unit, and 16 in day care. MRI and intervention radiology under anesthesia were restarted at ACTREC. Critical incident report form was introduced in the ICU and OT.

The adult solid tumor unit of the Department of Medical Oncology reviewed about 8300 patients in the OPD. About 3600 OPD were treated in the Bone Marrow Transplant Unit and the hematolymphoid unit handled approximately 800 in-patients and 6900 in the OPD. The department of Radiation Oncology treated over 700 new patients. A new state-of-the-art linear accelerator (Varian True Beam) was installed and commissioned for clinical use towards the year-end. The indigenously developed Multi Leaf Collimator (MLC) system installed on the Bhabhatron-II telecobalt unit received regulatory approval for clinical use. The highlights of the surgical services include intra-operative image-guided neurosurgery using navigable 3D ultrasound, fluorescence guided-resections of malignant gliomas, and minimally invasive laparoscopic gastrointestinal surgery. About 2000 major surgical procedures were performed in ACTREC.

The Pathology laboratory provided diagnostic services for histopathology, frozen section, immunohistochemistry and cytology for cancer patients. It processed approximately 2740 histopathology specimens, 2320 frozen sections and 360 cytopathology specimens and performed about 3500 IHC tests. The Molecular Hematopathology laboratory conducted specialised tests such as somatic hypermutation in lymphomas and CCAT/ enhancer binding protein alpha gene mutations (CEBPA) that are not available elsewhere in India. The Department of Radio diagnosis provided diagnostic imaging services. The Microbiology laboratory processed about 9074 samples.

The Department of Transfusion Medicine provided round the clock, safe and adequate supply of blood/ blood components to cancer patients.

The achievement of Clinical Pharmacology lab involved in drug development included the encouraging preclinical findings of chlorophyllin as a radio protective agent and its technology transfer to an industry partner. The lab's bio-analytical facility received a boost with the installation of a LC-MS/MS system capable of small molecule quantitation, metabolite identification and quantitative proteomics. The Research Translational Research lab showed for the first time that circulating fragmented nucleic acids emerging from dead cells can freely enter into healthy cells and damage their DNA by integrating into their genomes. Compounds that can degrade circulating NAs have been devised in this lab, suggesting novel therapeutic possibilities, especially in cancer treatment.

^{60}Co Teletherapy Sources for Cancer Hospitals

Eleven ^{60}Co-Teletherapy Sources (CTS) with total activity of about 98.3 kCi in the range of 138 and 167 RMM were supplied to various cancer hospitals in India. Twelve decayed sources were unloaded from

the teletherapy units and stored for fabrication of irradiator source. These sources were fabricated at RAPPCOF, Kota using ^{60}Co produced indigenously in nuclear power reactors. Total revenue generated is ₹ 5.50 Crores upto December 2015.

Cancer Awareness & Prevention

Intervention Arm Screening for esophageal cancer for 19 villages were covered – out of the total population of 16901, 4356 eligible population were screened. Double contrast barium swallow screening was done on 2665 population. One positive case for double contrast barium swallow screening was found. One case was detected for esophagus cancer and has been treated.

Intervention Arm Screening for oral cancer was done for total 74 villages. Out of the total population of 43966, the eligible population for screening were 12219. Oral screening was done on 8379 population out of which 137 cases were screened positive. Six cases were detected for oral cancer and were given treatment.

Control Arm screening was carried out in 75 villages. About 11193 population were screened. Twenty six cases were detected for esophagus cancer and 59 cases were detected for oral cancer.

WATER

Water Purification, Desalination of Water & Isotope Hydrology

Basic and applied research on thermal and membrane desalination and water purification was carried out. A pilot-scale thermal desalination demonstration plant was installed and commissioned at BARC.



Ultra-filtration plant

The Ultra-filtration plant of 250 m^3/hr capacity was installed and commissioned for the conventional pre-treatment for SWRO process. This membrane pre-treatment will give sustained pre-treated feed sea water quality irrespective of changes in raw seawater.

Nuclear Desalination Demonstration Plants (NDDP) at Kalpakkam have been in continuous round-the-clock operation. Around 50 m^3/hr and less than 10 ppm quality of ultrapure water from MSF plant was directly utilised as boiler feed water in MAPS. Multi Stage Flash (MSF) water blended with Sea Water Reverse Osmosis (SWRO) water and (100 m^3/hr, < 250 ppm TDS quality water) was used as portable water in IGCAR. The processed water from NDDP has enabled smooth functioning of other critical facilities such as MAPS, KARP, FBTR during the period of severe water crisis in Kalpakkam.

Multi Effect Distillation (MED) in combination with Thermal Vapour Compression (TVC) of capacity 240 m^3/day is installed and commissioned. The plant produces very high quality DM / distilled water of conductivity less than 5.0 micro-Siemens/cm (TDS: 2 ppm) directly from seawater (TDS: 35000 ppm) with the use of Medium Pressure (MP) saturated steam. Product water cost is in the range of 10-12 paisa/l.

A membrane process is developed to alleviate the risk of scale formation while dealing with nearly saturated solution. Simulation has been carried out using saturated solution of calcium sulphate, which is treated with Nanofiltration (NF) membrane batch system and hydrodynamic conditions like flow rate and operating pressure are optimized.



Saturated solution membrane treatment scheme

BARC has developed a simple and low cost method based on an innovative chemical agent for removal of fluoride from contaminated water. The Method has been successfully tested in 10 different villages of Madhya Pradesh with the ground water having about 2-6 ppm of fluoride (toxic levels), which could be brought down to the permissible limit of 1 ppm. The method has several advantages including regeneration of the chemical agent after use and solidification and storage of the fluoride containing waste to avoid its migration back to the environment.



Chemical agent for fluoride removal



Field application of fluoride removal technology in Madhya Pradesh

BARC has designed a solar photo-bioreactor capable of treating domestic waste water and simultaneously generating biomass for biofuel generation. The bioreactor is a column type vessel with small footprint and the biomass is a granular



Solar photo-bioreactor

consortium consisting of bacteria, cynobacteria and microalgae. Laboratory trials have shown that the bioreactor can cause significant reduction in the turbidity (50 NTU to 2 NTU), total organic carbon (43 ppm to 6 ppm) and pathogen count (by four orders of magnitude) and nitrogen / phosphorous (below discharge limit). Discussions are in progress with industry for technology incubation for commercial application.

Isotope hydrological investigation was carried out in Goa to investigate the impact of iron ore



Son river sampling near Patna

mining to groundwater and surface water quality in downstream of the mine pits. Trace elements analysis of mines water and groundwater demonstrated that mines water is not contributing to the groundwater. Isotope techniques in aquifer mapping at a model project site in Patna district of Bihar state was carried out to understand recharge mechanism and dynamics of groundwater demonstrated that during pre-monsoon, shallow groundwater receives recharge from the River Punpun and Son while the deep groundwater receives recharge from River Ganga.

INDUSTRIAL APPLICATIONS

Ahmedabad Municipal Corporation and BARC signed a MoU to set up a Sewage Sludge Hygienisation Plant at Ahmedabad as a part of the initiative for cleaner India (Swachcha and Swastha Bharat). This is a first of its kind radiation hygienisation plant where sewage sludge will be hygienised using Radiation Technology, inoculated with useful bacteria and converted into manure for use on land applications. The fully automatic, 100 tons/day facility is expected to be operational by end of 2017.



Senior Officials from Ahmedabad Municipal Corporation and BARC during signing of MoU

Flow dynamics study of heavy petroleum residue in an industrial-scale soaker operating in a petroleum refinery at M/s IOCL, Haldia was carried out by measuring the Residence Time Distribution (RTD) of the residue using ^{82}Br radiotracer as dibromobiphenyl.



Flow dynamics studied

A separator for carbon soot from flue gas is locally fabricated and demonstrated with a separation efficiency of more than 80%. This type of units can be used as pollution abatement devices in thermal power plants.

At RRCAT, a fiber drawing system has been designed and developed for drawing fused silica fibers suitable as suspensions to isolate optical components of a high-resolution displacement



Experimental Setup for Carbon Soot Separation

interferometer from ground noise. The system makes use of a 50W sealed CO_2 laser and a pair of diamond turned axicon optics to symmetrically heat a 3mm "pre-form" fused silica rod and a servo driven pulling mechanism to draw the pre-form rod into a 600 microns diameter fiber. A servo control system was also developed to simultaneously control the laser power, the pre-form in-feed rate and the pulling rate to maintain the specified diameter. Testing and trials of the integrated system has been completed.

A fiber laser based system has been designed and developed to micro-machine metals. The developed system has a micro-machining area of 100mm diameter with a minimum feature size of 50 microns. The system was developed as per requirements of the Precision Engineering Division, BARC for micro-machining of features in metals and micro-structuring of metal foils.



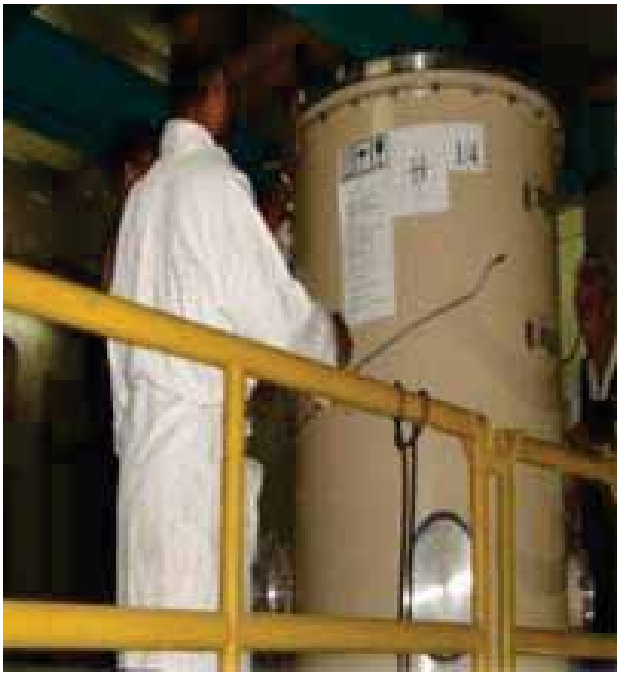
The laser based fiber drawing system



The photo of the developed fiber laser micro-machining system

The upgradation work of 2MeV Electron Beam Accelerator (EBA) to operate upto 5 MeV/15 kW at BRIT, Vashi complex has been completed during the time period. BARC Safety Committee has approved for initial trial operations at 4.5MeV/9kW Beam power. EBA facility characterization has been carried out using Film/alanine Dosimetry. The process thickness has been evaluated to be 12.5mm to 33.0mm for unit density material. Dose uniformity is within 5% over the multiple product packages of 800mm×600mm (l×b).

The machine can deliver from a lowest dose of 0.5kGy and products can be processed on semi industrial scale, which can accommodate a range of



RF Cavity Replacement during ILU-EBA Upgradation



EB Parameter Display in ILU-EBA Facility

low, medium and high dose irradiation of products viz. atta, pulses, spice, fish, meat, polymer materials and semi-precious stones etc. Both, the mesh conveyor and power roller conveyor have been repaired and restored back to operation so as to enable continuous irradiation at the speed of 0.9m/min to 4.2m/min. All the civil & mechanical modifications of the facility planned during upgradation work have been completed.

During the year, products irradiated in the facility include fish, meat (for shelf-life extension under chilled condition), wheat powder for disinfestation, polymer cable joint end-caps (for crosslinking and high temperature applications), waste water for hygienization, etc.

Electron Beam cross linkable polymer composite HDPE and EPDM which are both temperature-resistant and radiation-resistant has been developed for applications in cable insulation & nuclear gasket industry.

Quality of product developed had excellent high temperature resistance for nuclear gasket applications. At 120₹C, it can be used up to one month. At 100₹C, it can be used for 2 months. At 70-80₹C, this can be used for 4 months; had excellent gamma resistance for nuclear gasket applications (up to 1300kGy); had Good processibility and had Tuneable mechanical properties. This material can be recommended to be applied for nuclear gasket application, where a high temperature and radiation resistant gasket is required.

Radioisotope Sources supplied by BRIT

The various engineering products offered by BRIT included the supply of more than 1183 kCi of radioactivity in various forms and for varied uses. The combined revenue for the engineering products and radiation processing services is estimated close to ₹ 26.3 Crores upto December 2015.

Industrial Irradiator Sources

Sixty six irradiator sources with total activity of around 1066.5 kCi were supplied in seven consignments to various processing plants within the country and were also exported. The irradiators to which these sources are supplied are namely, (a) KRUSHAK, Lasalgaon – 55.4kCi; (b) AIIPL, Vasai – 248.477kCi; (c) NIPRO, Satara – 375kCi; (d) OEFL, Kolkata – 96.5kCi; (e) GAMPPL. Hyderabad – 100 kCi; (f) FIPLY, BARC – 45kCi; (g) INNOVA, Bengaluru – 146.135kCi. Total revenue earned from ^{60}Co Irradiator sources during the year was approximately ₹ 8.11 Crores till December 2015.

A total of 700kCi of irradiator sources are planned to be supplied in March 2016. These include MSAMB, Vashi – 350kCi; Aligned Industry, Bhiwandi – 100KCi and Sri Lanka – 250kCi.

Radiography Sources

Nearly, 869 radiography consignments of ^{192}Ir and ^{60}Co with total activity of approximately 37.5 kCi were supplied to various radiography customers in the country. The revenue earned from radiography source replenishment and other service offered by BRIT during the year was approximately ₹ 6.78 Crores. It is planned to supply five hundred and fifty more radiography sources in March 2016.

Custom Made Sources (CMR) and Reference Sources

Custom Made Sources of ^{60}Co, ^{137}Cs and ^{46}Sc were supplied on request, for Nucleonic Gauges and other calibration uses in 974 consignments upto December 2015. A total of 5.67Ci of radioactivity was supplied for reference and custom made sources for revenue of ₹ 26.91 Lakhs. Eighteen custom made ^{60}Co radiation sources with total activity of 1.656mCi were supplied till November 2015. It is planned to supply thirty two more ^{60}Co sources with an activity of 3.2Ci and forty custom made ^{137}Cs radiation sources with 4Ci activity by March 2016.

A contract is expected to be signed with Los Alamos National Laboratory (LANL), USA for providing technical support on repatriation of decayed radioactive sources in India back to USA. The work involves collection of devices containing sources such as ^{241}Am, ^{137}Cs and ^{226}Ra from 5 institutes, removal of sources from devices and repatriation to USA.

Isotope Application Services

Isotope Application Services (IAS) Group of BRIT offered its valuable services to various industries. The total revenue from the IAS services till December 2015 amounted to ₹ 63.82 Lakhs.



Radiotracer handling for gamma scanning

BRIT in collaboration with BPCL, Mahul, Mumbai, did the troubleshooting of Catalyst Cracking Unit (CCU) by combining Gamma Scanning with ^{60}Co and Radiotracer Technique. These services helped in identifying the misbehaviour of cyclones in the reactor and also to study the distribution of catalyst powder. Thus, IAS division of BRIT helped Bharat Petroleum Corporation Limited (BPCL) immensely to plan the shutdown and take necessary corrective actions leading to the saving of several crores of rupees by minimising the downtime.

Gamma scanning of stripper in Guru Gobind Singh Refinery at Bathinda was carried out to study the cause of poor product quality. Gamma scanning also helped Hindustan Petroleum Corporation Limited, Mumbai refinery to understand flow dynamics of hydrocarbons inside extract tower of the column.

Leakage detection in each of the following underground oil pipelines were located successfully using ^{99}Mo radiotracer technique by BRIT during the report period: 12" diameter Mumbai-Pune Pipeline of Hindustan Petroleum Corporation Limited (HPCL); 10" diameter Jawaharlal Nehru Port Trust (JNPT) to



Refinery at Bathinda, Punjab

Vashi Pipeline of Indian Oil Corporation Ltd. (IOCL); 14" diameter black oil pipeline of HPCL from Mumbai refinery to Vashi terminus; 20" diameter black oil pipeline of HPCL from Mumbai refinery to Pirpav Jetty; 14" diameter black oil and white oil pipelines of Indian Oil tanking Ltd. The results helped the respective oil companies to repair the leak and restore the pumping operations on immediate basis.



Pipeline carrying aviation tourbo fuel



Leaky heat exchanger

A pipeline carrying aviation tourbo fuel from Mumbai refinery of HPCL to Santacruz airport was suspected to have dent/blockage. A cylindrical pig tagged with radioisotope was passed through 22 Km pipeline to identify the location of blockage.



Shield integrity confirmation for APSARA nuclear reactor, BHAVINI nuclear reactor and for Areva, USA, a project by L&T Ltd.

A leaky heat exchanger was identified in a series of heat exchangers using radiotracer technique in IOCL refinery at Digboi, Bharat Oman Refinery Ltd. Bina, Madhya Pradesh.

During the report period, the Radiation Physics Group of IAS Division, BRIT was involved in the services of Source loading pattern designed for six Gamma Irradiators (Category IV) for source replenishment; Dosimetry and Radiation Protection survey of Portable Research Irradiator (Category I); Feasibility assessment of utilizing canisters filled with vitrified nuclear waste for sewage treatment; Radiometry of Shielding casks for Nuclear Recycle Board M/s. MRR Engineers, Vasai and Radiological safety of radiation Processing Plant and Decayed Source Removal Facility at BRIT, Vashi.

CHAPTER-5

BASIC RESEARCH



The status of MACE mechanical structure at Hanle



200m long 30kA hybrid superconducting CICC in 2m dia coil form on a Bobbin

The Department of Atomic Energy has contributed significantly towards strengthening of basic research in India. The Department pursues basic research in its R&D centres that ranges from Mathematics to Computers, Physics to Astronomy and Biology to Cancer. It also provides grants-in-aid to nine institutes of national eminence. Following were the major activities and achievements of DAE in basic research, during the period of report.

MATHEMATICS & COMPUTATIONAL SCIENCES

At the Bhabha Atomic Research Centre (BARC), extra-ordinary fast fluid transport through Carbon Nanotubes (CNT) of specific diameter has been established using two phase thermodynamic (2PT) method. Results show the energetically favourable conditions for spontaneous filling of CNT (6,6) with both the polar like water and non-polar fluids like methane subjugated by the increased translational and rotational entropies were found to be sufficiently high to conquer the unfavourable increase in enthalpy (ΔE) during CNT confinement. This offers a methodology, orders of magnitude more efficient than commonly used thermodynamic calculations.

At SINP, a challenging integrable defect problem is solved with an innovative application of space-time duality, hidden in integrable systems. Oceanic rogue waves are modelled satisfactorily through exact dynamical lump soliton of a novel nonlinear equation, controlled by ocean currents. Arbitrary bending of optical solitonic beam is achieved, regulated by boundary resonant medium, within the framework of integrable models. A novel class of exactly solvable spin Calogero models, associated with the D_N root system has been constructed by using the polarized spin reversal operators. An exact formula for the partition functions of the related spin chains has been derived in terms of products of known partition functions of Polychronakos spin chains of type A_{N-1}. Several global properties of the D_N-type chain's spectrum such as the asymptotic level density, the distribution of consecutive spacings of the unfolded spectrum and the average degeneracy have been analysed at the large N limit. The effect of topological defects on screening and transport properties of gapless graphene have been analysed. The von Neumann entropy arising from scaling symmetry breaking has been calculated and its relation to the Cardy formula and the associated quantum information theory has been pointed out.

The School of Mathematics, TIFR continued the research activities in Mathematical Sciences. A new invariant, the Hilbert-Kunz density function was developed. A structure theorem for saturated subgroup schemes of GL(V) was proved. Essential dimensions of moduli spaces of vector bundles on curves was computed. Automorphism groups of Bott-Samelson-Demazure-Hansen varieties were computed. Fundamental Group of a GIT quotient of a smooth projective variety was shown to be isomorphic to that of the variety itself. Homogeneous holomorphic hermitian principal bundles over hermitian symmetric spaces were classified. For a given algebraic stack, the relationship between its Nori fundamental group and that of its coarse moduli space was established. Conditions were described under which the stack can be uniformized by an algebraic space. For the isomonodromic deformation of an irreducible logarithmic connection parametrized by the Teichmuller space, it was shown that the bundle on the general curve is stable. In a sequence of hyperbolic or relatively hyperbolic groups, various notions of laminations were investigated and were used to prove quasiconvexity results for infinite index subgroups of H. Equality of linear and symplectic orbits of a unimodular element in a symplectic module was established. Some explicit cases of the Bloch-Beilinson conjecture were investigated. A possible positive characteristic analogue of the Grauert-Riemenschneider theorem is being investigated, with some results obtained so far. Essential dimensions of moduli spaces of Lambda-connections are also being studied. Mixing properties of horospheres in hyperbolic 3-manifolds whose ends are degenerate, is being investigated. The notions of geometric height and graded (geometric) relative hyperbolicity were used to characterize quasiconvexity in hyperbolic groups, relative quasiconvexity in relatively hyperbolic groups, and convex co-compactness in mapping class groups and outer automorphisms of free groups.

The research activities of the Centre for Applicable Mathematics, TIFR was focused on numerical analysis of PDE's. Inversion of a class of circular and elliptical Radon transforms was pursued. An efficient numerical algorithm for the inversion of an integral transform arising in ultrasound imaging was developed. Stability estimates for inverse boundary value problems for the bi-harmonic operator with bounded potentials was obtained. A method to determine the lower order perturbation of the polyharmonic operator from partial boundary data was analyzed. Micro local analysis of restricted ray transform on rank m symmetric tensor fields was pursued. Interesting results on concentrating solutions on orbits of Hopf-fibration class for semi linear equations of Brezis-Nirenberg type were obtained. Profile decomposition for the class of BV functions was studied. Global stability of radial hedgehog solutions for nematic liquid crystals within the Landau-de-Gennes theory was studied with explicit geometric dependence criteria. A nonlinear hyperbolic system was formulated as a boundary value problem on the half line and its vanishing viscosity-capillary limit under self similarity was studied. Regularity results for nonlocal Hamilton-Jacobi-Bellman equations were obtained. The entropy framework for stochastic conservation laws with levy noise was developed. Well balanced schemes for Euler equations with gravity and entropy stable schemes were developed. Fluid flow along with heat transfer was studied numerically for a multi fluid model with variable fluid parameters. At low and higher temperatures, existence of multiple solutions for a nonlinear combustion model in two dimensions was proved.

At the School of Technology and Computer Science, TIFR research was pursued in the areas of computer as well as systems science. Research on wireless communication, information theoretic secrecy and algorithmic analysis of timed logic formulae were some important areas of focus. In a breakthrough discovery, it was shown that a simple power control policy can achieve finite delays and non-zero capacity in a large wireless network, where previously only infinite delays and zero capacity was known. New information theoretic methods for secure computation and communication in the presence of jammers were formulated. Some new impossibility results for the capacity of broadcast channels with feedback were also obtained.

The Harish Chandra Research Institute (HRI) continued the research work in Mathematics and the research in Harmonic analysis involved the study of Schrodinger equation on Modulation spaces, Hardy Sobolev inequality for the twisted Laplacian, Maximal operators along hyper surfaces and Fourier integral operators. The results on modulation spaces, showed that the only nonlinearity that can act (by composition) on a large family of Modulation spaces of interest is real analytic. Optimal Hardy-Sobolev inequality has been proved for the twisted Laplacian. Since the twisted Laplacian corresponds to the magnetic Laplacian for a constant magnetic field, the Hardy-Sobolev inequality proved generalizes the classical Hardy Sobolev inequality to the magnetic Laplacian. The work on Maximal operators along hyper surfaces concerns mapping properties in Lebesgue spaces. For a large class of hyper surfaces, boundedness was proved. The study on Fourier integral operators involved delicate oscillatory integral techniques and it is still in progress.

In Algebra & Geometry, all finite groups whose non-linear irreducible characters of the same degree are Galois conjugates have been classified. Work on generalisations of the Atiyah-Weil theorem on holomorphic connections and of the Krull-Remak-Schmidt theorem of Atiyah were continued. Work was done on minimal surfaces interpolating between real analytic curves and on surfaces which are in some sense algebraic. Work was also done on geometric quantization of finite Toda system and on Ramanujan's identities, minimal surfaces and solitons. A project of studying generalized Seiberg-Witten equations reduced to dimension two and also a project of exploring ways of viewing many equations coming from physics as integrable systems for instance the vortex equations, Feuter equations etc. has been seriously taken up.

In Number Theory, a series of study on the well-known conjecture, namely, Four Exponential Conjecture has been taken up. New results have been obtained in the area of zero-sum problems with weights. Work is in progress on some questions of monochromatic solutions of certain equations. A

study on the cardinalities of the sets of quotients and products of a large set of integers A in various contexts. A version of the well-known Perron's formula, suitable for study of short interval questions, is obtained. Study on the convolution sums of the divisor functions and their applications has been carried out. The Kohnen plus space has been extended for certain even levels and the theory of newforms has been studied. Generalization of a conjecture of D. Zagier regarding the asymptotic behavior of the inverse Mellin transform of the symmetric square L-function associated to Ramanujan tau function for general cusp forms have been completed. Work is in progress to get better estimates as these estimates give information of the associated `heat kernel'. Gauss's quadratic reciprocity law and Riemnan's non-differentiable function has attracted attention of many researchers. A combined proof of both these facts by using an integrated form of the theta function was given. Study of the complex power of the Dirichlet series associated to the Hecke eigen forms was done.

The Institute of Mathematical Sciences (IMSc) continued to contribute significantly and extensively to the DAE mandate for supporting basic sciences. It remained involved in joint projects with national and international institutes for many projects on Algorithms and complexity of Algebraic problems, Arithmetic vs Boolean complexity, Developing tools for dynamical modelling of C. Elegans neuronal network activity, Parameterized complexity of local search, Provably Efficient pre-processing algorithms, Mechanisms of active intracellular transport: Connecting Experiment and Theory, Provably efficient exact algorithms for NP-hard problems, Electron Transport along Monoatornic Electrochemical wire and chains, Wave propagation in disordered excitable media and simulated cardiac tissue, Particle physics phenomenology of the standard model & beyond and Quantum gravity & string theory. For the Faculty Associateship Programme, Refresher Courses for college teachers and Science Popularisation programmes the Institute members interacted extensively with their colleagues in the Universities.

During the year, IMSc conducted various conferences and workshops on various topics such as New Scientific approaches in understanding Indus Valley Phenomenon, Summer School in Mathematics, Facets 2015: Outreach workshop on Aspects of Mathematics, Teacher's Enrichment Workshop for Mathematics Teachers at engineering colleges, ATMW Analytic Number Theory, One Percent: Mathematics program for school students, Nag Lecture: Public Lecture, Workshop & Conference on Modelling Infectious Diseases, Workshop on Number Theory and Conference in number theory.

The School of Mathematical Sciences, NISER strives to become a citadel for mathematics and allied subjects in terms of teaching and research. The undergraduate program in the school was carefully designed to train the students to acquire creative mind and analytical skills that are needed to pursue their career. In addition to formal courses and research, seminars were conducted regularly. Outstanding mathematicians from throughout the world presented their latest research findings in various fields of mathematics in the seminars. Major facilities that were provided included State-of-the-art Computing facility and a High Performance Computing Cluster for theoretical calculation. The School introduced strong curriculum in the fields of applied mathematics, financial mathematics and computer science for students can to take up prominent careers in financial/industrial establishments.

PHYSICS

At BARC, Neutron induced cross-sections for fusion technology application were determined for the first time for ^{55}Fe radio-nuclei by surrogate ratio method demonstrating the usefulness of surrogate method to update the nuclear data library and measure cross-sections for unstable targets for fusion technology.

Cubic boron nitride backing plates have been introduced in the indigenously designed Mao bell type of Diamond Anvil Cell (DAC). Experiments upto 1 Mbar carried out with this modification ensured obtaining full diffraction rings on the imaging plate detector. High pressure study on yttrium chromite showed that it did not undergo any phase transition even upto 1 Mbar.

High pressure reactivity of the alkali halide KBr with bromine was explored by laser heating the DAC at a pressure of 14 GPa. High temperature Raman and Angle Dispersive X-ray Diffraction (ADXRD) measurements of the post heated samples indicate the formation of a cubic Pm3-n phase similar to the $NaCl_3$ phase observed recently.

A new methodology comprising finite strain theory, Hugoniot jump conditions, Second Order Elastic Constants (SOECs) and their pressure derivatives was developed and used to estimate Third Order Elastic Constants (TOECs) of diamond. Density functional theory was used to compute SOECs and their pressure derivatives. Required shock wave Hugoniots were estimated along <100>, <110> and <111> directions by classical molecular dynamics simulations. This method obtained better agreement with experimental results for calculated TOECs.

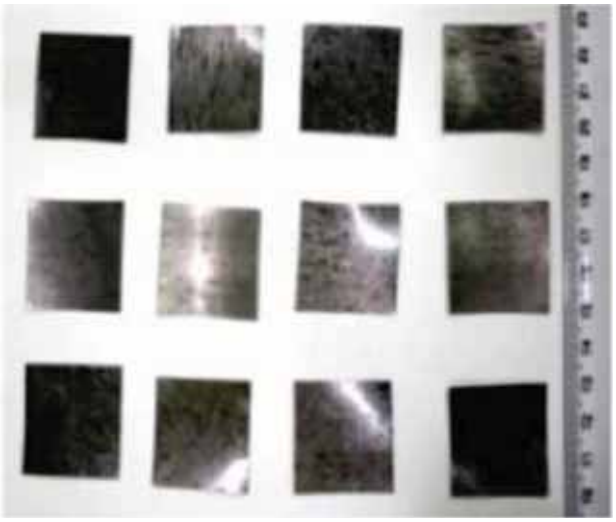
Dye-sensitized Quantum Dots (QDs) are promising candidates for Dye Sensitized Solar Cells (DSSCs). Experiments and first principles calculations have shown that the absorption peak due to dye molecule is not affected by the size of the QD but absorption peak due to the QD blue shifts with decrease in QD size. Charge transfer using Natural Transition Orbitals (NTOs) is found to occur from dye-to-QDs and is solvent-dependent. In the emission spectra, luminescence intensity of the dye is quenched by the addition of the QD indicating a strong interaction between the QD and the dye.

Hetero-junction colloidal QD sensitized solar cells using CdSSe alloy QDs were fabricated to demonstrate 4.5% power conversion efficiency which is the highest reported value for CdSSe alloy QDs.

Spectroscopic studies were performed on radiation damage in borosilicate glass used for vitrification of Trombay HLLW with 1-2 MeV ^{129}Xe beam. Beam quality for specific ions was measured by recording their transverse emittance in situ. To assess the long term radiation stability, borosilicate and iron phosphate glasses were irradiated by 2 MeV $^{129}Xe+20$ ions, simulating the radiation damage due to recoil of alpha emitting heavy nuclei. Experiments pertaining to projectile x-rays spectroscopy for a range of projectile energies and targets were also carried out.

The Small Angle Neutron Scattering (SANS) facility at Dhruva reactor was upgraded by the installation of multidisc neutron velocity selector. The data of velocity selector as compared to BeO filter used earlier provide better Q resolution, lower Q values and overall wide Q range. A large number of user groups make use of this facility.

Th metal foils having 100 μm thickness were produced at BARC for Th (Argon gas filled) Hollow Cathode Discharge Lamps installed on precision astronomical echelle spectrographs as prime calibrators. To convert the material into thin foils, it was refined to 99.2% purity level using electron beam melting technique. Later, the material was cold rolled to produce foils of required thickness.



Thorium Metal Foils



Collimator & Moderator Housing for Neutron Radiography

A Collimator housing assembly and its supporting platform for Neutron radiography facility was designed, manufactured and installed at VSSC, Trivandraum under a MoU between BARC and VSSC.

The TeV Atmospheric Cerenkov Telescope with Imaging Camera (TACTIC) at Mt. Abu, Rajasthan is used to study mainly extragalactic Very High Energy (VHE) gamma-ray sources having low red shift, flaring history and hard gamma-ray emission spectra. During the year, six potential sources viz. Crab nebula, Mrk421, PG1553+113, IC310, 1ES2344 + 514 and 1ES1440+122 were observed for nearly 400 hours using the telescope. Preliminary data analysis of the recorded data on the above mentioned sources revealed that the Mrk421 which is an active galactic nucleus was found to be at a high gamma-ray emission state at TeV energies. All other objects except the standard candle source Crab nebula were observed to be at flux levels below the TACTIC sensitivity level. The high state of the Mrk421 was found to be at about 60% of the Crab nebula gamma-ray flux and the total number of photons above 850 GeV detected during 70 hours of TACTIC observation is 636 ±75 with 8.43 statistical significance. An averaged differential energy spectrum of the detected photons has also been measured which fits well with a simple power law with a photon spectral index value of 2.62 ± 0.20 between energies 850 GeV and 18 TeV. This measured spectrum is consistent with the expected source spectrum on the basis of its earlier observations made by various world class gamma-ray telescopes operating all over the globe.

The setting up of a world class low energy threshold gamma-ray telescope viz. Major Atmospheric Cerenkov Experiment Telescope (MACE) at Hanle in Ladakh region of India is in progress. It is designed to use 21m diameter tessellated parabolic light collector with 1088 pixels camera at its focal plane. More than 150 MT of mechanical subsystems have been transported to its site at Hanle. Mirror facets for the telescope basket have already been manufactured for the first time in India.

Bulk production of high-speed signal processing cards required for the camera integrated



The status of MACE mechanical structure at Hanle

modules for the telescope has been completed. Monte Carlo simulation studies of the telescope carried out indicate that it will be possible to achieve an energy threshold of about 40 GeV and its sensitivity is expected to be about 2% of the Crab nebula flux for nearly vertical showers at the Hanle site.

At TIFR under Theoretical Physics, complete evolution of strongly interacting matter formed in ultra-relativistic heavy-ion collisions was studied. A new observable, called zeal, was proposed, to analyze events with jets in heavy ion collisions. A first principle calculation was presented for the first time to study the spectroscopy of doubly charmed baryons. An up to date electroweak fits of various Randall Sundrum models was presented. Various aspects of Minimal Supersymmetric Standard Model (MSSM) as well as next to minimal MSSM were studied with LHC data. Muon g-2 problem in the paradigm of R-parity violating MSSM was studied. Lepton flavour violation in supersymmetry at the LHC was also investigated. It was shown that Sunyaev-Zeldovich distortions of the cosmic microwave radiation due to circumgalactic gas, and its cross-correlation with x-ray data, can be used to determine the gas fraction even when there is redshift evolution of this gas fraction.

A new method was proposed to study clumps in giant molecular clouds using observations of reflected x-rays. It was shown that eV-mass sterile neutrinos may remain compatible with bounds from structure formation, if their free-streaming length is

shortened by interactions. Temporal fluctuations in a supernova were shown to lead to a new instability in the flavor composition of neutrinos emitted by the supernova. Cosmo-particle physics, particularly, in the context of inflationary magnetic field was also studied. Melting of three sub-lattice order in a frustrated triangular easy axis anti-ferromagnet was analyzed and the existence of a new multi critical point was uncovered. Electric field driven Transition from a Mott insulator to metal was analyzed. Abelian sandpile model on a square lattice for K > 2 downward neighbors per site was studied and K = 3 case was solved. Cold atom implementation of biased bilayer honeycomb lattice with Bernal stacking was proposed and an instability of repulsive fermions in this lattice towards incommensurate spin density wave states was found. The effect of quenched disorder on the zero-range process with random capacities was also investigated.

In the field of Strings, it was demonstrated that the dynamics of black holes in a large number of dimensions may be reformulated as the dynamics of a codimension 1 membrane propagating in flat space. An exact formula for S matrices in large N super symmetric matter Chern Simons theories was determined. The constraints imposed by symmetries on correlation functions of perturbations produced during the epoch of inflation in the early universe was determined. A precise definition for entanglement entropy of a gauge theory on a lattice was given and its properties were explored. Results were derived on entanglement and thermalization in a large variety of two dimensional quantum quenches, and these were related to thermalization in black holes. A holographic dual to chiral symmetry breaking and decompactification in QCD was developed.

In Astronomy & Astrophysics, India's first Astronomy satellite ASTROSAT was launched and put into orbit. Charge Particle Monitor (CPM) was the first payload to be operational followed by the Cadmium Zinc Telluride Imager (CZTI), the hard X-ray detector. The Soft X-ray imaging Telescope (SXT) onboard ASTROSAT saw its first light. All functions were normal and performance continued as per specifications. SXT is currently undergoing calibration using cosmic X-ray sources. The analysis software is also being upgraded. The Large Area X-ray Proportional Counter (LAXPC) instrument onboard ASTROSAT became fully operational. First light observations were carried out and all functions were found to be normal and its performance continued as per specifications. In the next few months all instruments will be ready to make observations of interesting objects in the universe. Also, development of mirrors for a hard X-ray imaging telescope is underway. Laboratory model of Infrared Spectroscopic Imaging Survey (IRSIS) payload for an Indian Satellite is being assembled and tested. The Preliminary Design Review and the Critical Design Review of TIFR-ARIES Near Infrared Spectrograph (TANSPEC; 0.6 - 2.5 microns) was successfully completed and TANSPEC is now under fabrication. Study of a wide variety of problems related to solar physics, seismology, high energy astrophysics, black holes and other compact objects such as neutron stars, interstellar medium, star formation, Astrochemistry, tests of general relativity, origin of ultra-high energy cosmic rays, gravitational lensing, dark energy as well as the supernovae and gamma-ray bursts were conducted.



Astrosat before integration with PSLV

At the National Centre for Radio Astrophysics at TIFR, a giant radio galaxy at a redshift of z 1.3 was discovered by GMRT whose radio spectra along with X-ray observations show it to be a rare example of a Giant Radio Galaxy caught in a dying phase in the distant universe. GMRT & ATCA observations of the host galaxy of the Gamma Ray Burst (GRB) 980425 resulted in the first detection of HI 21-cm emission from a GRB host, which indicate that the host galaxy has recently undergone a minor merger, and identify the location of the GRB as

coincident with the region of highest gas column density. The GMRT continued routine operations smoothly, work on the GMRT upgrade achieved several important milestones. There was good progress on completion of the front-end systems for 250-500 MHz band and the 550-900 MHz system. Wideband OF systems for all the 30 antennas was completed. 16 antenna, 400 MHz back-end system for interferometry and pulsar observations was released. Next generation monitor and control system was developed. A new PC104 based servo controller for all 30 antennas and further installations of the brushless motor drives for the servo control of the antennas, was completed. Phase-II of the upgraded GMRT (uGMRT) was released to members of NCRA for internal exploratory proposals that test the system and also allow some early science explorations to be carried out. Phase-II will be released for external users from April 2016 onwards, on a shared risk basis.

The research in Condensed Matter Physics in TIFR lead to the successful installation of a new optical floating zone furnace. Single crystals of Kondo lattice compounds CeTAl4Si2 (T = Rh, Ir) were grown and their anisotropic magnetic properties were studied in detail. Non-centrosymmetric superconducting BiPd single crystals were grown by Bridgman method. Preliminary evidence for mixed parity superconducting gaps was observed. Single crystals of Gd_2TiO_7, Ho_2TiO_7 were successfully grown. A single Crystal of honey comb lattice $Ba_2Ni(PO4)_2$ was grown and its anisotropic physical properties are currently being studied. Synthesis of single crystals of rhenium based dichalcogenides ReS2 & ReSe2 and study of their structural and optical properties were conducted. Quasiperiodic airhole patterns in achieving broadband plasmonic and photonic response, and sharp changes in plasmon mediated giant Goos-Hanchen shift was demonstrated. The origin of broadband response of quasiperiodic structures is part of ongoing work. A new multi-mode qubit was invented. 10 fold improvement in a parametric amplifier bandwidth and 50 fold enhancement in coherence time of superconducting qubits was achieved.

In High Energy Physics at TIFR, a source for quantum entangled photons was made operational. The result of the Galilean nature of the propagation of light was validated with an experimental comparison in the same configuration, employing sound. Cosmic gravitational effect in spin transport through helical molecules was confirmed. Experimental results on quantum coherence and their analysis without the use of the vacuum modes are expected soon. Observations of pulsars, supernova remnants, binary sources and Blazars were made with HAGAR. G-APDs were characterized. The prototype amplifier for a G-APD based camera was tested and the design was finalized. Calibration box for CTA-LST prototype was assembled and tested. A 16 channel prototype for the G-APD camera will be tested soon. The GRID project for CMS computing continued to run successfully and will now continue under the aegis Worldwide LHC Computing Grid (WLCG). CMS T2-Grid Computing centre at TIFR recorded about 95% average reliability and availability. With a computing power equivalent to 7.8k HS2006 and storage of about 1 Petabyte, approximately 3 billion physics events have been processed.

In Nuclear & Atomic Physics, development of an experimental set up with Compton suppressed clovers, $LaBr_3(Ce)$ detectors and CsI(Tl) detectors for the study of such long lived isomers in ^{110}Ag, ^{121}Sn and ^{180}Ta isotopes is underway at TIFR. A new velocity slice imaging set up for dissociative electron signal from molecular chlorine (Cl_2) using velocity slice imaging was commissioned. A new femtosecond laser system was installed. The installation of new supersonic molecular beam based velocity slice imaging set up is expected soon. Low lying states in ^{108}Ag isotope around a very long lived isomer with a half-life of 413 yrs was investigated using discrete gamma spectroscopy. Such isomers have the potential to provide material with high energy storage capacity and may play an important role in nucleosynthesis. The role of different negative ion states to dissociative electron attachment, was probed. Negative ion momentum imaging experiments and absolute cross section measurement for dissociative electron attachment was conducted. In accelerator based atomic and molecular collision studies, collective Plasmon excitation was shown for a PAH molecule coronene (C24H12) which may provide new inputs towards the UV photon absorption in interstellar medium, or in the

search for materials suitable for UV plasmonics. Collisional study with water and bio-molecules provided useful input for heavy ion induced radiation damage of biological matter. Sequential and concerted fragmentation dynamics were identified and measured in highly ionized CO_2 and N_2O molecules using a newly developed RIM spectrometer.

The main thrust of the research activities in Condensed Matter Physics at SINP deals with observation of colossal piezoresistance effect in $Sm_{0.55}$ $(Sr_{0.5}Ca_{0.5})_{0.45}MnO_3$ single crystal. A new mechanism has been presented whereby doping a correlated band insulator leads to a half-metallic ferrimagnet. This study can open up new opportunities in the area of spintronics. Enhanced dielectric response has been observed for the $Gd_2Ti_2O_7$-SiO_2 nano-composite with smaller $Gd_2Ti_2O_7$ particles. Giant enhancement of Magneto Resistance (MR) by the formation of $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) $Pr_{0.67}Ca_{0.33}MnO_3$ (PCMO) core-shell nanostructure has been achieved.

Research activities in Surface Physics were continued at SINP. Synthesis of the condensed and soft materials in the form of ultra-thin layer and nanometer sized particles with different morphology are implemented by sophisticated growth techniques, like, Molecular Beam Epitaxy (MBE), Metal Oxide Vapour Phase Epitaxy (MOVPE), cluster ion deposition, sputtering, ion implantation, Langmuir-Blodgett (LB) techniques along with other conventional growth techniques, like, spin coating and wet chemical methods. The state-of-the-art characterization techniques were utilized for structural, compositional, optical, tribological and surface/interface analysis in routine manner.

Using in-house CL-SEM facility, SINP has investigated different LSP modes of varieties of gold (Au) nanoparticles with a high degree of spectral and spatial resolution (in the range of about 10-25 nm) which is of fundamental importance for applications in biosensing, single molecule detection and photovoltaics.

The evolution of electronic structures of 20 nm thick rubrene films exposed to ambient environment with time has been studied by UV and X-ray Photoemission Spectroscopy (UPS and XPS), Near Edge X-ray Absorption Fine Structure (NEXAFS) spectroscopy, and Density Functional Theory (DFT). A new theoretical approach for Photo Acoustic (PA) image simulation of an ensemble of cells with endocytosed gold nanoparticles is reported. The influence of poor solvent and thermal annealing, and their specific roles in the crystalline ordering of poly (3-dodecylthiophene) [P3DDT] films which are of immense importance in their performance as semiconducting materials were investigated using complementary techniques. Synthesis of both pristine Fe_3O_4 and the Fe_3O_4@SiO_2 core@shell structure was reported. Photoluminescence and photoconductivity properties of both pristine and SiO_2 coated Fe_3O_4 particles were studied for the first time. Lipophilic attraction between hydrocarbon chains is the driving force at all stages of long term monolayer dynamics was proved through studies. Detailed investigation of the low-frequency dielectric and conductivity properties of conducting polymer nanowires are done. Results, obtained show that these polypyrrole nanowires behave like conventional Charge Density Wave (CDW) materials, in their nonlinear and dynamic response, together with scaling of relaxation time and conductivity. The growth, morphology, and magnetic structure of ultrathin Cr films grown on a Ag(001) substrate are studied using Low Energy Electron Diffraction (LEED), Angle Resolved Photoemission Spectroscopy (ARPES), and ab initio Density Functional Theory (DFT) calculations.

Research activities in Nuclear Physics included experimental study of low & intermediate energy nuclear structures and nuclear reaction mechanisms using different accelerator centres in India and a few abroad. In addition members of the division are actively involved in the setting up of the FRENA facility for nuclear astrophysics research. The work on the simultaneous R-matrix analysis of $^{13}C(p,\gamma)^{14}N^*$ capture reaction and the low energy $^{13}C(p,p)$ elastic scattering data to constrain the gamma as well as particle widths has been completed using the multi-level, multi-channel R-matrix code AZURE II. The analysis of the experimental measurement of fusion excitation function and quasi-elastic barrier distribution function

of $^{7}Li+^{64}Ni$ has recently been completed. Study of the astrophysically important $^{12}C(\gamma)$ reaction have been carried out using the indirect method.

Research in applied nuclear physics involves probing the atomic, nuclear, molecular and nanocrystalline systems using nuclear probes, lasers, X-rays, electron and ion beams. Several new classes of materials have been studied using positron annihilation spectroscopic tools. Inulins, the nano-meter size semi-crystalline particles, composed of oligomeric fructose units, have been subjected to fine micro-structural analysis under temperature variations using mainly positron annihilation spectroscopy for the first time. A four detector TDPAC spectrometer, with $LaBr_3$ (Ce) and BaF2 scintillation detectors, has been installed where the excellent γ-ray energy resolution of $LaBr_3$ (Ce) detector is employed for detecting the 133 keV γ-ray energy of ^{181}Ta (emitted from the ^{181}Hf PAC probe). Experimental and numerical investigations on Micro Pattern Gas Detectors (MPGD) have been continued. Exploration of the possibility of finding out an environmentally friendly gas mixture has been initiated and effects of detector ageing, especially due to SF6, are under study. Inner shell ionization in heavy elements, such as Thorium and Uranium, by electron impact at energies 15 to 40 keV was investigated using energy dispersive spectrometer at the electron spectroscopy laboratory. The energy dependent inner shell ionization cross-sections, specifically that of the L-shells and sub-shells were evaluated and attempts were made to explain the results in the light of DWBA theory and related simulation.

In Theoretical Physics and Astrophysical Sciences the scientists at SINP have dealt with research in the areas of Particle Physics Phenomenology, Non-perturbative Studies of Quantum Field Theories, Gravity and Cosmology, Strings, QCD at Finite Temperature and Density, Nuclear Theory, Research on Dark Matter, Neutrino mass models and baryogenesis, Gravitation, Physics of Supernovae and Neutron Stars, Dark matter search with PICO-2L & bubble nucleation in superheated droplets and High Energy Gamma Ray Astronomy.

In Plasma Physics at SINP, the research activities encompassed a variety of theoretical and experimental topics in the field of linear and nonlinear wave propagation. Theoretical studies using nonlinear analysis in Lagrange variables for various types of electrostatic modes in unmagnetized and magnetized plasmas have been carried out to demonstrate wave breaking phenomena due to phase-mixing processes. Such studies have relevance to electron energization and plasma particle heating in astrophysical environments and laboratory experiments. Studies are also being pursued to understand the formation of different types of nonlinear structures in classical as well as quantum plasmas. In the field of strongly coupled dusty plasmas, effects of velocity shear have been extensively studied to show new types of instabilities in dust acoustic and shear waves. The stability of large scale vortex in a strongly coupled dusty plasma is being studied with short scale perturbations. Experimental activities are being carried out in the MaPLE (Magnetized Plasma Linear Experiment), Double Layer Experiment (DLX), glow discharge plasma and the tokamak devices.

The gamma ray spectroscopic study is one of the forefront research activities of the Centre for the investigation of nuclear structure. The light ion beams (alpha and proton) induced reactions are used to study the heavy nuclei near the line-of-stability, which are the only way to produce such nuclei. The d ecay spectroscopy of neutron rich nuclei are studied by employing light-ion induced fission reaction and subsequently radiochemical separation. The INGA (Indian National Gamma Array) setup and the in-house setector setup were used for this. The next campaign of INGA is scheduled to be setup at VECC in the coming year. Apart from INGA, several varieties of gamma



Some of the in-house clover HPGe detectors at VECC

detectors are available and are being procured at VECC such as clover HPGe, LEPS, segmented clover detector etc. For lifetime measurement of nuclear states in the range of a few ns $LaBr_3$(Ce) detectors are also used. A Total Absorption Gamma Spectroscopy (TAGS) setup using BaF2 detectors has been designed and tested for accurate beta-decay feeding measurements, which has application in the reactor decay heat calculations.

A method has been developed to calculate microscopically mass and charge distributions of spontaneous fission yields. Application of this method to other systems and a comprehensive study of fragment properties are in progress.

The study of nuclear liquid gas phase transition is an important area of research for last few decades. This work focuses on how the phase diagram is modified by finite size and Coulomb effects. It is observed that even for arbitrary small particle numbers, phase coexistence can be clearly identified by the behavior of the grand canonical particle number distribution.

The physics of hypernuclei is an important area of study in the regime of intermediate and high energy heavy ion collisions. The average number of normal and hyper fragments production from different fragmenting systems with finite strangeness is calculated in the framework of 3 component canonical thermodynamical model. The most important feature which emerges from the theoretical study of mass distribution is coexistence of liquid-like and gas-like hyper fragments in a certain temperature interval. The temperature dependence of Helmholtz's free energy, entropy, specific heat at constant volume and average size of largest cluster is being studied in fragmentation of hypernuclei.

Preliminary results were obtained for the work to investigate if bimodality emerges from a transport model calculation based on Boltzmann-Uehling-Uhlenbeck (BUU) equation. Equation of State of a completely degenerate relativistic electron gas in magnetic field based on Landau quantization of charged particles in a magnetic field is developed.

Photofission of actinides has been studied in the region of nuclear excitation energies that covers the entire Giant Dipole Resonance (GDR) region. The mass distributions of ^{238}U photofission fragments have been explored theoretically for eight different endpoint Bremsstrahlung energies from 11.5 MeV to 67.7 MeV which correspond to average photon energy of 9.09 MeV to 15.90 MeV.

The role of entanglement cannot be overemphasized in the modern day Physics, be it the quantum information theory, strongly interacting systems in condensed matter or the black-hole physics. Its quantification and measurement have been understood to a great extent. What is not very clear, is how the entangling interactions behave when they mediate the interaction between two systems. This issue has been addressed when two interacting systems are fully chaotic. It is shown that the behaviour of all entangling interactions between strongly chaotic systems are universal and put forward a theory to explain it. This work initiates the field of fluctuation transitions of complex multipartite systems. Further studies on exploring the dynamics in terms of other quantities like various entropies is in progress.

The Institute of Physics (IOP) is one of the major hubs of research in basic science in the Physics. IOP performs vibrant research 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 main accelerator facilities at IOP are a 3MV Pelletron accelerator and a low-energy implanter. These are being used for studies in low energy nuclear physics, ion beam interactions, surface modification and analysis, trace elemental analysis, materials characterization, and radiocarbon dating studies. One of the important research areas in the Institute is the field of Nanoscience and Nanotechnology in general and surface and interface studies in particular. The Institute has several advanced facilities for sample preparation and for the study of various physical and chemical properties of nanostructures and bulk condensed matter systems.

The high energy physics group of IOP remained involved in pursuing research in String theory, Cosmology and Particle physics. Some of the

topics of recent interest are gauge / gravity duality, black hole Physics, anisotropic power law inflation, different aspects of relativistic heavy ion collisions and dual superconductor model of Hadronization. Connection between phase transition in cosmology and Condensed matter system such as liquid crystal were investigated. In high energy phenomenology, the role of neutrinos in unraveling the mysteries of the universe, cross section processes of one loop which are important for the analysis of LHC data have been studied.

Research areas in Condensed Matter Physics theory spanned mesoscopic systems, statistical mechanics for non-equilibrium systems and biophysics. Some of the topics investigated were dynamic phase transition in DNA, fluctuation theorems and phase transitions in driven lattice systems.

In Nuclear Physics, the research remained focused on nuclear structure and nuclear reaction. The mechanism for the formation of super heavy elements in astrophysical objects, nucleus-nucleus reaction and study of cluster decay properties have been pursued. Recently discovered super heavy nuclei and a new mode of fission decay for neutron-rich heavy nuclei has been studied. Measurement of charged particle multiplicity and transverse energy at mid rapidity and elliptic flow in Pb-Pb and P-Pb Collisions at 2.76 and 5 TeV with ALICE detector at CERN, LHC are reported. In addition, studies on quantum information were also carried out.

Major activities in experimental physics included studies on accelerator based materials science, surface and interface physics and Nano systems. Investigations in these areas were carried out by using the state-of-the-art facilities developed at IOP. 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. Surface Physics Beam line and Microbeam Line are being tested and will be functional soon. A beam time allotment committee has been made. Proposal calls are being called now from BRNS to get the proposals funded to use IOP facility.

This year IOP is celebrating its 40th year of academic activities by organizing various academic events like colloquium fest, conferences and workshops in the campus. As a part of this celebration, IOP has already organized 7 conference in the campus where eminent scientists from various parts of the country and also from abroad took part. Another 4 conference have been planned.

The research activities at HRI are carried out in five major areas of Physics and they are Astrophysics, High Energy Physics, String Theory, Condensed Matter Physics and Quantum Information and Computation. The Astrophysics group has been working on General Relativity, High Energy Astrophysics (with specific emphasis on black hole astrophysics), Astrophysics of Galactic Centre, Analogue Gravity Phenomena, Dark Matter problems & the Galactic Rotation Curves and application of dynamical systems methods in large scale Astrophysical fluid flow under strong gravity. The group maintained a strong visitor program through which several undergraduate and post-graduate students were trained during the year through short-term projects under the supervision of the members of the group.

The condensed matter group at HRI carries out several fundamental studies on a variety of areas such as spin transport in nanoscale systems, strongly correlated fermionic or bosonic systems, electronic structure and morphology of nanosystems, topological quantum matter, and non-equilibrium systems. Application of the Kolmogorov argument for the case of turbulence in a stratified fluid showed that the observation of Bogiano-Obukhov scaling can be ensured only for stable stratification. Interesting results such as unusual oscillations and zero-pi transitions in Josephson junctions with Weyl semi-metals and spin-polarised valley current in silicene were obtained. A new and robust way to distinguish the Majorana bound state using an Aharonov-Bohm interferometer was proposed. Electronic structure of magntic superatoms deposited on substrates and the newly discovered 2D material phosphorene were explored. Strain effect on electronic properties of phosphorene and metal-phosphorene interfaces were studied. Anomalous hall and spin Hall Effect were studied using non-perturbative T-matrix formulation. A

detailed study of topological liquids, where the non-perturbative nature of the generalized spin-orbit effect plays an important role, is being carried out. Study of correlated, quantum matter includes the coexistence of magnetism with superconductivity leading to gapless states, effect of site dilution on superconductivity, frustrated Mott insulators, and the competition between electron-electron and electron-lattice correlations. A methodology for correlated bosons is being developed and a possible physical realization of low-dimensional topological phases using Rydberg atoms is being explored.

The High Energy Physics group of HRI have been mainly working in two fields: neutrino and collider physics. Members of the neutrino physics group are actively involved in the development and physics studies of the India-based Neutrino Observatory (INO) which is planned as India's largest basic science project. HRI scientists took a leadership role in the collaboration between Indian institutes and the Fermilab (USA) by participating and making pivotal contributions in the Long Beamline Neutrino Experiments (LBNE). The collider physics group is working under the umbrella of the Regional Centre for Accelerator-based Particle Physics (RECAPP) at HRI. Their research centered on the experiments at the LHC in CERN, the biggest ever international experiment in the history of fundamental science.

Quantum information and computation is an emerging area of research that promises to qualitatively change our abilities to communicate and compute. The quantum information group at HRI has been working on multiparticle quantum correlations. For an efficient transmission of classical information from one sender to several receivers individually these correlations have been carefully studied and quantified at HRI.

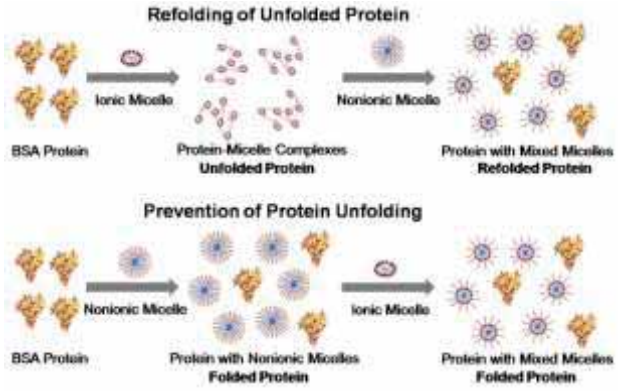
The string theory group at HRI has remained focused on several directions of research. This includes a derivation of Ward identities from one-particle irreducible string field theory, formulation of superstring field theory and formulation of a covariant action for type IIB supergravity. It was also shown that in simple cases single-centered black hole microstates carry strictly zero angular momentum. Research was also focused on interpolating functions and their relation to the Stokes phenomenon. Investigations on pure Lovelock gravity in arbitrary dimensions showed that Lifshitz and Schrodinger solutions exist on special loci in the Lovelock parameter space. Realization of the BMS algebra in three dimensions has also been obtained. Effort has been devoted to studying early universe cosmology, in particular, models of inflationary cosmology in the context of string theory. The studies have been primarily in the setting of type II B flux compactifications. Higher derivative corrections in toroidal compactifications of type II string theory have been analyzed using techniques of maximal supergravity and string amplitudes.

The School of Physical Sciences, NISER continued to carry out research in the areas of Cosmology and Galaxy formation, Black holes and String theory, Particle Physics and Quark-gluon Plasma, Hadron Spectroscopy, Statistical Mechanics and Soft matter, Quantum Optics and Non-linear dynamics, Magnetism and Superconductivity and several other areas of Condensed Matter Physics and Material Sciences. The 5-year integrated M. Sc. programme in Physics included courses from core areas of physics such as Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics and Mathematical Physics. In addition, elective courses based on upcoming areas in physical sciences are also offered for final and pre-final year students. The Ph.D. students under went one year of course work which included courses from the core areas of physics such as Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics, Particle Physics and Condensed Matter Physics. Facilities provided for Research and Teaching included Cryogenic Free Physical Property Measurement System, Low temperature Magneto Resistance Set-up, High energy physics experiments at CERN and BNL, Scanning Electron Microscope and Lithography, Ultrafast Time-resolved Spectroscopy for quantum life measurements of molecular dynamics and Ultracold atoms and BEC facility using atom trapping by lasers.

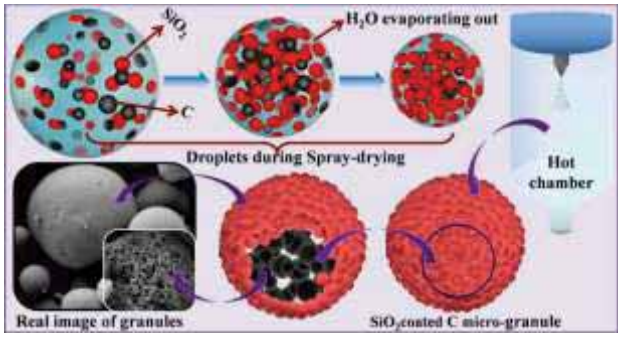
CHEMISTRY

Nano particle, protein and surfactant are the three major components of soft matter. Each one of

these is used for specific applications and many additional applications arise by adjoining these components together to obtain interesting functional objects. Binary mixtures of components such as nanoparticle-protein, nanoparticle-surfactant or protein-surfactant as well as three components nanoparticle-protein-surfactant systems were studied using Small-Angle Neutron Scattering (SANS) with contrast variation. Protein-surfactant studies showed that combination of non-ionic-ionic mixed surfactants can be used to refold the unfolded protein or prevent any unfolding in these systems. The ionic strength plays important role in nano-particle-protein systems to tune the short-/long-range attraction and hence the protein adsorption on nano-particles.



Schematic of protein re-folding and prevention of un-folding using micelles



Schematic of the formation of the nano particle assembly by thermal evaporation

Nano-structured spherical micro-granules of core-shell morphology have been realized by utilizing the contrasting interfacial interaction of hydrophobic and hydrophilic nano-particles with liquid solvent. By enforcing evaporation induced assembly, a hydrophobic nano-structured carbon core has been wrapped inside a hydrophilic envelope consisting of correlated nano-silica. The adsorption properties of nano-structured carbon core will be useful to purify drinking water, whereas, the interstitial micro-pores in silica shell can provide water transport channel.

Such micro-granules have been incorporated into a polymeric ultra-filtration membrane, which enhances the water permeability without sacrificing any separation characteristics of the membrane. The schematic shows the one step facile process of evaporation induced assembly of nano-particles via spray-drying to realize such core-shell morphology of the micro-granules.

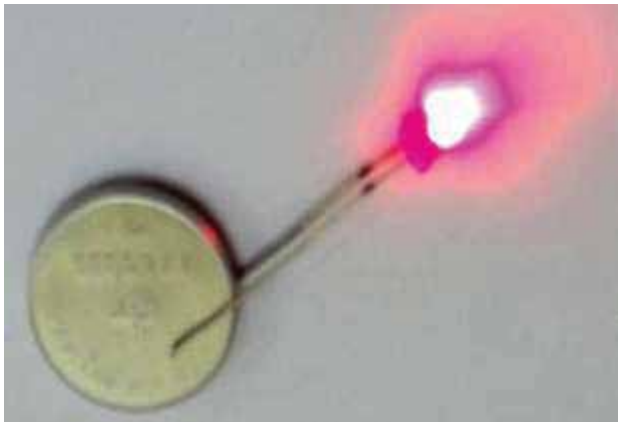
BARC has developed the material technology for the anode (nano lithium titanate) and cathode (nano lithium iron phosphate carbon composite) materials of lithium ion battery. Technology has been transferred to a private company for commercial scale production of lithium ion batteries. BARC has signed a MoU with ISRO Satellite Application Centre, Bangalore for providing characterization support to ISRO's development of multi-junction solar cells and lithium ion batteries.



Nano Lithium iron phosphate



Nano Lithium titanate



Test lithium ion battery

Extensive characterization work relating to structure, morphology, elemental composition of electrode active materials, electrolytes and gases generated in lithium ion batteries was carried out.

BARC in collaboration with CSIR-National Physical Laboratory, New Delhi has prepared the first quartz certified reference material of the country following international guidelines. The reference material is certified with respect to trace levels of Al, Ca, Fe, K, Mg, Na and Ti and is made available to users as Bharatiya Nirdeshak Dravya BND 4101.01. The reference material is useful for analytical laboratories in the public and private sectors.



Quartz certified reference material

BARC has developed a high end two-dimensional infrared (2D-IR) spectrometer for advanced studies in chemistry and biology. The spectrometer offers time resolution of a few tens of femto-second which enables understanding chemical reactions at molecular level. This spectrometer is first of its kind in India. Technology is in the advanced stages of transfer to a private company for commercial production in India.



2D IR Spectrometer

Heterodyne Detected Vibration Sum Frequency Generation (HD-VSFG) spectroscopy was developed at BARC for monitoring soft interfaces like biological membrane-water interfaces. Laser scanning confocal fluorescence lifetime imaging and single molecule spectroscopy was developed for the first time.

BARC's National Centre for the Compositional Characterization of Materials (NCCCM), Hyderabad has been validated as a supplier by European Commission for homogeneity, stability and characterization of major element content in food and trace element content. Portable sensors based on Nano crystalline SnO_2 thin film have been developed for detection of NH_3 gas (from 5 ppm onwards) and SO_2 gas (from 2 ppm onwards) at room temperature. An electrochemical sensor was developed for evaluating the efficacy of glycolysis inhibiting anti-cancer drugs on cancer cells at sub-lethal concentrations. Bifunctional magnetic

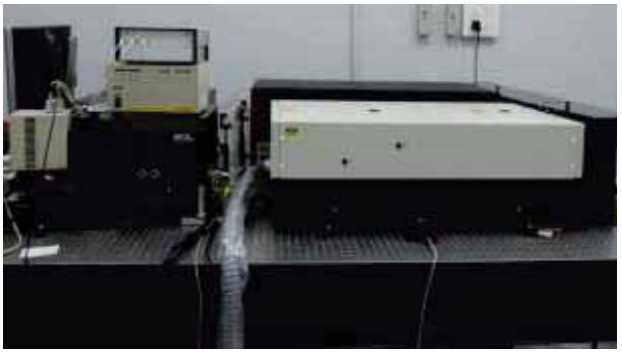
nanoparticles with specific binding groups such as folic acid were developed for targeted delivery of anticancer drugs.

Symmetric Mass Distribution (MD) has been observed in ß delayed fission of ^{180}Tl, contrary to the theoretically predicted asymmetric MD in this mass region at low and medium excitation energies. Mass distributions have been measured in ^{35}Cl+^{144,154}Sm systems at near barrier energies by measuring the Time of Flight (TOF) of the two fragments in coincidence. The MDs for both the systems appeared to be symmetric at all the energies studied. This suggests that the potential energy surface of the present fissioning systems could not be described purely by liquid drop model and may be modified by single particle effects.

A C-pivot tripodal diglycolamide (T-DGA) when compared with a N-pivot tripodal diglycolamide (DGA-TREN) showed unique reversal in the extraction of actinides in ionic liquid (C_4mimNTf_2) vis-à-vis that in molecular diluent mixture of dodecane + iso-decanol. This has great relevance in the separation of actinides by simply changing the diluent of the solvent system. X-ray Absorption Fine Structure (XAFS) studies involving Eu^{3+} complexes of the ligands carried out were in conformity with the density function theory calculations indicating 1:2 complexes for DGA-TREN with one DGA arm binding. Extraction and coordination studies of a new ligand containing hard and soft donor atoms with uranyl nitrate show that the ligand bonds through the hard oxygen atoms to uranyl nitrate group leaving the soft thio-ether group uncoordinated.

Electro Spray Ionisation Mass Spectrometry (ESI-MS) studies were carried out for understanding the interaction of Pd with Thiourea (TU), Benzoyl Thiourea (BTU) and N,N, Diethyl Benzoyl Thiourea (DEBT). Studies have shown that ML2 type of species are found to be more stable when compared to the other species. The strength of the complexation was found to be in the order Pd-DEBT2> Pd-BTU2 > Pd-TU2.

Time Resolved Laser Induced Fluorescence Spectrometer (TRLFS) for studying speciation of lanthanides and actinides with different complexing agents, sorbents and host matrices has been

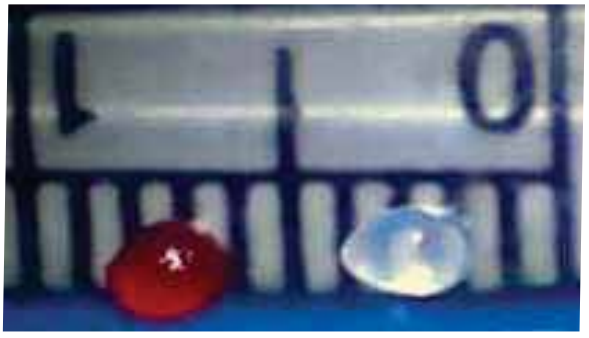


TRLFS system

installed and commissioned. Nd –YAG pumped dye laser in TRLFS system enables to study metal speciation at sub-micromolar concentrations.

Several green asymmetric allylation protocols in a tailored room temperature ionic liquid have been formulated using Bi-metal and different chiral templates and used for enantioselective syntheses of the advanced synthons of the anti-cancer compounds dictyostatin and cryptophycin. Chemoenzymatic asymmetric syntheses of cytotoxic macrodiolides viz. clonostachydiol and acremodiol were accomplished using diversity oriented synthetic (DOS) protocols. A BODIPY-1,3-diketone composite was developed as a fluorescent sensor for various environmental toxicants such as Cu^{2+}, CN- and S^{2-} ions at sub-micromolar levels. Its efficacy in detecting the designated ions in human cell lines was ascertained.

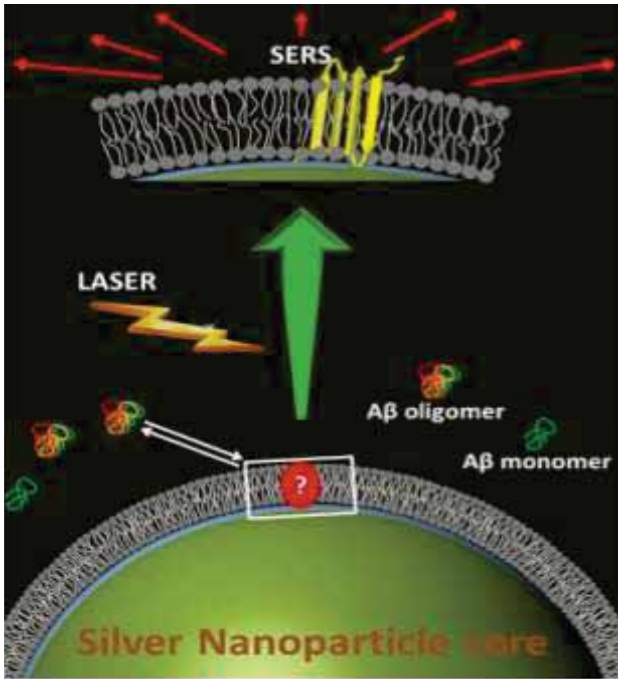
A new type of biocompatible and task-specific hydrogel beads was synthesized by N-succinoylation of chitosan, followed by Ca^{2+}-alginate treatment and γ-ray-mediated grafting of an indigenously designed D-glucose based bisacrylamide cross-linker. The polymeric beads had



Optical microscopic image of DOX-loaded and native pH-sensitive hydrogels

excellent mechanical stability and swelling characteristics, and were found to be useful in controlled and sustained delivery of the anticancer drug, Doxorubicin (DOX) as well as bio-recognition of lectins.

At TIFR, a technique was developed to determine the conformation of membrane proteins in physiological conditions using Surface Enhanced Raman Spectroscopy. This was used to determine the conformation of the toxic amyloid beta oligomers thought to be the origin of Alzheimer's disease. The conformation of another membrane binding protein, Amylin, which causes Type II diabetes is being determined. The study of the dynamics of spin-dependent quenching of a singlet state (Pyrene) by a stable free radical (TEMPO) at a fixed distance was initiated and two linked molecules of this kind were synthesized. Photoelectron spectroscopy of hydrogen bonded complexes involving NH---N interactions was initiated.



Structure of the toxic Alzheimer's amyloid beta molecules revealed using fat coated silver nanoparticles

A possible connection between Alzheimer's disease and chemical neurotransmission defects was discovered using advanced multiphoton microscopy. Currently, calcium levels are being measured in neuronal cells with multiphoton microscopy. The effect of protein aggregates on Calcium levels is being determined. Efficient pulse schemes were developed to improve spectral resolution in solid-state nuclear magnetic resonance. Data on exciton dynamics and corresponding electron-phonon coupling in low bandgap conjugated polymers were obtained from the TIFR-developed femtosecond stimulated Raman spectrometer. Ratiometric fluorescent sensors for inositol phospholipids which mediate cell signaling processes, was developed. The active site of thermostable cytochrome P450 enzyme was modified to metabolize cholesterol. Mono-nuclear copper protein analogues for electron transfer function are currently being generated. Significant contributions were made in nuclear magnetic resonance methods development and applications in the areas of biophysics, metabonomics, solid-state materials, hardware and software, and in-cell studies.

Research in the chemical sciences at SINP is aimed at developing nanotechnology and novel advanced materials for a myriad of applications in sustainable nano-architecture addressing both their development and applications. Different architecture of nanomaterials have been developed which include tunable gold nano-flowers, silver nano-wires, selenium nano-spheres etc and successfully used in effective drug delivery and bioanalytical detection. The nuclear chemistry group along with the international collaboration working at GSI, Germany independently confirmed new element 117 and discovered new isotope ^{266}Lr. Dose distribution profile for photon and charged particle therapy have been studied in the framework of particle interaction and transport code FLUKA.

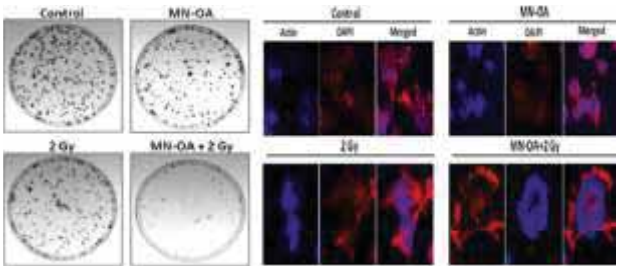
The aim of the School of Chemical Sciences at NISER continued to impart high quality undergraduate and postgraduate level of knowledge to students coupled with cutting edge research activity by the faculty and the students of the school. In addition to traditional Organic, Inorganic, Physical and Theoretical Chemistry areas, the school embarked on teaching and research activity in the interface areas. The various facilities provided for Research and Teaching included 700 MHz NMR, Thermo Gravimetric Analysis, Differential Scanning Calorimetry, GC Mass and ESI Mass Spectrometers,

State-of-the-art NMR Spectrometer for 1D and 2D Experiments and Time-Resolved Fluorescence Spectrometers.

BIOLOGY

At BARC, two novel pathways for damaged DNA repair were discovered in the radio-resistant bacteria Deinococcus and Anabaena. Activation of LexA to LexA* via a pH dependent cleavage was responsible for the DNA double strand break repair in Anabaena. Deinococcus was found to possess a eukaryotic type Ser/Thr protein kinase (RqkA) that contributes to its radioresistance through phosphorylation-mediated activation of the DNA repair protein (RecA). RqkA-mediated phosphorylation inhibited FtsZ and FtsA interaction. These effects of RqKA in DNA repair and cell division established a new type of DNA damage response mechanism involving a cell cycle checkpoint-dependent kinase in this bacterium.

The combination γ-irradiation (2 Gy) and magnetic nanoparticle-oleic acid (MN-OA) enhanced the killing of WEHI164 fibrosarcoma cells by reducing colony formation and not by apoptosis induction. The new protocol induced polyploid cells with incomplete karyokinesis as well as multiple centrosomes causing mitotic catastrophe.



Colony reduction *Mitotic catastrophe by ý-ray+MN-OA*

The potential of G1-4A, a Tinospora cordifolia-derived polysaccharide as an adjuvant of the chemotherapeutic drug, Camptothecin (CPT) was assessed in murine lymphoma model. G1-4A treatment increased tumour latency and decreased tumour volume. Macrophages and dendritic cells, isolated from the G1-4A-treated mice were able to induce higher tumour cell killing and increase the expressions of maturation markers.

An advanced and economic Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) Cascade based tool has been developed and used for genome editing and gene silencing in Mycobacterium tuberculosis (Mtb). A suite of vectors for the expression of CRISPR-Cas system in human cell lines have been constructed to target the CHK2, ATM and brca1 genes in mammalian cells. A targeted inactivation of gfp gene at P1 to P4 promoter regions by this system has been developed for gene silencing to target multiple drug resistance development in Mtb.

Given that Oxidative Stress (OS) homeostasis is key to various abiotic stresses, the status of the Antioxidant Enzymes (AOE) in a cyanobacteria and some rice cultivars was evaluated. A membrane-bound Mn-dependent Superoxide Dimutases (SOD) was found to protect cells of the cyanobacteria, Anabeana 7120 against OS under nitrogen fixing condition.

γ-H2AX assay based on the detection of radiation-induced DNA Double Strand Breaks (DSBs) in-vivo, has been established in the Biodosimetry Laboratory of BARC as a potent tool for dose estimation in case of both high and low dose gamma radiation exposures. Standard dose response curve was established and is found to be linear with a slope. Using this assay, dose estimation can be done within 2 to 3 hrs after getting blood samples with a minimum detection limit of 30 mGy.

In a breakthrough discovery at TIFR, a unique protective antigenic epitope (EWGWS) in malaria parasite enolase that is highly conserved among various species and strains of the parasite was identified. Evidence for a novel role for kinesin in the storage and use of fat in liver was demonstrated. Evidence for the regulation of actomyosin dynamics by the microtubule cytoskeleton in the regulation of cell and tissue dynamics during Drosophila morphogenesis was presented. Possible clinical trial of GDL-NLC mediated antimalarial delivery was established. Potential targets of transcription factor Lhx2, which regulates fundamental steps in the development of the cerebral cortex were identified. Regulation of histone and DNA modifying enzymes by early life stressors and fast-acting antidepressants was demonstrated. Persistent molecular, cellular and behavioral consequences of serotonergic manipulations during adolescence was

also demonstrated. An in-vitro experimental system was established to study contraction of the actomyosin based contractile ring during cell division. Temporally variable developmental and metabolic pathways that are modulated by common and rare genetic variants to increase sporulation in yeast, were identified. Using several genetic conditions as well as chemical treatments the importance of plasma membrane homeostasis in cell size maintenance and epidermal homeostasis was shown. Metabolic sensing via Sirt1 in liver/fat tissues was established. These findings have significant implications in understanding the onset and progression of diabetes/obesity. The dual roles of nuclear PARP1 in mediating apoptosis as well as DNA repair was shown to operate via nucleolar protein parylation changes. It was demonstrated that DLC1 binding to nNOS does not affect the electron transport between the FAD binding domain and heme. Fragmentation studies on heme proteins induced by electrons, ions and photons was conducted. Two genes UNC-16 and LRK-1 were shown to regulate synaptic vesicle biogenesis. Standardization of a heat shock technique to generate tetraploid zebrafish embryos, was conducted. Experiments revealed that a heat shock at 20-22 minutes post fertilization was most effective in generating true tetraploid zebrafish embryos.

At the National Centre for Biological Sciences, TIFR, a combined NMR, X-ray and biophysics facility was setup. An 800 MHz NMR spectrometer and an X-ray diffractometer has been made operational. Significant advances were made in the understanding of plasma membrane organization, control of lipid composition and signalling and the understanding of cellular mechanisms in the development of cancer. A new programme on the understanding of how pathogens such as the malarial parasite (Plasmodium) and M.tuberculosis hijack and control cellular trafficking and signalling pathways was successfully started. A new programme to understand the cellular and molecular basis of mental illness was started in collaboration with inStem (Institute of Stem Cell Biology and Regenerative Medicine, Bangalore) and NIMHANS (National Institute of Mental Health and Neurosciences, Bangalore). The ICTS-NCBS Joint Program in Biology was launched. It is expected to bring together the theoretical biology and systems biology community in India. The role of calcium signaling in the Drosophila flight circuit was elucidated.

Significant progress was made in addressing cell biological mechanisms underlying neuromuscular development and synaptic function and plasticity. Significant progress was also made in understanding ecological and evolutionary processes across multiple scales from the level of the individual to that of the ecosystem. The genetic and evolutionary basis of butterfly mimicryin the Western Ghats was decoded.

Notable studies on stress and memory showed how stronger stresses increase generalization, which may result in incorrect associations of benign stimuli with stressful events. Significant studies on olfactory coding showed that odour responses are encoded using linear coding and convolution with the stimulus. In the area of insect flight control the role of different sensors in stabilizing flight was demonstrated. Significant studies advanced the understanding of movement in zebra fish larvae. A brain simulation software package, Multiscale Object Oriented Simulation Environment was released. The development of a stimulation system for investigating brain network input-output computations in health and disease is expected soon.

Field emission Scanning Electron Microscope with correlative, cryo and elemental analysis was installed. A high resolution and high speed imaging facility equipped with a seven laser high speed TIRF microscope and high resolution microscope SIM-STORM was opened. Animal House remodelling was completed and the mouse high barrier Specific Pathogen Free (SPF) was expanded. Mouse Genetic Engineering Facility (MGEF) installed two complete mouse transgenesis microinjection setups, and a mouse embryo transfer procedure room. The High-throughput Screening Facility commissioned three Biomeks liquid handlers for chemical based screens.

Studies on the recognition of multiple stranded DNA (Quadruplex) and putative anticancer agents from plant source at SINP have shown that

agent, ellipticine binds to DNA with a 3:2 stoichiometry in terms of ellipticine: DNA. A two color Single molecule FRET imaging set up for real time monitoring of complex macromolecular systems has been developed. Modes of interactions of a cyanine dye with proteins have been investigated using spectroscopy, crystallography and theoretical docking study. Research in the area of Disease Biology continued to focus on two major disorders; haematological and neurological. Disease HbE-thalassemia along with sickle cell anaemia and leukaemia are being studied as model for haematological disorders while Alzheimers, Huntingtons, and the Prion diseases are being studied for the neurodegenerative diseases. New initiatives were taken to study epigenetic regulator proteins and nuclear lamins and their involvements in disease processes. Multifaceted approaches are used to study the structure and conformation of proteins which are involved in various regulatory processes in biology under normal and diseased conditions. The mechanism of phosphorylation and the structural elements that direct the phosphorylation to occur with high fidelity in case of fructokinase and ribokinase have been figured out with high resolution structures.

The School of Biological Sciences, NISER aims to establish itself as a leading international centre for research and teaching with harmonious synthesis of classical and modern biology - always promoting scholarship, original thinking, innovative ideas and cutting edge research. The school is on a mission to become a centre of excellence in education and research in biological sciences providing training at undergraduate, graduate, doctoral and post-doctoral level. It provides effective interdisciplinary learning ambience through extensive subject coverage in all fields of modern biology and inter-phasing with other scientific disciplines keeping pace with recent developments in the field of scientific research and undertaking high quality research activities in defined areas of biosciences so as to make an impact at national and international level. Some of the state-of-the-art facilities for Research and Teaching included X-ray Diffractometer for Protein Structure Analysis, Confocal Microscope Facility, DNA sequencing and Surface Plasmon Resonance Facility, Micro-array facilities for Genomics, Robotics and Fly Facility and Plant Growth Facility.

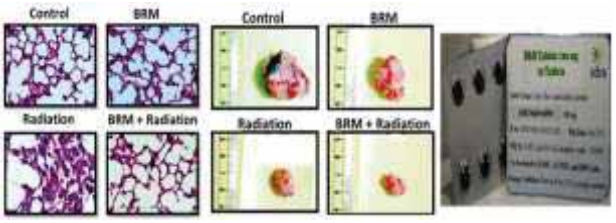
CANCER

The Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) is the research and development unit of the Tata Memorial Centre, Mumbai. ACTREC, which is located in Navi Mumbai, comprises of two sub-units the Clinical Research Centre, 111 bed Research Hospital that focus on research and treatment of cancer patients and the Cancer Research Institute that focuses on basic and applied research on cancer.

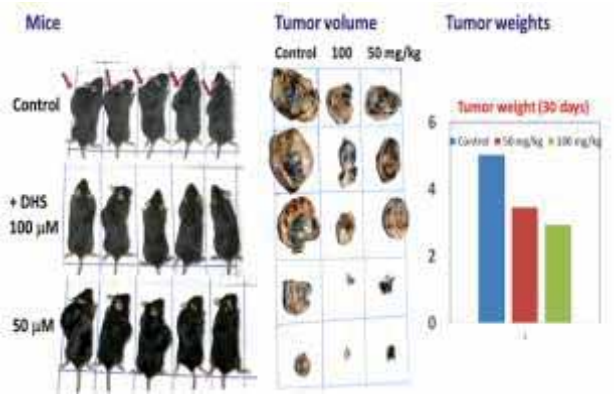
During the year, the Cancer Research Institute's (CRI) 20 Principal Investigator led laboratories remained engaged in a large number of basic and applied research projects. The research projects covered areas like - immune dysfunction in cancer patients, a new subtype of T cells that contributes to angiogenesis and is associated with poor survival, proteins that regulate cell cycle progression and impacted tumor progression and metastasis; role of glycosylation in cancer metastasis, molecular basis of inherited and somatic cancers, a large cohort of 3500 families with inherited cancer, genetic basis of tobacco related cancers, integrated somatic mutation analysis, detection altered expression of H2A variants in liver cancer, resistant glioblastoma cells, non-classical programmed cell death, structure and function of proteasomal assembly chaperones, structure and function of proteins and design of small molecule inhibitors, development of the Raman based methods: in vivo/ in situ methods for routine screening and diagnosis of cancer, minimally invasive micro spectroscopy methods, functions of keratin, vimentin and their associated proteins in epithelial homeostasis/ cancer, molecular targets in oral and cervical cancers, molecular basis of disease progression in chronic myeloid leukemia, molecular and cellular mechanisms governing stem cell regulation, complexity of drug resistance using ovarian cancer, developing strategies to gene targeted radio-iodine therapy for breast cancer treatment, minimal residual disease in solid tumours, immunomodulatory effects of vitamin D3 and progesterone in receptor negative breast cancer cell lines.

A combination of a natural dietary polyphenol and N-acetylcysteine (NAC) was found to be highly effective towards reducing lung tumor burden in mice. The adjunct property of NAC was due to its ability to glutathionylate several survival factors (p53, Nf-KB etc.) that rendered them localized in the cytoplasm and remain non-functional in the tumor cells.

A non-toxic herbal radioprotector (BRM) developed at BARC provided 80-82% survival to mice against whole body γ-irradiation (7.5 Gy) by enhancing hematopoietic stem cell abundance and reducing bone marrow aplasia. The formulation enhanced the radio-sensitivity of human breast cancer cells while radioprotecting lungs and other normal organs, as revealed from ectopic tumor-bearing SCID mice experiments. An incubation technology for an oral BRM formulation was transferred to a private firm for clinical trials as a prophylactic/therapeutic radioprotector and an adjuvant in radiotherapy.



Normal lung protection *Breast cancer radio-sensitiztion* *Oral BRM tablets*



DHS as a chemotherapeutic agent against human neuroblastoma

A rational structure-activity based approach led to the identification of a resveratrol congener (DHS) as a potential chemotherapeutic agent against human neuroblastoma, a major cause of childhood death from neoplasia. It activates the p53-regulated checkpoints and Base Excision Repair (BER) pathway to reduce the DNA replication rate via DNA polymerase inhibition. This was also validated in SCID mice neuroblestoma tumor model.

An indigenous synthesis of the precursor of ^{18}F-FLT, a tumor imaging agent has been developed. This would help in making the PET tracer at a cheaper cost for assessing tumor proliferation, its staging and identifying the treatment outcome of patients.

R&D work on thyroid cancer continued and included thyroid cancer biomarker discovery using Serum Proteomic approach, Role of Juglone and Ascorbic acid synergy in naphtoquinone induced cytotoxicity in thyroid cancer cell lines and Quercetin mediated reversal of invasion and redifferentiation in thyroid cancer cell lines.

Studies to evaluate radioprotectant mixtures for simultaneous decorporation of radioisotopes ^{85}Sr, ^{131}I, and ^{137}Cs in animal models were carried out. The mixture contained calcium iodate, calcium carbonate and calcium potassium ferrocyanide was compared with conventionally used Prussian blue, potassium iodate and calcium gluconate for the decorporation of these radioisotopes. Whole body clearance of all three radioisotopes were noted in these animals. The mixture has a better shelf life for deployment.

Efforts to produce Single Domain Antibody against human Thyroglobulin (hTg) through phage display library and its diagnostic role in thyroid cancer has made significant progress. Recombinant bacteriophage displaying single domain antibody (SdAb) against hTg was evaluated in radiometric assay using phage coated to magnetic particles. Laboratory Animal House Facility in BARC, provided support for animal experiments required for RIA-Services, R&D and QC of radiopharmaceuticals.

SYNCHROTRONS & THEIR UTILISATION

During the year at RRCAT, both the synchrotron radiation sources, Indus-1 and Indus-2, were operated round-the-clock. Indus-2 was operated at beam current up to 200 mA and 2.5 GeV energy while Indus-1 was operated at 100 mA current

and 450 MeV energy. The Indus-2 storage ring is operating with a highly stable electron beam. The user orbit in Indus-2 was optimized to a new orbit with minimized closed orbit distortion, which eliminated the need for applying orbit bumps for individual beam lines and the beam life time improved from 15 hours to 18 hours at 100 mA at 2.5 GeV. The temperatures of the dipole chambers during machine operation also came down within safe limits, thus facilitating Indus-2 operation for the users at higher stored beam currents. The improved performance of the Indus synchrotron radiation sources is reflected in a substantial increase in the number of users. The user experiments have more than doubled from 190 in 2013 to 390 in 2015. During 2015 the availability of 13 beamlines in Indus-2 for user experiments was about 4370 hours.

The two planar undulators U1 and U2, one for Atomic, Molecular and Optical Science (AMOS) beamline and another for Angle Resolved Photoelectron Spectroscopy (ARPES) beamline, installed last year in the Indus-2 storage ring, were commissioned. At 2.5 GeV beam energy, the effect of operation of undulators on the beam optics was studied by changing pole gap of the undulators from 250 mm (maximum) to 25 mm (minimum) in several steps. Both the undulators U1 and U2 were first commissioned at a low stored beam current of 4 mA. After successful commissioning, the current was upgraded in steps to a current more than 100 mA. The interlock limits based on beam position were determined experimentally by defining an allowable close orbit movement detected at the insertion device beam position indicators. At 2.5 GeV with beam current 108mA, an exercise of step-by-step gradual pole gap variation of U1 undulator was started from its initial maximum value of 250 mm up to minimum value of 25 mm. No significant change was observed in betatron tune values, the temperature of vacuum chamber, vacuum and beam lifetime. Images of the synchrotron radiation beam emitted from the undulator and its neighboring bending magnet were recorded using a fluorescent screen beam viewer.

An APPLE-2 (Advanced Planar Polarized Light Emitter-2) type undulator made of permanent magnet blocks was installed in the long straight section, LS-5, of Indus-2, after carrying out offline tests. This insertion device will be used for generating radiation with adjustable polarization and to enhance the peak spectral brightness of synchrotron radiation by two to three orders of magnitude in the spectral region from 300 eV to 2000 eV including higher harmonics. For installation of the undulator, several ultra-high vacuum compatible peripherals for the undulator like tapered vacuum chamber and beam position indicator assemblies were designed and manufactured by precision machining and TIG welding.

The control systems of Indus accelerators, microtron injector and industrial accelerators have been upgraded and new sub systems have been added. A beam based alignment system has been installed in Indus-2 to minimise the closed orbit distortion of its orbit, higher beam life time, reduced variation in machine tune and reduced corrector strength. A control system (hardware and software) for beam based alignment was developed to control 72 active shunt power supplies. Prototype processing electronics using an embedded web server for monitoring the beam position monitors of the booster synchrotron at a higher repetition rate of 1 kHz was developed.

To enhance the performance of the bunch-by-bunch feedback system and hence improved beam stability, design, development and installation of upgraded versions of ultra-high vacuum compatible horizontal and vertical stripline kickers has been carried out. The Indus-2 Low Conductivity Water (LCW) plant is used for cooling of accelerator components, power devices in magnets and RF power supplies etc. and is operated round-the clock. The system was upgraded to increase the process cooling water temperature stability to better than ±0.7°C as compared to the earlier stability of ±1°C.



The inside view of the assembled horizontal and vertical stripline kicker magnets

This has helped in improving the stability of Indus-2 operation.

A new, improved 20MeV injector microtron has been developed for Indus synchrotron radiation source facility of RRCAT. The beam was accelerated up to 22nd orbit where the beam energy is 20 MeV. A beam current of 30 mA was measured in the 22nd orbit.

The magnet power supplies used in Indus-1 and Indus-2 have been upgraded. These include four power supplies (80 A, 25 V) for quadrupole magnets in the transport line TL-2 which feeds the electron beam from the booster synchrotron to Indus-1 and three in the transport line TL-3 which feeds the electron beam to Indus-2. Four numbers of Fast Orbit Feedback (FOFB) power supplies and three numbers of active shunt power supplies for independent adjustment of Indus-2 quadrupole currents were also developed. High voltage DC and pulsed power supplies have also been developed for ECIL for use in an explosive detection system.

The Indus synchrotron radiation sources, a national facility, are being used by scientists and students from various universities, national institutes and research laboratories all over the country. A soft x-ray reflectivity beamline (BL-3) has been commissioned recently, which is the 13th beamline on Indus-2 and operates in the energy range of 100 eV to 1500 eV. Test experiments have been carried out successfully, and the beamline is now open to users.

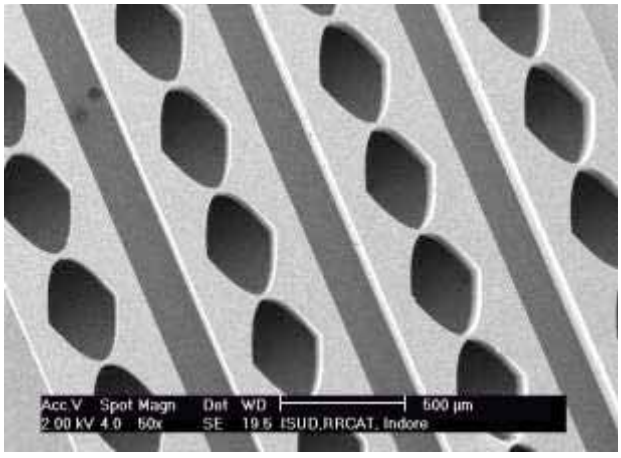
Some of the operating beamlines have been equipped with advanced user facilities. A Closed Cycle Cryostat (CCR) based cooling system and a high temperature stage have been installed in the image plate of the Angle Dispersive X-ray Diffraction (ADXRD) beamline (BL-12). A new high temperature stage (upto 1100 K) has been commissioned which can be used both in the scanning extended x-ray absorption fine structure (EXAFS) beamline (BL-9) as well as the dispersive EXAFS beamline (BL-8). A Fourier Ttransform Infrared (FTIR) system with a closed cycle cryostat has been installed at the photo-physics beamline at Indus-1 (BL-5). A dedicated beamline is under fabrication for the utilization of the light emitted from the newly installed APPLE-2



The closed cycle cryostat based sample cooling stage installed at the image plate of the ADXRD beamline (BL-12)

undulator. The most important application of circular polarized light is in the study of magnetic materials by carrying out X-ray Magnetic Circular Dichroism (XMCD) experiments.

Using the x-ray lithography beamline (BL-7) of Indus-2, x-ray lenses for use in the hard x-ray regime have been fabricated in a new antimony free material, code named SUEX. A focal beam diameter with full width at half maximum (FWHM) of 0.8 micron was obtained when this lens was used at the Diamond Light Source, UK. Next, Fresnel zone plates (FZP) with a focal length of 25 mm have been fabricated in polymethyl methacrylate (PMMA) on ultra-thin titanium film using 30 keV electron-beam lithography. These have been designed for focusing of capillary discharge based argon x-ray laser (wavelength: 46.9 nm).

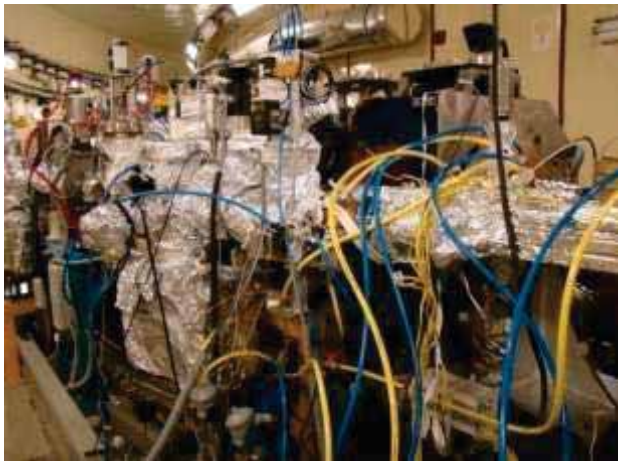


Scanning electron microscope image of the SUEX lenses developed at BL-7 beamline

During the year, the Indus beamlines have been widely utilized by users for a variety of experiments. Work on the installation and vacuum testing of various components for beamlines and front ends has been carried out. The front end for the Indus-2 Photo Emission Electron Microscope (PEEM) beamline (BL-22) has been designed, fabricated and commissioned. Some of the components like pre-masks, water cooled beam viewer, scanning wire monitors etc. have been designed, indigenously fabricated and installed in the front ends of insertion devices based Atomic, Molecular and Optical Studies (AMOS) and Angle Resolved Photo-Electron Spectroscopy (ARPES) beamlines. A compact two stage differential pumping system (length 415 mm) has been developed, tested and installed on the BL-3 of Indus-2 to provide a windowless transition between high and low vacuum regions of the beamline.

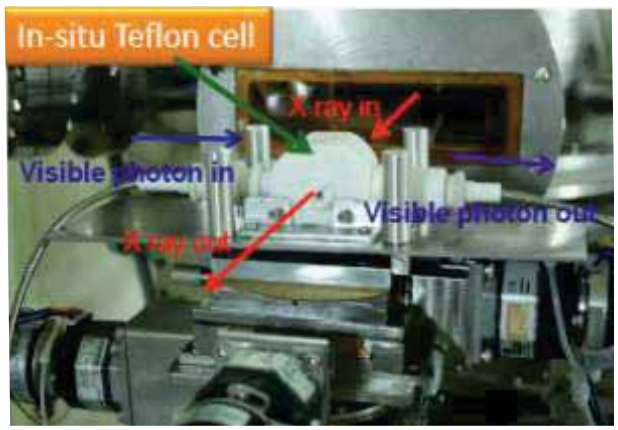


View of the PEEM beamline (BL-22) front end that has been installed on the Indus-2 ring



View of the front end components in BL-10 (ARPES beamline)

At BARC, growth of block copolymer stabilized Au@Pt nanoparticles was investigated simultaneously by in-situ Time Resolved Extended X-ray Absorption Fine Structure (EXAFS) and UV-Vis absorption spectroscopy at the energy dispersive EXAFS beamline (BL-08), INDUS-2 Synchrotron Radiation Sources (SRS). Core shell nanoparticles have been synthesized by mixing aqueous solution of chloroauric acid and chloroplatinic acid with ascorbic acid and pluronic block copolymer P85. The EXAFS spectra have been measured for 60 minutes from the instant of addition of reducer, at an interval of 1 second at both Au and Pt L3 edge simultaneously. The radial distribution function obtained from EXAFS analysis showed reduction of Au-Cl and Pt-Cl bonds and appearance of Au-Au/Pt and Pt-Pt/Au bonds with time which signifies reduction of Au and Pt precursors to Au and Pt nanoparticles. From the EXAFS analysis it is evident that within 10 seconds of addition of the reducer, gold nanoparticles are formed which acts as seeds for further reduction of Pt precursor and subsequent formation of Pt shell on Au core. The above observation is also corroborated by the evolution of the surface plasmon peak of gold nanoparticles and its disappearance due to Pt shell formation as observed by in-situ time resolved UV-Vis spectroscopy.



Facility for simultaneous measurement of EXAFS & UV spectroscopy

Crystal structures of various important proteins were determined using Protein Crystallography Beamline (PXBL21) of Indus-2 and the structure data were deposited in Protein Data Bank (PDB) database, a depository of macromolecules structures. Fifty five users from the various institutes have used the beamline for their diffraction studies.



Low temperature experimental setup at the IR Beamline at INDUS1



The bendable Kirk Patrick Baez mirror system

An in-situ low temperature (liquid nitrogen (77 K) & liquid helium (4.2 K) infrared absorption/reflection facility has been setup at the IR beamline at Indus-1 SRS and tested in the temperature range of 5 to 500 K in steps of 1 K and various experiments have been performed. This facility will help to understand the thermodynamics of the local molecular structure, probe the electronic structure, metallic properties and superconducting band gaps in various materials.

To focus hard x-rays at the sample position, elliptically bendable Kirkpatrick Baez (KB) mirror system has been installed at the Extreme Conditions X-ray Diffraction (ECXRD) beamline at INDUS-2. This system comprises two sets of Pt mirrors coated on trapezoidal shaped Si substrate providing aberration free focusing in both vertical and horizontal directions. Bendable mechanism provides freedom of choosing the focal plane and caters the focusing requirements of both the XRD variants, viz. angle dispersive XRD and energy dispersive XRD incorporated at the beamline. The demagnification at EDXRD station and ADXRD station is ~30 and ~8 respectively; which can be varied based on requirement.

Diffraction Enhanced Imaging (DEI) has been implemented in imaging beamline at INDUS-II. This technique can provide quantitative phase information of weakly x-ray attenuating materials and can provide better contrast. This beamline has been augmented with x-ray microscope detector achieving resolution down to 2 microns.

CYCLOTRONS & THEIR UTILISATION

K130 Variable Energy Cyclotron (VEC)

The K130 variable energy cyclotron is presently accelerating alpha, proton and deuteron beams using an internal PIG ion source. The cyclotron has been accelerating light ion beams in the range of 6.5–20 MeV per nucleon and also accelerating very low energy light ion beams (1-2 MeV per nucleon) and delivering it for performing experiments.

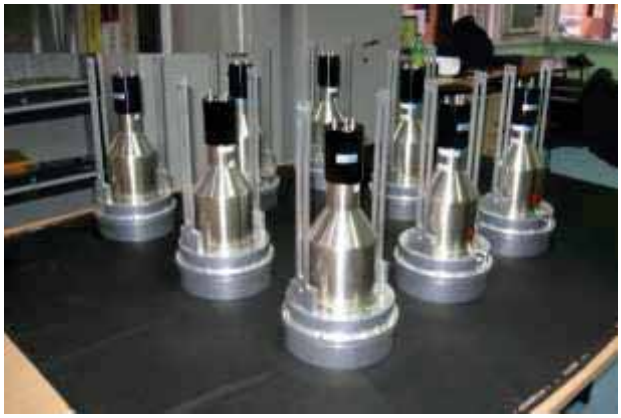
Low energy singly charged helium (He^{+}) of 3.33 MeV beam has been developed and this needed to operate the cyclotron in higher harmonic (third, fifth etc.) mode of operation. Higher harmonic operation of K130 cyclotron is significant since it requires stable operation of all the sub-systems, especially the magnet power supply and the RF power supplies.

The cyclotron has operated on a round the clock basis and has delivered uninterrupted and stable accelerated beams of proton, alpha and deuteron for conducting experiments in various fields of research mainly in nuclear physics, radio-chemistry, material science and producing of Rare Ion Beams (RIBs) etc. These beams have been utilized by in-house experimental groups of VECC, as well as by experimentalists from several national laboratories and academic institutions.

During the year 2015, extracted beam from cyclotron was available for a total time of 4779 hours.

Neutron detector development at VECC for fast neutron spectroscopy

A liquid scintillator based neutron detector for fast neutron spectroscopy has been developed. Several of these detectors are in use for different in-beam experiment at K130 Cyclotron at VECC. The construction of Modular Neutron SpecTER (MONSTER) through international collaboration with other institutes is also being done. MONSTER will be used for the decay spectroscopy experiment in FAIR, Germany.



Neutron detectors developed at VECC for "MONSTER"

Direct evidence of washing out of nuclear shell effects.

Stability of Super Heavy Elements (SHE) originates from the shell effects in nuclei. In the context of the production of these SHE at laboratories it is important to know at what excitation energy nuclear shell effect melts out. Researchers at VECC show first direct experimental evidence that for the Actinide nuclei ^{236}U, shell effect is washed out at the excitation energy of 40 MeV. The Uranium nucleus was produced over a wide excitation energy range of 20-66 MeV by bombarding alpha particles from the K-130 Cyclotron machine, on ^{232}Th target. The fragments originated from the fission on ^{236}U nucleus were detected in two large area gas detectors that were indigenously developed at VECC. Gradual change in the shape of the fragment mass distributions, from asymmetric to symmetric, was observed with the increase in excitation energy and it was found that at around 40 MeV, the shape of the mass distribution changed to completely symmetric one, indicating the vanishing of shell effects.

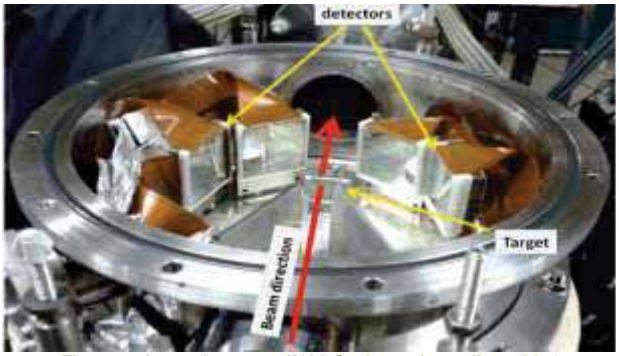
In another experiment at BARC-TIFR Pelletron, mass distributions of the fragments in the fission of ^{206}Po and the N=126 neutron shell closed nucleus ^{210}Po were measured. No significant deviation of mass distributions was found between ^{206}Po and ^{210}Po, indicating the absence of shell correction at the saddle point in both the nuclei, contrary to the reported angular anisotropy and prescission neutron multiplicity results. This result provides benchmark data to test the new fission dynamical models to study the effect of shell correction on the potential energy surface at saddle point.



The experimental setup in the scattering chamber at K130 Cyclotron beam line with two MWPC indigenously developed at VECC

Experimental search for the Hoyle analogue state in ^{16}O

Clustering is a unique phenomenon that occurs particularly in the structure of light nuclei: for example, the famous Hoyle state in ^{12}C, which is considered to be a well-developed three- cluster structure and also known to play a leading role in the



The experimental setup at K130 Cyclotron beam line with 4 double sided silicon telescope

formation of ^{12}C itself as well as the synthesis of other heavy elements in the Universe. The study of the - clusters structure of light nuclei is very interesting and important from the nuclear structure as well as from the astrophysical point of view. A high resolution, high statistics complete kinematic experiment has been carried out to investigate the structure of the Hoyle analogue state in ^{16}O by inelastic scattering of 60 MeV - beam from the K130 cyclotron.

Transfer reaction study of ^{26}Al - a nucleus of astrophysical interest, using VECC deuteron beam

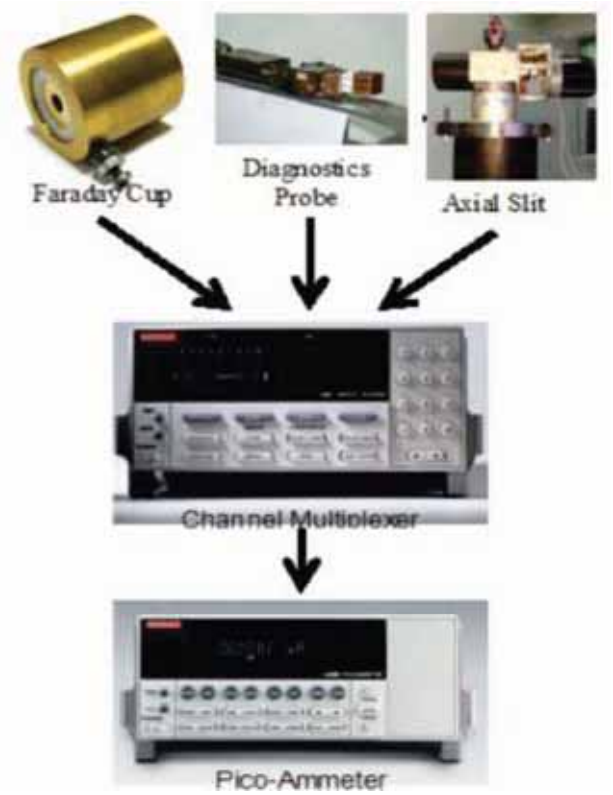
The nucleus of ^{26}Al, the first cosmic radioactivity detected in the interstellar medium, has recently evoked lot of interest in astrophysics. Since the lifetime (10^6 years) of ^{26}Al is much shorter compared to the galactic evolution time (10^{10} year), it may be used as an isotopic chronometer for galactic evolution. Therefore, there has been lot of activities, both experimental and theoretical, in the recent years, to understand the nuclear structure of ^{26}Al using various transfer reaction channels, such as, $^{28}Si(p,^3He)$, $^{24}Mg(^3He,p)$, $^{27}Al(p,d)$, $^{27}Al(^3He,)$ etc.; however, no direct measurement of the $^{27}Al(d,t)$ reaction has so far been available. The structure of ^{26}Al was investigated using the single nucleon transfer reaction $^{27}Al(d,t)$ at 25 MeV bombarding energy. The spectroscopic factors for different excited states of ^{26}Al were extracted using zero-range Distorted Wave Born Approximation (DWBA) calculations and compared with earlier reported values.

The experiment, marked as the beginning of VECC deuteron beam programme, was performed using 25 MeV deuteron beam from the K130 Cyclotron. The angular distributions of various transfer channels were measured using three-element telescope, consisting of a single-sided 55 µm Si(E) strip detector (16 vertical strips), a double-sided 1030µm Si(E) strip detector (16 x16 strips, along mutually orthogonal sides) and four CsI(Tl) detectors, each of thickness 6 cm. The angular distributions for different excited states of ^{26}Al were analysed using DWBA code. The spectroscopic factors were extracted and compared with those obtained using other transfer channels as well as with the shell model predictions of the same.

Development of EPICS based Beam Current Monitoring System for K=130 Cyclotron at VECC

A computerized beam current monitoring system is developed and integrated with the existing EPICS based control system of K=130 Cyclotron at VECC. Previously, the beam-currents at several places in internal acceleration region and external beam lines were measured and displayed using analog techniques from the beam-diagnostics equipment like Faraday Cup, Slit, and diagnostic probes inside the cyclotron cavity. The operators had to manually multiplex between various current sources to a single analog current meter. The present developed current measurement system is fully digitized and automated.

Currently, nineteen (19) channels including eleven (11) Faraday cups, two (2) diagnostic probes and eight (8) slits are being monitored. All the channels are connected to the inputs of a switch



Hardware Description Block Diagram for Beam Current Monitoring System

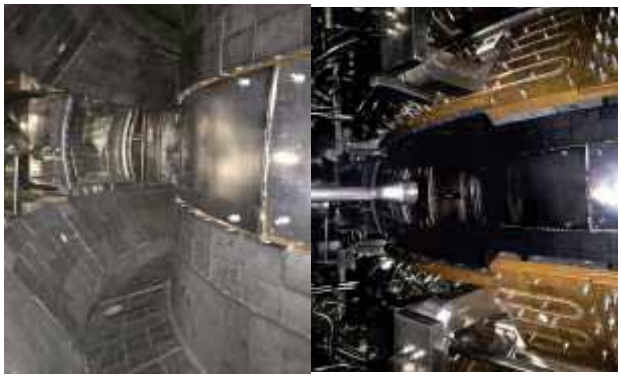


GUI for Beam Current Monitoring

system (with two scanner cards). The multiplexed output is connected to pico-ammeter. Both switch system and pico-ammeter are remotely controlled via Ethernet. A GPIB-to-Ethernet and RS232-to-Ethernet converter are used to interface the switch system and pico-ammeter respectively. The Operator is facilitated with intelligent GUI control like the provision to switch between different channels and current ranges, simultaneous monitoring of slit currents etc. This system is successfully installed and commissioned and is presently being used in beam tuning of K=130 cyclotron.

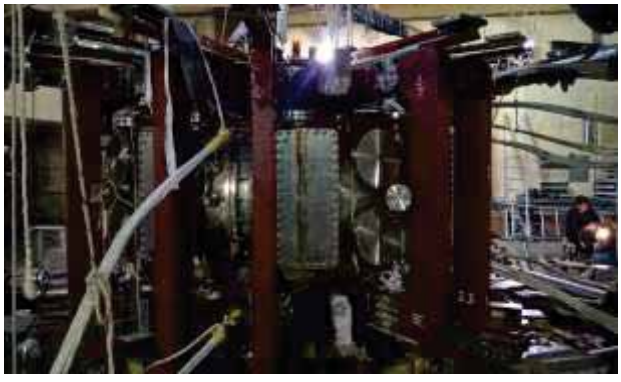
PLASMA & FUSION TECHNOLOGIES

At the Institute of Plasma Research (IPR), the Steady-state Superconducting Tokamak-1(SST-1) has completed the 1st phase of up-gradation with successful installation and integration of all its First Wall components (also known as plasma facing components). After this, one set of experiments have been done. After these experiments, a vessel opening had been done for an audit of the installed First Wall Components along with improvements of some of the installed diagnostics and addition of some new diagnostics. In the forthcoming experiments, the core plasma parameters are expected to be improved with further optimizations and with wall conditioning.



SST-1 Vacuum Vessel with installed First Wall Components

For Aditya-Upgrade, the decommissioning of the existing machine was done with accurate documentation for understanding and rectifying the problems faced before in machine operation. The new circular vessel along with the tested and refurbished Toroidal Field coils have been integrated to the upgraded machine. The operation of the machine will start after the completion of the engineering validation of the installed components and subsystems.



Installation of TF coils with new vacuum vessel is in progress

The new SS grill antenna designed for launching Lower Hybrid Current Drive (LHCD) power has been fabricated and installed in SST-1. The Aditya upgrade programme has provided an opportunity to upgrade the current drive system for the upgraded machine. The 42GHz/500kW Electron Cyclotron Resonance Heating (ECRH) system has had a matured operation experience during the recent SST-1 experiments. Along with that 82.6GHz/200kW has been planned to operate using the same launcher.

Various relevant technologies of fusion science are being developed under the 12th Five Year

Plan by indigenizing the technology available elsewhere either by collaboration through participation in the experiments or through fundamental developments. The 1:1 prototype Edge Localized Coils for the Joint European Torus (JET) at United Kingdom has been successfully realized. State-of-the-art copper sheathed MgB_2 strands have now been in-house manufactured in several meters of single length. The already operationalized High Heat Flux has been used to test many first wall components like tungsten coatings developed on CuCrZr and SS316L substrates. Development of precise diagnostics for liquid lead-lithium pressure, flow-rate, tank-levels etc. are in the focus for Blanket technologies. Experimental set-up to estimate the effective thermal conductivity of lithium ceramic pebble bed has been built. Under an IAEA agreement, Tungsten was studied for radiation damage and fuel retention because tungsten is the main armor material which faces the plasma in fusion reactor. This study was done with collaboration from various institutes in India

Small basic plasma experiments like Large Volume Plasma Device (LVPD), Interaction of Low Energy Ion and Neutral Beams with Surfaces, SYstem for Microwave PLasma Experiments (SYMPLE), Plasma Torch experiment, and Plasma Wake-Field Accelerator (PWFA) experiment etc. are contributing to the fundamental studies in plasma. They, as well, are creating avenues for training man-power for future ventures by providing opportunities in the form of doctoral and other degree course theses both through the institute and from other institutions in the country.

The robust plasma theory and simulation programme, with its one of its kind computational facility, is helping to understand the various experimental results obtained by the institute. Through collaborations from all over the country and some outside the country, the same programme is also working to explain the various plasma phenomena observed. It also guides the future experiments through simulations without actually spending enormous money on them.

Facilitation Centre for Industrial Plasma Technology (FCIPT) is dissecting the various plasma phenomena so as to exploit them for potential societal benefits through short time projects. These projects are being funded by both national and international agencies, while some of them are being sponsored by relevant private companies. They cover a wide variety of subjects from bio-medics, waste treatment, power through green technology, satellite building, nano-technology etc. In this period four MoUs / technology transfer were done with government and private agencies.

While assisting the activities at main campus, the Guwahati campus namely Centre for Plasma Physics, is also taking lead in different programs like development of a neutron source based on inertial electrostatic confinement fusion scheme. The other programs at that campus like theory and simulation, dusty plasma experiments, divertor simulation study experiments etc. are also going strong.

At BARC, a novel technique has been developed for preparation of specific composition of Dysprosium titanate material for high temperature application. The developed process has given reproducible results.

An innovative space saving online fabrication facility consisting of foil wrapping setup, a triangular mechanised cable insertion system, orbital welding machine along with tube handling system, set of swaging machine, bending machine and coil winding machine has been set up for the fabrication of long length Cable In Conduit Conductors (CICC) in the existing facility.

200m long CICC on a bobbin has been fabricated in the facility and after completing the



200m long 30kA hybrid superconducting CICC in 2m dia coil form on a Bobbin

quality control tests, sent to IPR, Gandhinagar for magnet fabrication.

MATERIALS SCIENCE

At BARC, radiation induced changes in microstructure of Ni-42%Cr-1% Mo alloy were studied by depth dependent doppler broadening measurements on Ar^{9+} (315 keV) irradiated samples. It was observed that the S-parameter (low momentum region contribution) continuously decreases up to a particular depth and reaches a constant value which is typical for an alloy sample. On irradiation, the S-parameter in the damaged region was observed to increase with fluence. The defect density increases with increase in the irradiation dose up to 47.27 dpa.

Nanoporous aluminium oxide and ultra-nanoporous (pore size < 20 nm) membranes used as templates for fabrication of nano-rods, nano-tubes for sensor applications were fabricated by a two-stage anodization of Al in H_2SO_4 medium at 25V and 0°C. Conditions for electro polishing and anodizing have been optimized to obtain ordered nanoporous alumina templates with average pore diameter of 40 nm and interpore distance of 65 nm. Small Angle X-ray Scattering and Field Emission Scanning Electron Microscopy (FESEM) have confirmed the presence of nanotubular pores of 33nm to 49nm uniformly distributed with an inter-pore distance of 43nm to 55nm and overall porosity between 27 to 33.5%.

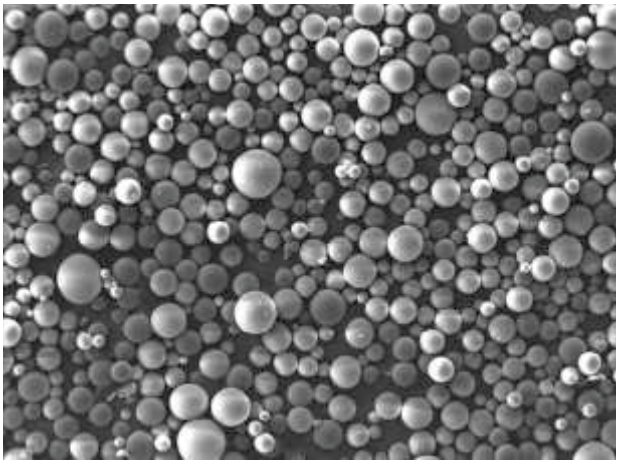
Several functional and energy conversion ceramics such as beta-alumina, BeO and Solid Oxide Fuel Cell (SOFC) ceramics have been fabricated. One end closed tubes of dense beta-alumina for the electrolytic cell of Alkali Metal Thermal to Electric Converter (AMTEC) have been fabricated by cold isostatic pressing followed by sintering at 1450°C. A process was developed to prepare specific shapes of high density BeO ceramics having required permittivity and tan values as a function of frequency for heat sink application in high power output multiplexers for communication satellites. Assessment of multi-cell assemblies for fuel cell and steam electrolyser modes was initiated with assembly of two tubular solid oxide cells in parallel and tested in SOFC mode.



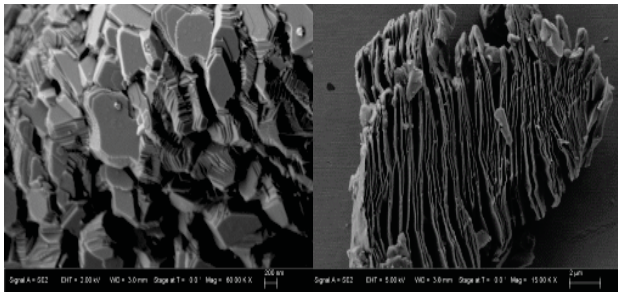
Multi-tube solid oxide electrolyser cell

A range of functional coatings have been synthesized using Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) and electro deposition techniques for diverse applications. TiN films of thickness (1-3μm) have been applied on sodium beta alumina, EN24 steel and phosphorous bronze by DC magnetron sputtering. Alumina thin film coatings (0.5-1 μm) on RAFM-steel, SS-304 and Si substrates were developed using RF balanced magnetron sputtering. Diamond and AlN thin films have been formed by hot filament CVD and reactive sputtering respectively and their application for radiation dosimetry and neutron detection has been explored. Electro deposition using ionic liquid bath has been employed for obtaining high purity aluminium coatings of various thicknesses on T91/RAFMS substrates for future applications in TBM for ITER. Anodizing and controlled atmosphere oxidation techniques have been devised for obtaining electrically insulative alumina/alumina-aluminide coatings. Anodizing technique has been extended for obtaining oxide coatings of Ti and Zr. Many other coatings such as electroless Ni-P, electroplated Ni, Cu, Sn, Cr, Ag and Au finding diverse application in DAE have been developed. Three module cluster deposition tool has been installed for the synthesis of p-type and n-type semiconducting boron carbide films from organic precursors using plasma enhanced CVD technique.

Monodisperse microspheres of Yttria Alumina Silica (YAS) glass suitable for treatment of hepatocellular carcinoma (20-30 microns size) and



Microspheres of Yttria-Alumina-Silica glass



Exfoliated and spark plasma sintered bulk Ti3AlC2 MAX Phase high temperature machineable carbide

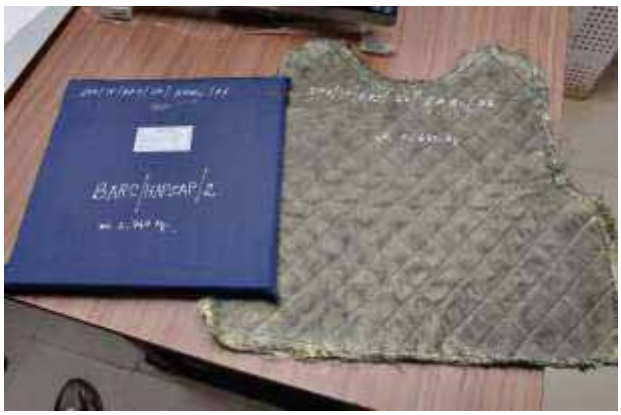
synovitis have been prepared by flame polishing glass powder and harvested by a separation technique.

MAX Phase carbides are potential high temperature machineable ceramics for nuclear reactors with better mechanical properties and irradiation stability than silicon carbide ceramics. Ti_3AlC_2 and Ti_3SiC_2 MAX phase carbides was synthesized in bulk and Nano particulate form for the preparation of SiCf-MAX phasem/ Cf-MAX phasem ceramic composites, monolithic structures and coatings. Nanoparticles/ MAXene were prepared from Ti_3AlC_2 powder by an exfoliation-milling technique. Dense MAX phase was also prepared by in-situ synthesis and powder consolidation using hot press and spark plasma sintering.

Development of long tapes of RE123 (RE-Y,Nd and Sm) High Temperature Super Conductor (HTSC) for power applications and seeds for preparing top seeded melt grown bulk single crystals for levitation application has progressed with the preparation of CeO_2-YSZ-CeO_2-RE123 multilayer thin films on <100> biaxially textured Ni-5%W alloy substrate developed earlier. The ceramic thin films were deposited by Pulse Laser Deposition using dense Y123, Nd123, Sm123, Ceria (CeO_2) and YSZ (Zirconia+8mol% Yttria) targets prepared by Cold Isostatic Pressing (CIPing) of powder and sintering.

Several boride ceramic composites such as, TiB_2-EuB_6, CrB_2-SiC, CeB_6-$TiSi_2$, ZrB_2-CrB_2, ZrB_2-NdB_6, B_4C-HfB_2 and CrB_2-NbB_2, with improved fracture toughness have been developed for high temperature structural applications. Dense borides were synthesized from primary boride ceramics through hot pressing and spark plasma sintering routes. Composites were examined for hardness, fracture toughness, microstructure/ phase analysis, oxidation behaviour and tribological behaviour.

In the case of CrB_2 composites, fracture toughness increased from 3.11 to 4.32 MPa.m1/2, with change in Nb content addition of 2.5 to 20 wt%. In the case of monolithic boron carbide the Coefficient of Friction (COF) at 10 Hz frequency was seen to decrease from 0.20 to 0.15 with increase of load from 3-10 N. Microstructural investigations showed that this behaviour was due to combined effect of abrasive and tribo-chemical reaction mechanisms. Composite fibres have been prepared by dispersing Carbon Nanotubes (CNTs), developed in-house, in polymeric fibres with improved toughness. They have been successfully utilized in ballistic applications.

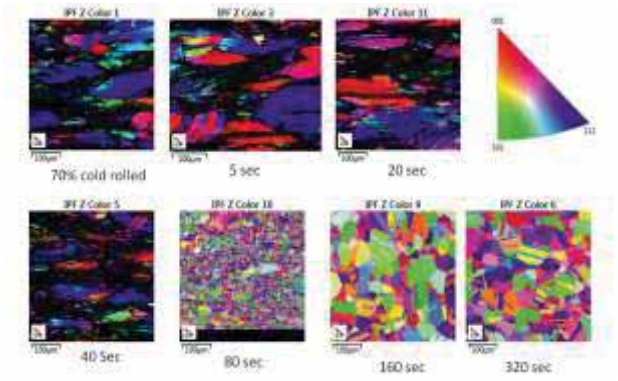


CNT dispersed composite fibre

Ni-Cr based alloys are indigenously developed for high burn up clad applications and studies were carried out to evaluate its irradiation resistance by irradiating imported Ni-42%Cr alloy

and indigenous SuperNi-42 alloy samples with a proton beam to doses of 1.7×10^{17}, 7×10^{17} and 1×10^{18} proton/cm^2 and with Ar ion beams to doses of 9.3×10^{14}, 2.3×10^{15}, 4.6×10^{15}, 9.3×10^{15}, 1.3×10^{16} and 2.3×10^{16} ions/cm^2. Irradiation induced changes in microstructure were characterized by x-ray diffraction, electron microscopy and slow beam Positron Annihilation Spectroscopy (PAS). Experimental and simulation data established that both indigenous and imported Ni-42%Cr alloy showed good resistance to irradiation.

Cold deformed SuperNi-42 alloy was subjected to heat treatment for different periods of time followed by detailed SEM characterization. Evolution of recrystallization microstructure was established using Scanning Electron Microscope-Electron Backscatter Diffraction (SEM-EBSD) analysis. Based on the SEM analysis, the dependence of grain size on the heat treatment parameters (temperatures and time) were determined and optimized. The targeted grain size of 20-30 µm was achieved at 1080°C.



Microstructure evolution in cold rolled SuperNi-42 heat treated at 1120°C

Aluminide coating on Ni-Cr-Fe based super alloys was developed for application at elevated temperatures. Solution-annealed super alloy 690 substrates were subjected to atmospheric plasma spraying using Al powder. Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) along the cross-section of as-sprayed specimen indicated presence of Al (200 µm) on the topmost surface and about 25 µm thick adjoining layer rich in Al and Ni. As-sprayed and heat-treated (1273 K) substrate revealed formation of multilayer (50 µm thick) next to the initial Al layer. The multilayer comprises Cr-aluminide, (Ni,Cr)Al, NiAl and $(Ni,Cr)_3Al$ types layers and finally, Cr-rich layer adjacent to substrate. Microscopic examination of the scratched surface has revealed good adherence of the layers.

A methodology for joining Stainless Steel (SS) 304L to Zircaloy-4, based on a novel Ga-assisted diffusion bonding technique was developed indigenously using Ni and Ti interlayers in a temperature range of 800–900°C for 30 and 60 min under vacuum. Characterization of the interface showed the formation of different intermetallics like $NiZr_2$, NiZr, Ni_3Ti, NiTi and NiTiZr at SS/Zry interface. Sound joints free from pores, discontinuities and cracks at the bond interface were produced by this technique. Bonding parameters were optimized to obtain shear strength in the range of 170 - 214 MPa. The joint bonded at 900°C for 30 min showed the existence of $NiZr_2$ on its fracture surface. Those joined at 850°C for 60 min showed Ni-Ti-Zr intermetallic on its fracture surface. These SS-Zircaloy-4 joints find application in various nuclear reactor fields.

Synthesis of novel Os_2C phase using laser heated diamond anvil cell

At IGCAR, Os_2C was synthesized by the high pressure–high temperature route using laser heated diamond anvil cell technique. The compound is found to be in hexagonal structure with space group P63/mmc and lattice parameter: a = 2.536 Å and c = 12.526 Å. Semi empirical method was used to estimate the hardness and found to be 22.1 GPa. The electronic structure calculations reveal that the Os_2C system to be metallic in nature and also lead to understanding the observed hardness in such metal rich systems.

Thickness controlled proximity effects in C-type antiferromagnet/superconductor hetero structure

The proximity effect between different ordered phases, such as superconductivity and magnetism, provide unique opportunities to study fundamental physics as well as to exploit the observed exotic phenomena for technological applications. The modulation of superconducting

state of YBa_2Cu3O_7 (YBCO) with C-type antiferromagnetic phase of $Nd_{0.35}Sr_{0.65}MnO_3$ (NSMO) in NSMO/YBCO hetero-structure was studied. The result indicates that an unexpected colossal magneto-resistance was observed below the superconductivity re-entrance temperature (Tr) for t = 200 nm which is attributed to the winning of exchange field over the pairing energy.

Deep Level Transient Spectroscopic studies for characterization of defects in detector grade Germanium

Deep level transient spectroscopic studies provide information on both crystal perfection of the material as well as on the electrical activity of incorporated impurities. For enabling low temperature measurements required for ultrapure Germanium crystals, a measurement system was set up. The results of the study indicate that the observed defect levels are comparable with defects levels reported in literature for detector grade Germanium.

Investigations on the thermal and radiation stability of Y-Ti-O nanoparticles in oxide dispersion strengthened steel using TEM and Atom Probe Tomography

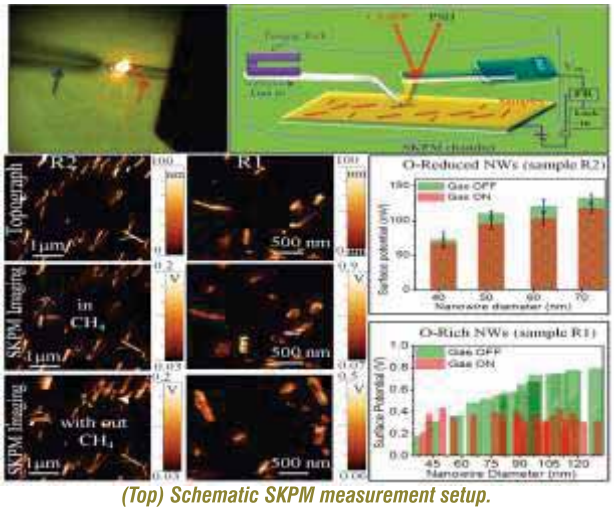
Model alloys of oxide dispersion strengthened steels produced in collaboration with ARCII, were subjected to advanced characterization techniques including ion irradiation experiments. The samples were analysed in India and in the UK as part of Collaborative Research between the UK and India on Oxide Dispersion Strengthened Steels. Three model ODS alloys (Fe–0.3Y_2O_3, Fe–0.2Ti–0.3Y_2O_3 and Fe–14Cr–0.2Ti–0.3Y_2O_3) were prepared. All alloys were characterized by high resolution transmission electron microscopy and atom probe tomography. In order to de-lineate the roles of temperature effects and ballistic processes in the reduction in particle size, a combination of low temperature followed by high temperature irradiations to study the particle dissolution and reforming kinetics was undertaken for Fe–14Cr–0.2Ti–0.3Y2O3 alloy. Atom probe tomography results of samples irradiated at 150K show oxide particle dissolution. Large diffuse clusters of yttrium remain, but the titanium and oxygen are mostly displaced from the clusters showing the ballistic effect of irradiation. The chromium shell that is observed around the oxide particles in the un-irradiated Fe-Cr-Ti-Y alloy are also absent after low temperature irradiation.

Raman spectroscopic study at the sub-diffraction limit using coupled system with surface probe microscope

Understanding of light-matter interaction and its application is one of the most important achievements. Role of both the evanescent field of localized surface plasmon resonance (plasmonics) and confinement of polarized light in the dielectric contrast of semiconductor-insulator periodic pattern (photonics) were studied. The polarized resonance Raman spectroscopic studies with strong electron-phonon coupling to understand the crystalline orientation of a single AlGaN nanowire of diameter 100 nm were also demonstrated. The study of optical confinement effect due to the dielectric contrast of nanowire with respect to that of surrounding media assisted with electron-phonon coupling of resonance Raman spectroscopic studies are useful for the spectroscopic analysis in the sub-diffraction limit of 325 nm (₹/2N Á) using an excitation of 325 nm and near ultraviolet 40x (N Á =0.5) far field objective. The study was continued for developing optical and spectroscopic imaging of nanostructures in the sub-diffraction limit using the near field scanning optical microscope and surface probe microscope system coupled with Raman spectrometer, respectively to understand electronic properties as well as chemical changes in III-nitride and oxide nanostructures.

Localized charge transfer process in methane sensing by GaN nanowires studies by in situ scanning Kelvin probe microscopy.

Intrinsic or extrinsic defects in materials strongly influence the physicochemical processes at the surfaces of semiconductor nanostructures involved in electrochemical and sensing devices. Intentional lattice oxygen defects were created on the surfaces of GaN nanowire for the elucidation of charge transfer process in methane sensing to understand the surface controlled sensing mechanism. Two nanowire samples were grown



(Top) Schematic SKPM measurement setup. (Bottom) Typical topographs and SKPM maps of samples before and after exposure to CH4. Nanowire diameter dependent SP values extracted from the SKPM maps

under different oxygen impurity concentrations for the study. Possible presence of 2(O_N) and V_{Ga}–3ON defect complexes were confirmed by both experimental and simulation results of electron energy loss spectroscopy studies on oxygen rich GaN nanowires. A comprehensive resistive response for sensor devices of ensemble nanowire along with a localized charge transfer process in single GaN NWs were studied in situ by scanning Kelvin probe microscopy. A localized charge transfer process, involving the V_{Ga}–3ON defect complex on nanowire surface was ascribed in controlling the global gas sensing behavior of ensembled GaN nanowire rich with oxygen content.

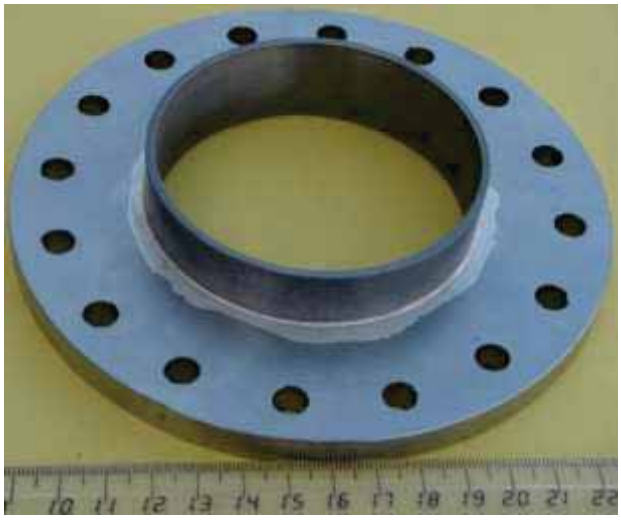
Nickel alloys containing (40-42)% of Cr and (1-1.5)% of Mo are being considered as a candidate structural material for future, compact VVER reactors. These materials exhibit unique service properties such as higher corrosion resistance under special operating conditions (sea water), higher strength and ductility properties and higher resistance to low temperature irradiation embrittlement upto a neutron dose of 15dpa compared to conventional austenitic stainless steel. Superni-42 alloy has huge practical applications in nuclear reactors, it has long service time and hence should be able to withstand higher damage (30 dpa). The alloy is being developed at VECC in collaboration with BARC and NFC. Proton irradiation was carried out simultaneously on imported and indigenously developed Ni-42%Cr-1.5%Mo alloy to the different doses. Different shapes of the samples were irradiated so that various post irradiation studies can be carried out directly. Preliminary studies using XRD on the highest dose samples show that the shape and breadth of the profile remain almost unaltered for both imported and indigenously developed samples as compared to the unirradiated samples respectively even after the high dose of irradiation. These samples have been analysed using Williamson Hall plot and Modified Rietveld analyses. XRD analysis revealed that the indigenously developed alloy is as good as the imported samples in respect of resistance to radiation damage.

XRD studies have been carried out on deformed copper (50% and 80% rolled Cu sheets). The stored energy along the different crystallographic planes was evaluated using the modified Stibitz formula and the accumulation of stored energy is much higher in {111} set of planes compared to the other planes was observed. The dynamics of the release of stored energy during annealing along two different crystallographic planes i.e.{111} and {220} have been investigated using in-situ X-ray diffraction measurements at 458K and 473K respectively. The release of the stored energy along the {220} set of planes was much slower compared to that along the {111} set of planes which revealed the contribution of two different processes. From the observed time dependent variation of the stored energy in the {220} set of planes, the process dynamics of the recovery and the recrystallization could be explained clearly and the processes were found to follow second order and first order dynamics respectively.

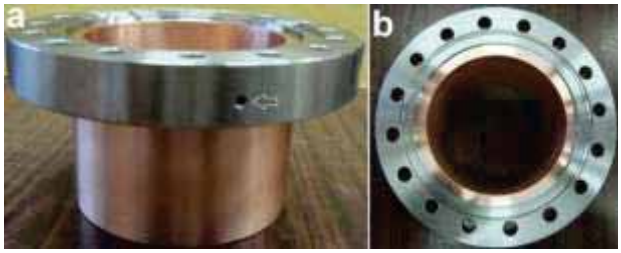
At RRCAT, several high-quality crystals have been grown by different techniques for various photonic applications. These include Er and Cr co-doped YVO4 for lasers, Cr doped Strontium Barium Niobate (SBN) crystals for pyroelectric infrared sensors and trans-stilbene for scintillation detectors. SBN crystals were grown with different dopants to optimize their pyroelectric properties. A pyroelectric infrared sensor was fabricated from the grown SBN crystal and tested for the detection of 1064 nm, 7ns Nd:YAG laser pulses. Trans-stilbene (tSB) is useful organic scintillator material, particularly for detection of fast neutrons in the presence of gamma radiation

background from radioactive materials. Platelets of tSB crystals were grown by low temperature solution growth with a new solvent, acetone.

A new indigenous process has been developed to produce Nb pipe/316L stainless steel flange joints suitable for use in low-beta SCRF cavities. The highlights of the new process are freedom from brittle intermetallics, uniform and controlled braze gap, efficient utilization of braze filler metal, simplified pre-braze fitting procedure, environment friendly cleaning procedure and simple storage conditions for pre-braze assembly. OFE copper-316L Stainless Steel (SS) transition joints find extensive application in particle accelerators all over the world. The usual practice for vacuum brazing of this transition joint involves electroplating SS part with Ni or Cu. In this context, defect-free brazed Cu-316L SS transition joints have been prepared without recourse to electroplating. Such transition joints find widespread applications in many particle accelerators components such as radio-frequency cavities of linear accelerators, radiofrequency quadrupoles, vacuum chambers for high brilliance machines, photon absorbers, profile transition chambers for insertion devices, pinhole assemblies etc.

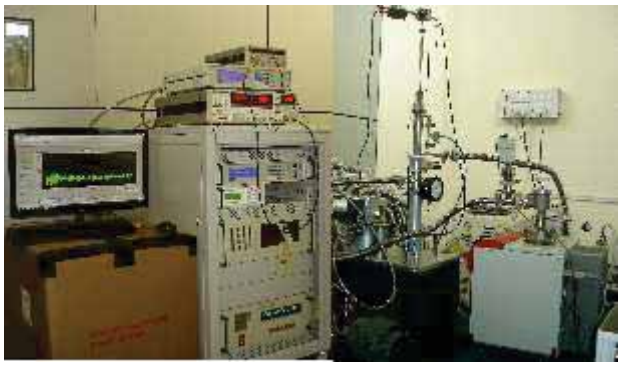


Nd pipe and stainless steel flange joint



(a) Side and (b) top views of vacuum brazed port joint between OFE copper and unplated 316L SS

Basic research on various properties of materials of technological interest is being conducted using the synchrotron radiation source, lasers and other sophisticated laboratory facilities developed at RRCAT. Knowledge of mechanical properties is important for assessing the technological applicability of superconductors. An experimental facility based on the resonant ultrasound spectroscopy technique was designed and developed for the measurement of the elastic constants of such materials as functions of temperature (2 to 300 K) and magnetic field (up to 70 kOe). It is being used to study the mechanical properties of Mo-Re alloys, which are alternative materials to niobium in accelerator technology.



Experimental facility of Resonant Ultrasound Spectroscopy

Different buffer layers for the growth of semipolar (11-22) GaN were studied at TIFR. Optical and structural comparison of GaN nanowires grown on c, r, and m-plane sapphire substrates was also studied. Electronic band structure related properties of transition metal dichalcogenide semiconductors was studied. Re-evaluation of the exciton binding energy in bulk MoS2 and its relation with the binding energy of excitons in monolayer MoS2 are part of ongoing studies. Evidence of a reversible, glassy structure that appears with increasing pressure as well as with decreasing temperature in sub-millimeter-sized single crystals of Se, was observed. Such a transition is the basis for the recently discovered novel multiferroic behaviour. The nanofabrication facility has been running well and has been catering to different areas including nanoelectronics, nanophotonics, quantum circuits,

optoelectronics, THz spectroscopy among others. Improved temporal stability (in the presence of ambient conditions) of light absorbing perovskites using aligned nanorods of TiO_2, was demonstrated. Charge storage mechanisms in Bismuth vanadate structures are currently being elucidated. A key achievement in materials research was the engineering and assembly of atomically thin layers of graphene allowing them to be used for novel energy and sensing applications through doping. Also, an ammonia sensor-which can detect both ionized and un-ionized ammonia in sub-pico molar level, was developed using fluorinated graphene. In organometallic chemistry irontetracarbonyl stabilized germanium dichloride was successfully synthesised at ambient conditions.

INTERDISCIPLINARY AREAS

At BARC, the indigenously developed Matrix Assisted Laser Desorption/Ionization Time of Flight Mass Spectrometry (MALDI-TOFMS) has been utilized for characterization of $[M+(Ag)_n]^+$ complexes where M denotes the various peptides such as oxytocin, arg^8-vasopressin, bradykinin, bombesin, somatostatin and neurotensin. Intrinsic binding ability of Ag with various biologically important peptides were ascertained for biomedical applications involving the use of silver nanoparticles (AgNPs) for over-expression of various peptide receptors in different tumours /cancers. The MALDI mass spectra of $[M+(Ag)_n]^+$ complexes, and the possible amino acid residue responsible for Ag+ binding based on their relative affinity indicates unusual binding of upto seven Ag+ with these peptides. The study points to feasibility for AgNPs as carriers in targeted drug delivery system as well as an alternate for iodinated contrasting agent for in vivo and in vitro dual energy x-ray imaging. Radio labelled Ag with these peptides has a good potential as radio-pharmaceuticals for diagnostic and therapeutic applications.

X-ray structure of the phycoerythrin protein (PDB ID, 5AQD) has been resolved from a marine cyanobacterium, Phormidium sp. A09DM. This protein is a major component of phycobilisome solar energy-harvesting antenna complex. The crystal structure with 37500 non-hydrogen atoms clearly shows interaction of protein moieties with light absorbing phycoerythrobilin chromophores, which are linked to conserved Cys residues of phycoerythrin β monomers.

The crystal structure analysis also facilitated sequencing of cpeA gene (encoding -subunit of Phormidium phycoerythrin). The FrnE (drFrnE) protein of radiation-resistant Deinococcus radiodurans possesses disulfide reductase and isomerase activities and is thought to protect the proteome on Cd(II) exposure. A number of crystal structures of drFrnE with or without strong reducing agents, like DTT, TCEP, GSH and 2-mercaptoethanol (PDB IDs, 5CNW, 5CO3, 5COH, 5CP1, 5E59) were determined. The drFrnE protein harbors two Cx2-4C motifs (22-CXXC-25 and 239-CxxxxC-244). The crystal structure and mutational analyses reveal critical roles of both the Cys motifs. The elucidated structures, most likely represent intermediate stages of the catalytic cycle. Identification of drFrnE orthologs in many bacterial phyla also emphasizes ubiquitous presence of this protein in nature.

An experimental facility equipped with Super Conducting Quantum Interference Device (SQUID) Magnetometer, He-cryostate, Diamond Anvil Cell (DAC) was developed to explore exotic physical properties (electronic and magnetic) in novel transition metal compounds under high pressure and low temperature.



High Pressure Low temperature Facilities (He-Cryostate and SQUID Magnetometer)

Mainstream biology research including setting up of academic programmes began at TIFR Centre for Interdisciplinary Sciences (TCIS). A cell culture facility was set up. A fully motorized wide field

epifluorescence imaging system with a live-cell chamber was set up. In Biophysical sciences research labs were equipped with protein expression and purification facilities. A 700 MHz solution NMR spectrometer was installed and is functioning well. A 500 MHz solid-state machine is being installed. Amongst research discoveries, the surface active species on SBA nanoparticles that renders it catalytically active, was identified. Fluorescence experiments to show that different fibrils like Amyloid-beta are in equilibrium with the monomer, were conducted. Using solution NMR methods it was discovered that water provides the activation energy for the conformational dynamics of T4 lysozyme. In theoretical and computational research, investigations were conducted on how thermally generated non-elastic, non-affine, deformations may lead to the nucleation of defects and plastic flow as a result of a novel, discontinuous phase transition. Significant advances were made in determining phase diagrams of two-model glass forming liquids in the presence of external quenched disorder using extensive molecular dynamics simulation. In an intriguing problem related to stably stratified shear flow, a class of two-dimensional perturbations that are amplified greatly due to buoyancy force alone, was shown. In another breakthrough, physical constraints on signal propagation across flocks was elucidated. Computer simulation on the role of water in kinetics of protein ligand unbinding and the role of osmolytes on polymer collapse provided key insights in the fields of biophysics.

For Inter-Institutional Centre for High Energy Physics (IICHEP), the India Based Neutrino Observatory (INO) project made good progress with the industrial production of 400 RPC gas gaps. Design review of all components for the ICAL engineering module was completed. Prototyping and limited production of ASICs, boards and software as well as their testing on the RPC test stands are in progress. Detailed simulations were carried out to quantitatively determine the physics potential of the ICAL detector and a comprehensive White Paper was completed. Collection and analysis of data using a 12 layer RPC stack at Madurai will be carried out. Construction work at the INO site is halted due to a stay order from the Madurai branch of the Madras High court.

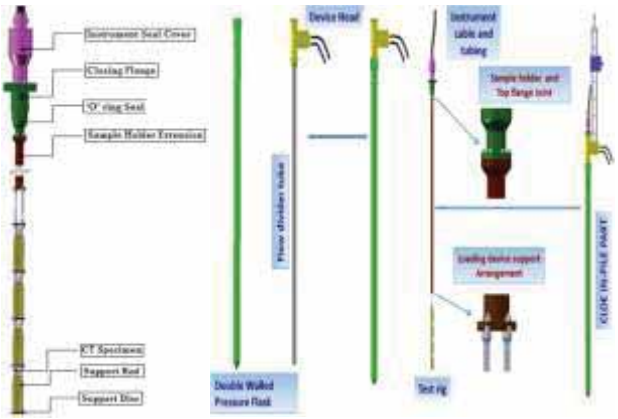
For the LIGO Project, good progress was made with the LIGO Scientific Collaboration for Gravitational Wave Observations. Both LIGO detectors have been upgraded and the first scientific run with enhanced sensitivity began in September 2015. The detectors will soon be able to make the first direct detection of gravitational waves.

For Indian Lattice Gauge Theory Initiative, Wilson flow was used to obtain the lattice scale in QCD with light quarks and the renormalization of the deconfinement order parameter. Gauge configurations will be generated for further work.

INTERNATIONAL RESEARCH COLLABORATION

To meet the objective of seismic margin assessment, Organization for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA) is organizing an international benchmark exercise on Metallic Component Margins under High Seismic Loads (MECOS). The experimental data on piping components and systems generated by BARC has been selected by OECD-NEA for this benchmark exercise. Participants have predicted a good match of global responses such as diametral growth, responses at various piping locations and free vibration characteristics with corresponding experimental results.

CLOE loop (Corrosion Loop Experiments) is designed to study the phenomenon of Irradiation Assisted Stress Corrosion Cracking (IASCC) in LWR operating conditions for installation in Jules Horowitz



General Configuration of In-pile Test Section

Reactor (JHR), France as a part of Indian in-kind contribution in the JHR Programme. The device would enable carrying out tests like crack propagation study, constant load test and slow strain rate test to understand the IASCC mechanism and its dependence on different environmental parameters. Preliminary design of In-pile test section of Corrosion Loop was completed.

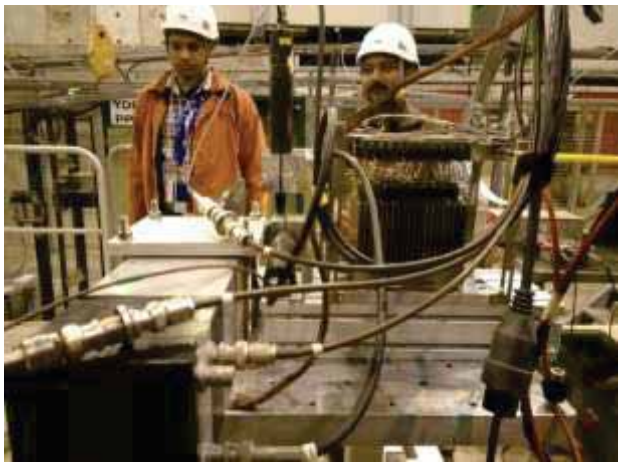
VECC continued the International Research Collaborations for various experiments. Hydrodynamics with event-by-event (e-by-e) fluctuating Initial Conditions (IC) is considered more realistic than a smooth initial-state-averaged density distribution in recent past to study the evolution of the hot and dense Quark-Gluon Plasma created in collisions of heavy nuclei at relativistic energies. A significant enhancement in the production of thermal photons for p_T >1 GeV has been seen due to fluctuations in the IC and consequently better agreement of the direct photon data in the region p_T 2--4 GeV has been observed both at RHIC (Relativistic Heavy-Ion Collider) and at the LHC (Large Hadron Collider) energies. The enhancement in the production of thermal photons is found to be an early time effect due to the presence of hotspots in the fluctuating IC. At the initial stages of the system evolution these hotspots produce higher p_T photons compared to a smooth IC and make the spectra flatter. In addition, the effect of IC fluctuation in found to be more pronounced for peripheral collisions than for central collisions and it is more at RHIC than at the LHC energy.

The bulk viscosity of the hadronic medium has been evaluated along the chemical freeze-out curve of the QCD phase diagram using Hadron Resonance Gas (HRG) model approach including Hagedorn density of states. It has been shown that the bulk viscosity at GSI-FAIR energies can be larger by a factor of five as compared to CERN-LHC energies. The effects of shadowing in Monte Carlo Glauber Model for describing heavy ion collisions at relativistic energies have been studied. It has been shown that with the inclusion of shadowing several experimental results can be reproduced which otherwise remain unexplained within the ambit of Glauber model. A computer code to solve full (3+1) dimensional relativistic hydrodynamics is being developed.

The elliptic and the triangular flow parameters v_2 and v_3 of thermal photons as a function of p_T both at RHIC and LHC energies have been evaluated for different centrality bins using e-by-e hydrodynamics with fluctuating initial conditions and the results have been contrasted with experimental data. The correlation between flow parameters and their corresponding initial state anisotropies from their e-by-e distributions have been studied to understand the effects of initial fluctuations on v2 and v3. Relatively stronger correlation is observed in v2 and epsilon2 than v3 and epsilon3.

The upcoming Future Circular Collider (FCC) facility at CERN is aimed to study proton + proton collisions at center of mass energy 100 TeV which is about 7 times higher than the top LHC energy for P+P collisions. Heavy-ion collision at FCC (Pb+Pb at $\sqrt{}$sNN= 39TeV) is expected to produce initial states having much larger temperature and energy density than those produced at LHC and RHIC energies. One also expects to have a long lived QGP and larger system volume at FCC. Heavy ion collisions at FCC thus can provide us with much enhanced production of thermal photons and valuable information about the produced system. The thermal photon spectra and its elliptic flow at FCC, RHIC and LHC have been evaluated and contrasted with data wherever available.

As a part of the up gradation programme of ALICE, VECC in collaboration with BARC and BEL-Bangalore has built a prototype sampling calorimeter module. The module consists of alternate layers of

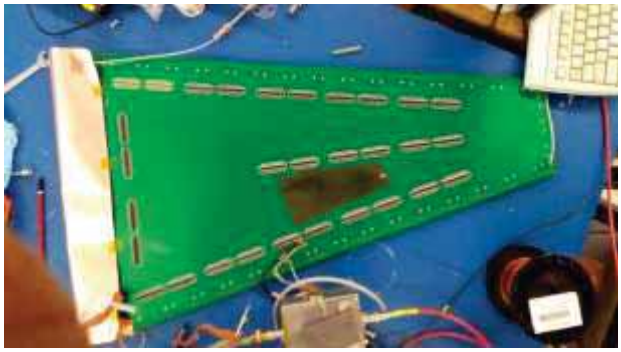


Si-Tungsten prototype calorimeter module being tested at CERN

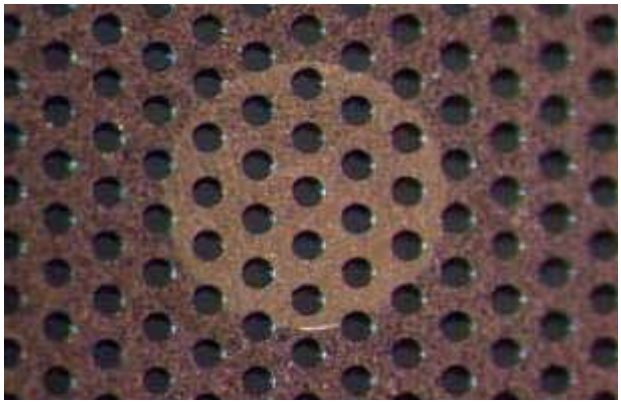
Tungsten converters and Si-pad detectors. The prototype has been tested successfully this year at CERN with pion and electron beams to study the formation of shower and its properties in detail.

The Photon multiplicity Detector (PMD) has successfully taken part this year in collecting data in LHC with Pb+Pb collisions at 5.02TeV center of mass energy. The detector modules and the readout system worked remarkably well during the data taking of more than 50 Million events generating unprecedentedly high particle multiplicity.

Two large-size advanced types of gaseous detectors i.e., Gas Electron Multiplier (GEM) and Resistive Plate Chamber (RPC) have been built and tested successfully at VECC during 2015. The GEM chamber of trapezoidal shape (length 80cm and larger width of 40cm) is a real-size prototype module built for the Compressed Baryonic Matter (CBM) experiment in the upcoming FAIR (Facility for Antiproton and Ion Research) facility at Darmstadt, Germany. The module of triple-GEM configuration has been tested with X-rays and proton beams using self-triggered electronics and has been found to give more than 95% efficiency upto a beam rate of 1.5 MHz/cm^2. For this chamber, GEM foils from CERN were used and other components built indigenously. An effort has also been made successfully recently to produce 10cm x 10cm size GEM foil at ECIL, Hyderabad and a single GEM chamber has been built and tested VECC using the ECIL made GEM foil.



Large size-GEM chamber at VECC



Close-up view of ECIL made GEM foil

A 2.5m x 1.25m RPC has been built at VECC using locally available bakelite sheets as electrodes. The module developed as a candidate of the INO RPC has not used any special surface treatment like oil-coating on the electrodes thereby making the production process considerably easier. The chamber has been tested with cosmic muons and found to give more than 95% efficiency, 15% uniformity over the surface and a time resolution.



Large size RPC built at VECC is being tested with cosmic muons

A 20 kW pulsed solid state amplifier and its 5 kW prototype amplifier system were designed and developed at RRCAT for the CLIC facility at CERN, Geneva. The prototype amplifier was first shipped to CERN for performance evaluation after which the fabrication of the 20 kW amplifier was completed. The 20 kW amplifier was thoroughly tested for its performance inclusive of heat runs of over 200 hrs. The amplifier has now been shipped to CERN.

A 30 kW solid state amplifier at 650 MHz has been designed and developed for the international collaboration program under Indian Institutions Fermilab Collaboration (IIFC). In this design, 15 kW of RF power was obtained by summing power output of 40 numbers of 500 watts RF amplifier modules using 40-way power dividers and combiners and high power directional couplers. The output power of two such 15 kW RF amplifier racks was combined using 2-way power combiner to get 30 kW RF power. RF



The 30 kW, 650 MHz solid state amplifier developed under the IIFC

power of 30 kW was tested with 50 ohms standard water cooled RF dummy load.

The LHC machine at CERN restarted (Run II) in 2015 after 2 years of shut down during which time consolidation of the machine as well as experiments were carried out to meet the challenges of LHC Run I. The LHC machine provided proton-on-proton collision at centre-of-mass energy of 13 TeV followed by proton-lead and lead-lead collisions at an energy of about 5 TeV/nucleon. For the Large Hadron Collider and Compact Muon Solenoid (CMS) Experiment, TIFR has participated in data collection, data quality monitor and data analysis. Also, several analyses based on Run I data are being collated. The current problem with magnet cooling is being mitigated. The CMS Collaboration also pursued a comprehensive programme of Phase I detector upgrades. Based on Run I collision data, the CMS collaboration has published about 80 physics papers in the last 6 months. Analysis of Run II data, collected in 2015 is ongoing and several results have been made public at an early stage. TIFR is also involved in the R&D activities of Phase II upgrade of CMS detector for LHC high luminosity operation.

The Belle experiment continued to study areas of rare decays of charm, beauty and strange-beauty mesons. An important milestone in building an electrically working prototype for the Belle II Silicon Vertex Detector (SVD), was achieved. The aim is to build one more electrically working prototype by March 2016, before entering the crucial production phase.

For the International Centre for Theoretical Sciences, the new campus at Shivakote, Hesaraghatta Hobli in north Bangalore was inaugurated in June 2015.The in-house research areas at the Centre grew successfully in disciplines like statistical physics and complex systems, gravitational wave astronomy and numerical relativity, non-linear dynamics and data assimilation, string theory and quantum gravity, and cross-disciplinary biology.

International Collaborations were continued at SINP with CERN in ALICE and CMS experiments and with SNOLab in PICASSO experiment. The two experiments, ALICE and CMS collected data with a very high efficiency and members of SINP took active parts in the data collection, data analysis and extracting important physics results from these experiments. The Institute has been a member of the ALICE collaboration since 1997 and is responsible for the Muon Spectrometer which is used to study heavy quark formation at the extreme forward angles in proton-proton as well as heavy ion collisions. The SINP team was involved in the development of the front-end electronics chip, fabrication of the second tracking station of the Muon Spectrometer and development of the di-muon high level trigger. The Institute has become a member of the CMS collaboration in early 2011 and has made a strong presence in the experiment from the very beginning taking major responsibilities in offline software and online data quality monitoring. The group is participating in the upgrade project of the hadron calorimeter and has successfully made part of the back end electronics of the future calorimeter system. Beamline in Photon Factory, Japan has been declared as Flagship project.

The Institute of Physics (IOP) remained actively involved in the International Collaborations with CERN (Switzerland), BNL (USA), ANL (USA),

GSI (Germany) and other laboratories abroad. The Institute is also participating in various research activities related to India based Neutrino Observatory.

For the Indo-Italian program on investigation of local structure and magnetism properties of Cobalt nanostrctures, most of the experimental part has been completed at the Institute of Plasma Research (IPR). Characterization, including synchrotron based analysis is in progress. As part of the project, an Indo-Italian work-shop (NEEM 2015) was held in Rome during October12-14, 2015. For the Indo-UK DST program Plasmonics based CZTS Solar Cells, IPR has successfully demonstrated that silver nanoparticle arrays are suitable as back reflectors and performed the MD simulation for the nanoparticle self-assembly. Optimisation of CZTS solar film is going on.

A MoU was signed between IPR and M/s B L Engineering, Ahmedabad in March 2015 for transferring Plasma Pyrolysis technology for solid waste. The MoU is for five years and on non-exclusive basis. A technical consultancy agreement was signed between IPR and GIFT city (Gandhinagar, Gujarat) for setting up of a 15 Kg/hr capacity plasma pyrolysis system for solid waste disposal at GIFT city premises in September 2015. The demonstration of this unit will pave the way for establishment of plasma pyrolysis as a candidate technology for smart cities. A MoU was signed between IPR and CLRI, a CSIR lab in Chennai in June 2015 for developing a plasma pyrolysis system for disposing tennary waste. A MoU was signed between IPR and WRA at Thane in Maharashtra for the improvement in surface properties of woollen fibres and fabric, in December 2015.

IMSc continued the joint projects with International Institutes on India based Neutrino Observatory (INO) and DINO (Darkmatter at INO), EU-FP7 Indo-European Network on Mathematics in Health and Disease and Belle & Belle II Collaboration.

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.

Total 14 out of 15 Procurement Arrangements (PA) have been signed. Pre-procurement activities for remaining PAs are going on. Eleven major contracts have been signed till date for the manufacturing of ITER components. Good progress has been made at the manufacturing site and some components are delivered to ITER and also to other Domestic Agencies sites. Quality audits were done regularly at the manufacturing sites by both ITER-India and ITER Organization teams. Good progress has been achieved at various other R&D activities that are necessary are being done at the ITER-India laboratory, which will then be transferred to the vendor site after due process and approval.

The summary of activities completed during the reporting period is given below:

So far the earned value in terms of credit received from ITER Organization (IO) is 21526 IUA (ITER Units of Account). Task Agreement (TA) credit received from IO till date is 2833.669 IUA.

Cryostat Base section Tier-1 manufacturing is completed and delivered at ITER site at France and manufacturing of Lower Cylinder is in progress. For In-Wall Shielding (IWS), Platforms for PS-2 of VS-4 and VS-5 are manufactured and delivered to EU-DA. Fabrication of support ribs and lower brackets for PS-1 of VS-6 has been completed and delivered to KO-DA. Factory Acceptance of manufactured IWS components is in progress. Manufacturing of first Lot of Cooling Water piping is completed and delivered at ITER site, France. Manufacturing of Acceleration Grid Power Supplies (AGPS) for SPIDER facility has been completed and will be shipped soon to Padova, Italy. Manufacturing of Prototype Grid for DNB Accelerator and for Prototype Post Insulators has been completed.

Prototype Cryoline installation at ITER-India lab is completed and qualification test is in progress. Cold Circulators has been installed in the Test Auxiliary Cold Box (TACB) and was tested



Prototype Cryoline Installed at ITER-India Laboratory

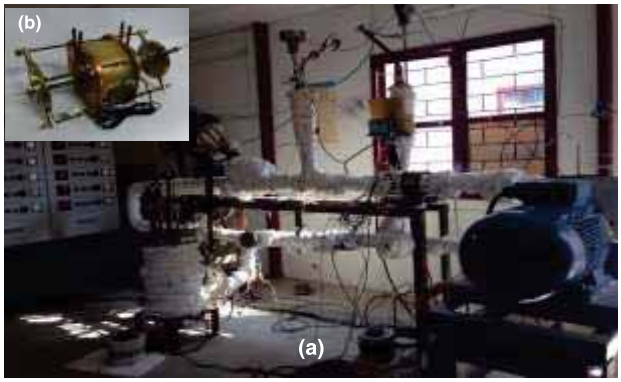


Diagnostic Neutral Beam Vessel with detachable top lid configuration installed and commissioned at ITER-India lab

successfully in Japan. Commissioning of Driver stage amplifier (HPA-2) in the frequency range 35-65 MHz is completed successfully. Diacrode based final stage amplifier (HPA-3) has been integrated with driver stage (HPA-2) amplifier and commissioning of HPA-3 is started at ITER-India lab. Vacuum vessel for Diagnostic Neutral Beam (DNB) is successfully installed and commissioned with all the interface needs for Operating components at ITER-India lab. Prototype Grid for DNB Accelerator and Prototype Post Insulators have been tested electrically upto 140kV and mechanically beyond 10kN. Development of Scaled & Full scaled Residual Ion Dump Panel was completed. Design and procurement activities for Gyrotron Test Facility at ITER-India lab is in progress.

Preliminary Design of Cryostat Instrumentation is nearing completion. Final design review was completed for Lot Y2 Cryolines and Preliminary Design Review was completed for Lot Y1 Cryolines. Preliminary Design review activities of Cryoplant Termination Cold Box (CTCB) of Cryodistribution System is in progress. Design and optimization of radiometer and power cum frequency splitter unit for the same has been completed. Design activities for Upper Port 9 viz. Thermo-hydraulic analysis, interface detailing and EM load analysis was performed.

For the Test Blanket Module (TBM) Program, Lead-Lithium R&D activities are focused towards the development of precise diagnostics for measurement of Pb-Li pressure, flow rate, and Pb-Li level in various tanks etc. for prolonged operation. In this connection, a sensitive flowmeter using water cooled Hallbach magnet has been developed, calibrated and successfully tested in Pb-Li environment. Remotely controlled pneumatic actuator valves, with operation range up to ~400°C have also been tested in a dynamic Pb-Li flow loop for 1000 hr duration. Pb-Li production system has also been developed and trails run have been started for indigenous development of Pb-Li eutectic alloy. An experimental set up is indigenously built to estimate the effective thermal conductivity of uncompressed lithium ceramic pebble bed in stagnant helium gas environment to simulate the thermal behaviour inside the fusion blanket. It is based on the principles of the steady state and axial heat flow method.



(a)Hallbach magnet arrangement
(b)Lead-Lithium loop for diagnostics testing



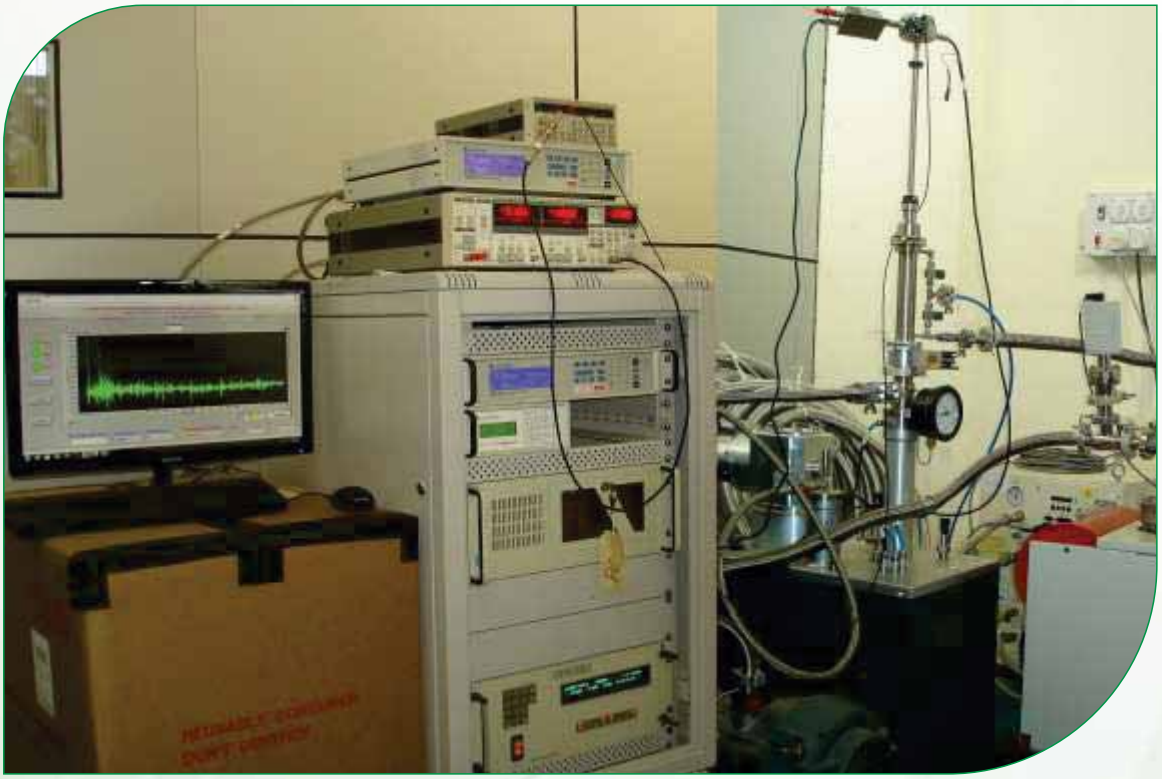
A small scale Pb-Li production system developed and tested

CHAPTER-6

RESEARCH EDUCATION LINKAGES



SST-1 Vacuum Vessel with installed First Wall Components



Experimental facility of Resonant Ultrasound Spectroscopy

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).

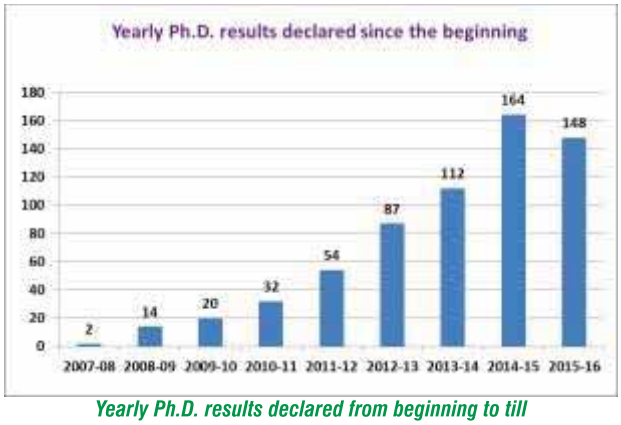
The Board of Research in Nuclear Sciences (BRNS) an advisory body of the Department of Atomic Energy (DAE) provides financial assistance to universities, academic institutions and national laboratories for encouraging and promoting scientific research in the areas of relevance to the mandate of DAE.

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) accredited as a deemed to be university by Ministry of Human Resource and Development (MHRD) has now completed ten years of its existence and it continues to grow. It has eight Boards of Studies namely as Chemical Sciences, Engineering Sciences, Health Sciences, Life Sciences, Mathematical Sciences, Physical Sciences, Strategic Studies and Undergraduate Studies. Degrees and diplomas awarded by HBNI include Ph.D, Integrated Ph.D, M.Sc (Engg.), M.Phil, M.Tech, M.Sc., Integrated M.Sc., DM, MD, MCh, M.Sc (Nursing), Post Graduate Diploma, Diploma in



Yearly Ph.D. results declared from beginning to till December, 2015

Radiation Protection, DRM and DMRIT. During this period, M.Tech. Programme at IPR has been started. Around 800 students are admitted every year and the total number of students enrolled with HBNI is more than 3300; out of this Ph.D enrolment number alone is around 1500. Till 31st December 2015, the Institute has awarded 633 Ph.D., 814 M.Tech, 9 M.Phil, 85 M.Sc. (Five years integrated and as a part of integrated M.Sc.-Ph.D programme), 33 M.Sc. (Engg), 243 Post graduate medical degrees, 206 Diploma in Radiation Protection, 56 Diploma in Medical Radioisotope technology and 42 Diploma in Radiation Medicine. During the period, 14 engineering Post-graduate students were inducted for DAE Graduate Fellowship Scheme (DGFS) for Ph.D. 148 students have been awarded Ph.D. degree till December, 2015. This number is likely to touch around 200 by the end of March, 2016. The following figure illustrates the yearly (April 1st to March 31st) Ph.D. results declared since beginning up to December, 2015.

HBNI continues to strengthen its linkages with premier research and academic institutes in the country and abroad. It has MoUs with many institutes such as Institute of Chemical Technology, Mumbai; Indian Institute of Science, Bangalore; Indian Institute of Technology, Bombay; Indian Institute of Technology, Madras; Indian Statistical Institute, Calcutta; Jadavpur University, Kolkata; Indian Institute of Technology, Kanpur; Tata Institute of Fundamental Research, Mumbai; Chennai Mathematical Institute, Chennai, University of Virginia, USA; CEA, France; University of North Texas, USA. During the year, three meetings of Council of Management, one meeting of Academic

Council and three meetings of Standing Committee of Deans-Academic of HBNI were held.

A Self Study Report (SSR) for submission to National Assessment and Accreditation Council (NAAC) was drafted and submitted. Subsequently, a peer team of NAAC visited HBNI for accreditation during April 25th to May 2nd, 2015. HBNI was accredited as 'A' grade university by NAAC.

Training School

Selection of trainees under Orientation Course for Engineering Graduates & Science Post-Graduates (OCES) and DAE Graduate Fellowship Schemes (DGFS) at BARC were pursued with high standards. BARC scientists were actively engaged in teaching, project handling, conducting laboratory practical and seminars for the BARC OCES programme. The Continuing Education Programme QUEST offering advanced courses to DAE staff located in Mumbai and to HBNI students continued. The One year post-M.Sc. Diploma in Radiological Physics course continued to meet the mandatory trained manpower requirement of radiation safety professionals in medical, industrial, research and agricultural applications of radiation.

Other academic programmes such as Diploma in Radiation Medicine (DRM), DNB in Nuclear Medicine were continued for Medical Graduates registered under Homi Bhabha National Institute, Mumbai (Deemed University). 3 students for DRM and 2 students for DNB are currently undergoing these courses. Medical Council has approved BARC to conduct MD (Doctor of Medicine) in Nuclear Medicine and two seats were granted. The course has commenced and is being continued. Eight students are pursuing the Diploma in Medical Radio Isotope Techniques (DMRIT) course.

Facilities were provided for practical training and executing projects for post-graduate students of various universities as well as Indian Academy fellow students. National Training Course on “Physical Protection of Nuclear Material and Nuclear Facilities” for security personnel and a 2 week National Training Course on “Design & Evaluation of Physical Protection System for Nuclear Material and Nuclear Facilities” were held at Mumbai.

At IGCAR, 46 Trainee Scientific Officers of the ninth batch completed their training in six disciplines and were placed in various units of DAE. In the present academic year, 37 Trainee Scientific Officers are undergoing training at the Training School. In the current batch, 52 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 sixth year by imparting induction training to 12 nos. of Geology and 5 nos. of Geophysics Trainee Scientific Officers (TSO). Human Resource Development was continued with in-house and external trainings in various institutes. 91 trainees and students from universities made study visits to AMD Headquarters and Regional Centers. AMD studentship programme and BRNS projects were continued in collaboration with various University/Academic Institutions as part of R & D efforts of AMD.

Human resource development activities at RRCAT were continued to be enhanced by extending the available research facilities for training of university students in the areas of accelerators, lasers and their applications. A large number of students carried out research work for their Ph.D. degree under the framework of Homi Bhabha National Institute. Opportunities were also provided to M.Tech / M.Sc. students to carry out their one-year / six-months project work towards partial fulfilment of their degrees.

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 with the optimized manpower models for Projects, Stations and Headquarters including multiunit Sites.

NPCIL consists of 11,583 strong and dedicated workforce (with 3670 engineers and scientists, 5944 technical employees, 1606 non-technical executives and staff and 363 auxiliary support staff) who spearhead the activities of organization. During the year, as a part of annual induction program of young talent to NPCIL, 13 Medical Professionals and 41 direct recruits in scientific categories (Group-A & B) were recruited through centralized recruitment process. In the career progression front, during the year, 872 employees in Scientific and Technical categories & 222 (85 executives and 137 non-executives) in non-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 is in operation and has been proved very successful and instrumental in improving the production by boosting morale of the employees and executives. In addition to this, award scheme for encouraging employees to work towards achievement of organization goals in an efficient and effective manner is in place in NPCIL.

Thirty Five Post M.Sc students were inducted into the research & teaching program of SINP during the year 2015-16. About 10 undergraduate associates and 30 students in the summer program are being trained in the Institute coming from different parts of the country.

The academic activities for Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) and Centre for Cancer Epidemiology (CCE) continued as in the past. At TMC, education is offered through several PG courses, training through short term Observer-ship and various other training programs. About 112 Post graduate Medical students were registered in 2015 for PG courses in various disciplines. One year Diploma in Fusion Technology was approved by HBNI. M.Sc. in clinical research has been initiated in 2015. About 500 specialists were trained under observership during the year and received about 38 specialists from countries like South East Asia, South Africa, West Indies and UK, and other neighbouring countries. About 120 graduate students worked towards the Ph.D. degree at ACTREC. These included 22 students of the JRF 2015 batch. As a part of the Centre's Short term and Summer Training program, 299 trainees worked under the supervision of the Centre's faculty. Eighteen local, national or international conferences, symposia, workshops, etc. were organized at the Centre, including one International Conferences focusing on Molecular pathways to therapeutics and a workshop on Genome Consortium (ICGC). The Centre also hosted 26 national and international experts who delivered research seminars on a variety of topics in the life sciences and cancer. Several cancer awareness and patient support programs were also conducted during the year.

IOP contributed in a significant way towards quality Human Resource Development in the form of one year pre-doctoral course followed by Ph.D. program. During the year, six scholars joined the pre-doctoral programme while six doctoral scholars received their Ph.D. degrees. Also, 13 Post-Doctoral Fellows joined the Institute in the year 2015-16.

In addition to offering an intensive Master's level and advanced courses for the students at HRI, the faculty members attended several conferences both in India & abroad and also visited other institutes, universities & colleges and gave lectures on the latest activity in several areas of Theoretical Physics. The Department of Physics conducted an outreach program which received a large number of undergraduate and graduate students from all over India to carry out projects on various topics of current research interest and hosted a visitors' program that attracted a large number of scientists from India and abroad. The group also organized instructional

schools to introduce young researchers and students to emerging areas. Another outreach activity called talent search examination was also conducted for senior school students in Allahabad to motivate them to pursue research in Physics. In the short span of less than 20 years the institute has produced over 50 alumni who have gone on to become faculty members at leading research institutions and universities in the country. HRI envisages an expansion of these activities in coming years with the introduction of a stand-alone, unique Master's program from 2016 that will train students to pursue inter-disciplinary research.

IMSc continued the intensive teaching programme with a high level quality. Students were selected at the graduate and postgraduate level through an all India joint entrance screening test followed by an interview. During the year, 6 Doctoral students were awarded Phd degree, 5 have submitted their Ph.D thesis and 11 students have submitted MSc thesis. Apart from this regular activity, IMSc also offered the opportunity of learning to few students during the summer vacation period. These students spent up to 6 weeks doing projects with faculty members. Several students visited the Institute for a semester working on short-time research projects.

Administrative Training Institute

The Administrative Training Institute (ATI), which commenced functioning with the motto "Prashikshaneshu Dakshprayate – Training Empowers" has made its presence at national level by bagging the National Award for Excellence in Training, 2015 in the category of Management of Training from Department of Personnel and Training, Government of India and UNDP.



Smt. Savithri Mani, Director, ATI receiving National Awards for Excellence in Training for the year 2015 on behalf of ATI, DAE

ATI has organized over 700 programmes and has covered over 19,000 participants with the help of the robust Training Management Information System (TMIS) developed in-house. This package takes care of major training activities right from drawing calendar, preparing schedules, nomination data, confirmation, faculty database, feedback, budget and expenditure management etc.

ATI offered wide range of programmes starting from induction to post retirement and periodic in-service programmes, subject specific workshops ensuring depth and range. Post training support for transfer of learning was another key feature of the training. ATI's another major achievement has been the "training at doorstep" for the different units. The methodologies adopted for delivery of training were face to face, distance learning and blend of both.

In addition to the face to face programme, over hundred Self-Learning Modules to help in learning at own place and pace with the focus of wider number of employees coverage have also been developed.

Against 110 programmes earmarked for the financial year 2015-16, ATI conducted 75 programmes till December 2015. This included one Experience Sharing Programme of the Heads of Units, two Experience sharing programmes of the Administrative Heads of Units, sixteen Personal re-engineering programmes exclusively for the CISF personnel stationed at various Units in NFC, Hyderabad, BARC, TAPS, KAPS, KAIGA, HWP, Manuguru and IGCAR, Kalpakkam.

Some of the major highlights of the ATI training programmes included Two six months long programmes on Hindi Stenography; Four induction



Experience sharing workshop of Secretary, DAE and other Heads of Units/PSUs/Aided Institutes held on 22.8.2015 at NUB, NPCIL, Anushaktinagar

training programmes for clerical / auxiliary cadres; Three programmes on Project Management; Four programmes on Ethics and Values in Administration for various levels of officials at Initiatives of Changes, Panchgani; Language essentials on Tamil, Kannada etc.; Workshop on Trade Union Activities; Pension and Retirement Benefits; Professional Development Programmes for Scientific Officers; Programmes on Information Tools; Workshop on Reservation in Service for Office bearers of Unions / Associations; Art of Writing for Scientific and Technical category officials; Workshop on Intellectual Property Rights; Security Awareness Programmes; Preparation of Handbook on Report Writing and Preparation of electronic archives of the programmes conducted during 2007-2012.

SPONSORED RESEARCH

Board of Research in Nuclear Sciences (BRNS)

The 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. While the Visiting Scientists programme of BRNS is meant for promoting short term in-house interactions amongst senior level experts, the Raja Ramanna Fellowship of BRNS is for reasonably long-term involvement of the eminent scientists and engineers in the various ongoing programmes of the Department. The Homi Bhabha Chair sponsored by BRNS is instituted to avail the honorable services of Scientists and Technologists who have distinguished themselves at national and international levels.

During the year 2015-16, 214 new research projects were sanctioned till December 2015.

Under DAE Graduate Fellowship Scheme (DGFS), fellowship was offered/awarded to Nine M.Tech. students studying in 5 different IITs. Thirteen new students were inducted under DGFS-Ph.D programme, bringing the total number of Ph.D. students under this scheme to 100.

Financial support to the tune of ₹ 230 Lakh was extended for conducting 121 seminars, which were conducted by professional organizations on various topics of relevance to DAE. Out of these, fourteen symposia were solely organized by the DAE fraternity and they were fully funded by BRNS. About 73 fellowships were offered under the Raja Ramanna Fellowship Scheme (Senior Scientists Scheme) and 3 Homi Bhabha Chairs were awarded.

Promotion of Mathematics

The National Board for Higher Mathematics (NBHM) continued to provide 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 in charge of the Mathematics Olympiad activity for talented young students at higher secondary level. This activity was 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) was decided through the Regional Mathematics Olympiad (RMO) and the Indian National Mathematics Olympiad (INMO) at the national level. Selected students from INMO were offered further summer training in mathematics through a Nurture programme for the succeeding 4 years and were provided scholarships and cash prizes.

This year six-member team secured 1 Silver medal and two Bronze medals and three Honourable Mentions at the 56th International Mathematical Olympiad held at Chiang Mai, Thailand from 4-6 July 2015.

NBHM continued to conduct Madhava Mathematical Competition for the undergraduate students. This competition has been designed 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 gave grants to various mathematical centres engaged in activities of promoting higher mathematics. The Chennai Mathematical Institute that runs a high quality undergraduate programme in mathematics has been 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, were the other institutes getting grants from NBHM based on various programme proposals.

Taking proactive role in spotting talent in the country, the Board provided scholarships and fellowships to the students, selected through nationwide competitive tests, to pursue studies at masters and Ph.D. levels.

During the summer vacation, active training programmes were organized outside the regular educational framework at the undergraduate level, called Mathematics Training and Talent Search. Supplementary training activities were also undertaken for selected students at postgraduate level, in a coordinated fashion, under the Advanced Training in Mathematics (ATM) programme.

During the year, NBHM sponsored 51 delegates for participation in the prestigious International Congress of Industrial and Applied Mathematics (ICIAM) -2015 event, held in Beijing, China during August, 2015.

NBHM has been providing grants to mathematics libraries around the country to enable them to purchase the latest books and journals in mathematics. Around 96 such libraries took advantage of this scheme of NBHM and updated their collections of Journals / Books in mathematics. NBHM also distributed selected books to various postgraduate institutions under its book distribution scheme.

Financial support was provided to 73 national and international conferences held in India and for 20 research projects. Travel grants were provided to 48 mathematicians to enable them to participate in conferences held in India and abroad. One university was provided faculty support in the form of two Visiting Professors, to strengthen the research and teaching potential at the institute. Post-Doctoral Fellowships were awarded to 67 researchers for the period of 3 years and 45 candidates were selected for the pursuance of NBHM Ph.D. programmes.

The new Web-based interactive system for communication, evaluation of proposals is in the advanced stage of completion.

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 following nine 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. University of Mumbai & Department of Atomic Energy Centre for Excellence in Basic Sciences (UM-DAE-CBS) has been recently granted the status of Aided institution of the Department of Atomic Energy w.e.f. 1st January, 2016.

The funds (Plan & Non-Plan) allocated (in crores) to these Aided Institutions by the Department of Atomic Energy during the financial year 2014-15 were TIFR - ₹ 666, TMC-₹ 540, SINP-₹ 119, IOP-₹ 36, IMSc,-₹ 49, HRI-₹ 39, IPR-₹ 630, AEES-₹ 72, NISER-₹ 91 and HBNI-4 crores.

Grants to Cancer Hospitals

The Department of Atomic Energy (DAE) is releasing grant to Dr. B. Barooah Cancer Institute (BBCI), Guwahati through Tripartite Agreement [which was signed among DAE, the North Eastern Council (NEC) and the Government of Assam]. This hospital is a Regional Cancer Centre (RCC) for

cancer treatment and control in the North Eastern Region (NER). During the year 2015 – 16, an amount of ₹ 12.36 crore has been released to the institute by the department.

The Department also extends financial assistance to Cancer hospitals located in other parts of the country. The budget provision for the year 2015-16 for such partial financial assistance is to the tune of ₹ 20.00 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 Department of Atomic Energy provides financial support for organizing Olympiad programmes and for participation in International Olympiads in Physics, Chemistry, Biology, Mathematics, Astronomy & Astrophysics and Junior Science Olympiad. The Indian Science Olympiad Programme supported by DAE, Department of Science and Technology and Ministry of Human Resources Development continued to bag laurels for the country.

Laboratories for physics Olympiads were strengthened and intensive preparations were carried out by HBCSE (Homi Bhabha Centre for Science Education) for the International Physics Olympiad which concluded in July 2015. Several teacher professional development workshops were conducted in mathematics and science, including one for physics teachers from Karnataka. In the learning sciences laboratory, a multi-touch interface was developed.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

Integration, Testing & Commissioning of BHEL steam water system / turbo generator Simulator

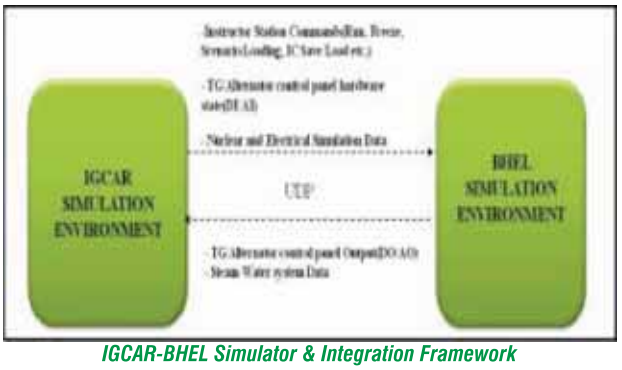
As a collaborative effort between IGCAR, BHAVINI and BHEL (Bengaluru), the steam water system / turbo generator simulator, a part of PFBR Operator Training Simulator, was commissioned at



Training Simulator



BHEL Simulator DCS Snapshots



IGCAR-BHEL Simulator & Integration Framework

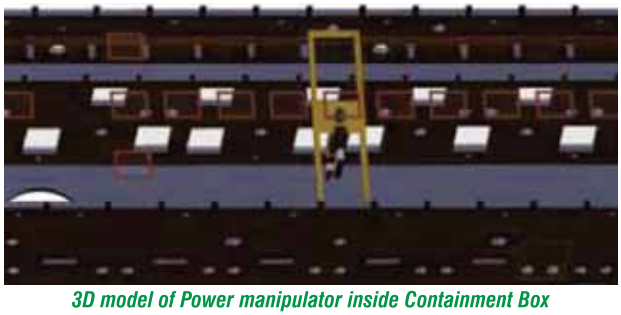
the Training Centre, BHAVINI. The simulator mainly consists of process models, virtual controllers and digital control system. The commissioning task comprised integration and synchronization of BHEL simulator with IGCAR simulator that was already in place, checking of process models and associated logics and controls, checking of parameter display tables, system flow sheet mimics and integrated performance testing. All the works related to commissioning were completed and the integrated simulator is ready for operator training.

Deployment of Wireless Sensor Network for Radiation Monitoring

Radiation monitoring is an integral part of the nuclear power plant. Area Gamma Monitors with local alarm facilities were placed at various entry/exit points for monitoring the radioactive material movements in Kalpakkam nuclear complex. In order to provide a centralized view and to have the record of events for future analysis, a Wireless Sensor Network was deployed. Dedicated Wireless Network Management Station was developed to display the radiation dose and trend of individual area gamma monitors.

3D Modeling and Animation of Power manipulator and Containment Box of Pyroprocessing R&D facility

A facility is being setup for demonstrating the important process steps in pyro-processing technology. Towards this, an interactive 3D visualization model was created to perform the interference and reachability analysis of power manipulator and containment box. The model aids in checking of interferences between various process equipment before actual erection and checking the feasibility of remote operation and maintenance prior to actual execution. Interactive animations of the various degrees of freedom of the power manipulator were created and integrated with virtual control panel similar to actual control screens. Viewing cameras were set up for enhanced visibility of animations. The 3D models and animations were ported to the Advanced Visualization Centre for viewing the system in 3D environment.



3D model of Power manipulator inside Containment Box

Advanced IT Enabled Customizable Knowledge Management Portal for IGCAR

The knowledge management portal aids in preserving and disseminating the knowledge and information in an organization. An enhanced, IT enabled, dynamic and customizable web based knowledge management portal was developed at IGCAR. The portal facilitates preservation of the explicit knowledge and dissemination of the required knowledge to the employees through online in an intranet. The uploaded knowledge assets in the central repository are classified based on extensive knowledge taxonomy topic tree for easy access. Advanced access restriction is provided for confidential documents of a particular Group/Division in organization. The portal is being used by the employees of various groups in IGCAR.



Advanced Knowledge Management Portal for IGCAR

Development of continuous air monitoring system

An indigenous continuous air monitor for plutonium has been developed jointly by IGCAR and BARC for use in radiological facilities.



Schematic diagram of RRCAT secure cloud drive

The aggregate computing power available to scientists and engineers in RRCAT now stands at 43.08 Teraflops with integration of a high performance computing cluster, Kshitij-4. Software for RRCAT Secure Cloud Drive has been developed, deployed and released to senior scientists. The facility enables access to large files over internet with necessary data security mechanisms in place. Workflow based software for activity management related to Indus upgradation/ maintenance/ shutdown has been developed and deployed on RRCAT Infonet for use by all concerned officials working for Indus operation and maintenance. Web based MIMIC panel for electric fence was developed and deployed for identifying location of the fault on a graphical representation.

As part of implementation of IT-enabled major work processes in NPCIL, various Computerized Based Systems (CBSs) were introduced which included Integrated Work Management System (IWMS) to create, assign, delegate and monitor for managing various maintenance tasks in the Nuclear Power Plants; Data Loss Prevention (DLP) capability for online data replication onto another server to enhance the availability of enterprise data with near total DLP capability; Samavikas for a comprehensive management of the Corporate Social Responsibility (CSR) programmes covering CSR Project Proposal submission by Stations, approval by HQ, online status reporting and project closure, CSR committee meeting management, etc.

CHAPTER-7

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES



Solar photo-bioreactor



Diagnostic Neutral Beam Vessel with detachable top lid configuration installed and commissioned at ITER-India lab

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

Solar Energy driven portable domestic Brackish Water Reverse Osmosis (BWRO), Stand-alone solar Photovoltaic (PV) driven battery-less Ultrafiltration system and Bicycle mounted water purification (RO/UF) unit driven by hybrid power system were transferred to private entrepreneurs for commercial deployment.



Solar BWRO plant with PV panels and DC pump

A total of 26 technologies have been transferred till December 2015 to 40 Parties. Eight new technologies introduced into public domain during the year were Optical spectrometer, Compact Full Range Vacuum Gauge with Electronic Control Unit (FRVG), ANUSPECT Gamma Spectrum Analysis software, Peripheral Pulse Analyzer, Hydrogen Sulfide Sensor, Compact SMPS based Sputter Ion Pump Power Supply, Biopesticide Based on Bacillus Thuringiensis Subsp. Kenyae HD-549 and Partially hydrolyzed guar gum for dietary fiber application.

Licenses for the 5 technologies that were renewed during the period were for “Rig Testing of Combined Particulate & Iodine Filters”, “Production of CaSO4 : TLD Card & Production of Dy. Doped Calcium Sulphate TLD Powder”, “Auto TLD Badge Reader”, “Spectroscopy Amplifier” & “Digital Pocket Radiation Dosemeter (DIGIDOSE)” and Renewal of MoU for incubation of Biodegradable and Edible films for Food and Pharmaceuticals.

BARC technologies posters were displayed at Golden Jubilee Special Agricultural Mela held at Agricultural College & Research Institute, Madurai; The International Conference on Electron Microscopy along with The XXXVI Annual Meeting of the Electron Microscope Society of India and at the National Symposium on Vacuum Technology and its Applications to Elctron Beams (IVSNS-2015) at Tata Institute of Fundamental Research, Mumbai.

COLLABORATIVE PROGRAMMES

Collaboration with Industry under Incubation included Incubation of Development of a Radioprotector Drug technology, Development of Diamond Waste Powder (Uniform Size Particles) Processing Methodology and Development of Fluoride Removal Reagent.

In order to promote technologies developed by BARC for rural populace, establishment of DAE Technology Display & Dissemination Facility (DTDDF) centres all over India are proposed under XII Plan in collaboration with educational institutes. Out of 24 proposals that were received from all over India, Preliminary meetings and site visits to 7 institutes have already been concluded. Further, MoUs with two institutes have been finalized.

SOCIETAL INITIATIVES

To promote rural entrepreneurship with BARC technologies under Advanced Knowledge & RUral Technology Implementation (AKRUTI) Tech Pack, four agreements were approved for signing with Companies/ Organisations and Individuals. The agreements provide a perpetual licenses for exclusive rural deployment of the technologies like Foldable Solar Dryer, Domestic Water Purifier, Soil Organic Carbon Detection and Testing Kit, Nisargruna, Vibrothermal disinfestor, Solar BWRO, Dip N Drink Membrane Pouch, Litchi Preservation and Banana Tissue Culture.

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 calendar year 2015, five DAE-IPR cell meetings were held. Ten new inventions and one national phase entry were reviewed for the patentability. DAE filed eight new patent applications which includes two applications under PCT (Patent Co-operation Treaty), five Indian and one application in USA.

During the year, seven of the previously filed patents have been granted to the Department. These include two each in India & USA and one each in Canada, Europe & South Africa. Following are the list of patents granted:

1. A penetration enhancing flux formulation for Tungsten Inert Gas (TIG) welding of austenitic Stainless steel and its application – by IGCAR (in India)
2. Single stage purification for uranium refining – by BARC (in Canada)
3. An innovative 'cut-and-feed' operation for enhancing the performance of ion-exchange chromatographic separation – by IGCAR (in Europe validated in France)
4. Generator of Collimated variable diameter hollow laser beam – by RRCAT (in India)
5. A Tri-Butly Phosphate (TBP) nitrate solvent extraction process for producing high purity nuclear grade rare earth metal oxide – by NFC (in USA)
6. A dual purpose atomic device for realising atomic frequency standard and magnetic field measurement – by BARC (in USA)
7. A method and equipment for separating non-conducting and non-magnetic minerals – by IREL (in South Africa)

The following six patents were commercialized and licensed to eight companies:

1. Ultrafiltration Membrane water purification device (by BARC)
2. A Storage Stable Microbial Decontaminated Litchi (Litchi Chinensis) with Extended Shelf Life retaining Pericarp Color and a Process thereof (by BARC)
3. Process for production of Biofungicides, such as trichoderma Spp. using Tamarind Seeds (by BARC)
4. A wound dressing capable of in-situ No_x release and a process for manufacturing the same (by BARC)
5. A penetration enhancing flux formulation for Tungsten Inert Gas welding of austenitic Stainless steel and its application (by IGCAR)
6. A method for treating exhaust gas emission produced during combustion of coal in a coal combustion plant for reducing suspended particulate matters (by HWB)

Apart from Patents, DAE has also filed 200 Trademarks applications during the period. These applications were filed under various Classes and consists of 49 logos, 31 word marks which include the acronyms of DAE and its 29 Units and the DAE slogan "Atoms in the Service of the Nation".

During the year, 101 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 regular training program, Patent Awareness lecture was delivered to trainees of the 58th BARC Training School, Mumbai. Lectures were delivered to trainees of the BARC Training School at AMD, Hyderabad [OCES-2014 and OCES-2015 Batches]. A one day Intellectual Property Awareness program was conducted for scientists at BARC, ECIL and IGCAR under the ages of Administrative Training Institute at their respective sites.

CHAPTER-8

INFRASTRUCTURE



Convention centre at Anushaktinagar, Mumbai



Construction of NISER Project at Jatni, Bhubaneshwar

CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible for providing infrastructure support to various Units of the Department of Atomic Energy (DAE) including its aided institutions. DCSEM is involved in planning, design & execution of various construction works for Housing, Schools, Hospitals, Laboratories, Institutional Buildings & infrastructural facilities to support 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, the major works completed by DCSEM at Anushaktinagar included the construction of first stone cladded Convention Center/Sr.Officers Guest House at Anushaktinagar Township consisting of two Auditoriums of 780 & 180 Pax and Guest House of 40 nos. of double occupancy rooms and 20 suites.



Convention centre at Anushaktinagar, Mumbai

Residential Quarters for CISF (II-B & IV-D) along with services & development work; Underground water tank of 10 lakh litre; Video Surveillance System; Renovation of Community Centers and Renovation of Residential Quarters for Phase-I (3150 flats); Other miscellaneous work like Police Chowky, Approach road for Convention Centre were completed.



Residential Quarters for CISF (II-B & IV-D)

Various works of DCSEM at Anushaktinagar, Mumbai under progress were the Restoration / Renovation of Old Houses more than 20 years old Phase-II; Up gradation of services under 12th Plan; Construction of 356 residential quarters; Hostel for trainees of BARC/HBNI Phase- I&II and Construction of Extension of V.S. Bhavan, Building for Fission based ^{99}Mo Production facility for BRIT.

Tender for about 312 flats for type V-E at Mandala, Anushaktinagar has been finalized and is awaiting clearance for award of work.

Major construction works completed by DCSEM for other units/ Autonomous units of DAE were as follows:

Construction of NISER Project at Jatni, Bhubaneshwar: a center for Education and Research in Basic Science. Work is under advanced stage of completion.



Construction of NISER Project at Jatni, Bhubaneshwar

Construction of ICTS (International Centre for Theoretical Sciences) Project at Shivakote, Hesarghatta, Hobli in North Bangalore, to provide infrastructure and resources for in-house research and a place where researchers from around the world can meet and interact in multi and interdisciplinary scientific discipline to make India a hub of Science. The Centre has a world class Residential and Educational campus with a modern library, state-of-the-art computing and networking



ICTS, Bengaluru



Academic block and Seminar & Library block

infrastructure and data centre with high speed connectivity, Auditorium and lecture hall equipped with modern audio-visual equipment for recording and broadcasting ICTS activities, Housing, Hostel, Dispensary and Child Care Centre etc. It is the 1st GRIHA rated complex constructed by DCSEM.

Phase-I construction of Global Centre for Nuclear Energy Partnership (GCNEP), which includes SNSS & Guest House Block 'A' building along with associated electrical works at Kheri Jassaur near Bahadurgarh, Haryana are under advanced stage of completion.

Construction of First Research and Technical (FReT) Block for TIFR, Hyderabad and Construction of Facilities for Research in experimental Nuclear Astrophysics (FRENA) laboratories for SINP, at Bidhannagar Kolkata are in progress.

Major work orders issued during the period under report were 100 bedded hospital & Ancillary building for TMC at Visakhapatnam (Retendered), Construction of R&D Laboratory for AMD and Eastern Regional Regulatory Centre for AERB building at VECC Kolkata.

Engineering Services Division of this Directorate maintains residential flats and public buildings of the Department in Mumbai including execution of up-gradation works required for the buildings. The Division is also responsible for the operation & maintenance as well as up-gradation of electrical power distribution, lifts, water supply, sewer lines, sewage treatment plant, fire fighting system etc. of the township at Anushaktinagar, Mumbai.

The Estate Management Section of this Directorate continued to manage the estate of DAE

and allotment of residential flats (10169), shops including public buildings and the security for the DAE Estate in Mumbai.

During the period of the report, schemes worth ₹ 321 Crores were executed for various DAE units including projects for DCSEM worth ₹ 130 Crores.

PURCHASE & STORES

Directorate of Purchase and Stores is one of the service organisations in Department of Atomic Energy set-up for shouldering the responsibility of Material Management activity with a mandate to procure right material at right price from right source, storing the same and issue to various constituent units of the Department. DPS caters to material management needs not only of Research and Development units of DAE but also of its industrial units i.e. Heavy Water Board, Nuclear Fuel Complex and Board of Radiation and Isotope Technology. With the increasing plan outlays and available infrastructure, DPS has taken initiative for utilizing information technology to meet new challenges of increasing departmental needs with no corresponding increase in manpower. DPS also concludes various service contracts such as transportation contracts, import / export clearance contracts, Marine Insurance Contracts, etc.

During the year, following works were carried out in DPS:

Enhancement of IT Infrastructure

For the purchase unit, steps for creating infrastructure for implementation of end-to-end e-procurement solutions were processed and competent authority in the Department for approving the proposal had requested to review the solution proposed and same is under review. In order to enhance handling of IT related activities, the Directorate has entered into an agreement with ECIL for providing support, and their personnel are now available.

For the stores unit, the existing software is being re-designed to make it accessible to all users in Single Sign On mode (SSO), so that it can work in an integrated manner with all stake holders namely Purchase, Stores, Accounts and Divisions/units of DAE etc. A 24x7 fully integrated solution facility is being planned instead of facilities available for general shift only. This will reduce substantial lead time for procurements and other services.

Procurement of Equipment from Domestic Manufacturers

The user requirements were met from domestic manufacturers. Requirements above the value of ₹ 25 lakhs are processed by floating Public Tenders giving wide publicity in important newspapers across India and by publishing in Indian Trade Journal in addition to uploading on DPS website as well as on Central Pubic Procurement portal. Import substitution activities were considered to reduce dependence on Import.

In addition to the above, a policy for providing preference to domestically manufactured electronics goods in government procurement has been put in force due to security consideration as notified by the Department of Electronics & Information Technology, Ministry of Communications & Information Technology, Government of India. Similarly Ministry of Micro, Small and Medium Enterprises also has notified Public Procurement Policy for Micro and Small Enterprises (MSEs) for promoting domestic micro and small enterprises in government procurements.

Procurement of Equipment from Foreign Suppliers

Equipment, not available locally were imported from other countries by floating tenders as depending on value. To meet the specific requirements of DAE as well as arranging pre-despatch inspection, technical evaluation, etc. help of Minister, Atomic Energy Wing, Embassy of India, Paris was sought in sourcing reliable suppliers from abroad.

Streamlining of Purchase Procedure and Addressing Revision of Purchase Manual

Towards streamlining of purchase procedure, a major initiative has been taken up in reviewing the Purchase Manual. During the period, all the 38 chapters of Purchase Manual were

reviewed and were submitted to DPS council to take further approval of Member Finance, DAE.

Uranium Fuel Imports

With the opening of nuclear trade to civil nuclear facilities, the procurement of Uranium Fuel with the objective of deriving maximum advantage in meeting the Department's goals through leveraging experience of DPS remained pertinent. During the year, 303 MT Natural Uranium and 58 MT Enriched Uranium were imported from M/s. TVEL, Russia. 252 MT Natural Uranium were imported from M/s. Cameco, Canada.

GENERAL SERVICES ORGANISATION

General Services Organization, Kalpakkam takes care of the common facilities such as Housing, Medical, Transport, Water Supply, Civil, Electrical, Telecommunications, 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, BARC Facility, 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.

Civil Work

In-house Architectural & Structural engineering design services have been carried out for the works relating to Additional classrooms at Kendriya Vidyalaya and Atomic Energy Central Schools; Dormitory for CISF Personnel and Biogas Plant.

During the year, 60 Nos. of NIT were released and Work orders for 54 works have been issued for ₹ 370.19 Crores under various project heads. Work order for construction of 120 Numbers of type III-C, 165 numbers of type IV-D and 135 Numbers of type V-E Residential Quarters in DAE Township at Anupuram for ₹ 163.11 Crores and



Tower: I-KURINJI



Tower: II-MULLAI

construction of 1.5 MLD Sewage Treatment plant in DAE Township at Anupuram for ₹ 3.74 Crores was issued.

The completed construction works were Tower: I - KURINJI (120 nos. Efficiency plus Apartment); Tower: II - MULLAI (120 nos. Efficiency plus Apartment); Main Sub Station-III; GSO Annex Building; Security fencing over compound wall at Sadras and Refurbishment of Multi-purpose Hall.

Electrical & Telecommunication

Augmentation of the electrical & telecommunication infrastructure and refurbishment

of aged systems was carried out. Various activities completed during the period were Replacement of 2 Nos. of 250 kVA transformers with 630 kVA, 11 kV / 0.433 kV Dry type Transformers in Sub station No. 7; Replacement of the modified VCB Panels in Sub stations No. 5 & 7 at Kalpakkam; Replacement of the 415 Volts PCCs of Sub stations No. 6 and 7; Renovation of Electrical system in DAE Guest House and Multi-Purpose Hall; Rewiring of Type IIIC, IVD and VE residential quarters in Kalpakkam Township; Internal Electrification of GSO Annex Building at DAE Township, Kalpakkam; Electrification and Area Lighting of 3 Nos. of tower blocks comprising 360 Nos. of residential flats at Anupuram Township and Installation, testing and commissioning of 200 Pair underground Telephone Cables in DAE Township, Kalpakkam and Anupuram for augmentation of capacity.

Computer

The Local Area Network for the GSO Annex building was established, tested and commissioned and the building was connected to the Campus Backbone. In the first phase of Upgradation and expansion of the Kalpakkam Township Backbone, old and obsolete Network Switches were replaced. A software package was developed in house for Capital Budget Monitoring. The package includes Work Flow of the Works Contract Bills and details of DPS expenditure. A software for Vehicles Entry Permit Management System was developed wherein employees can login on intranet and enter vehicles details for issue of Vehicle Entry Permit. For convenience of users, two new Automatic Token Issue systems (KIOSKs) were installed, tested and commissioned at Hospital and Anupuram Dispensary for issue of advance appointments and daily tokens for doctors and for pathology department tokens.

Mechanical

Erection, Testing and Commissioning of Fire Hydrant system to supply and maintain pressurized fire water in all the floors is completed for Efficiency Plus Tower blocks at Anupuram. Air-conditioning of Multipurpose hall at Kalpakkam Township is completed with total capacity of 80 TR packaged air-conditioners, comprising of 40 TR each for marriage hall and dining hall. Air-conditioning of GSO annex building at Kalpakkam Township is completed with packaged air-conditioners of total capacity 120 TR. Approval for storage of Chlorine cylinders to be used for water disinfection has been obtained from Chief Controller of Explosives, Chennai. Erection of chlorination system to add chlorine to drinking water is completed in both the Kalpakkam and Anupuram Townships. Installation of Road Safety Signage boards in Kalpakkam and Anupuram Townships was done. Erection of Latest testing facility of Ultra Scan Tool for the modern Engines (ECU controlled MPFI & CRDI Engines) at Autoshop was done. Propeller Shaft Safety Support Clamps were provided to all the DAE buses under chassis to prevent major accidents in case of any mechanical failure of universal joints/yoke-teeth.

Flood Relief and Rehabilitation

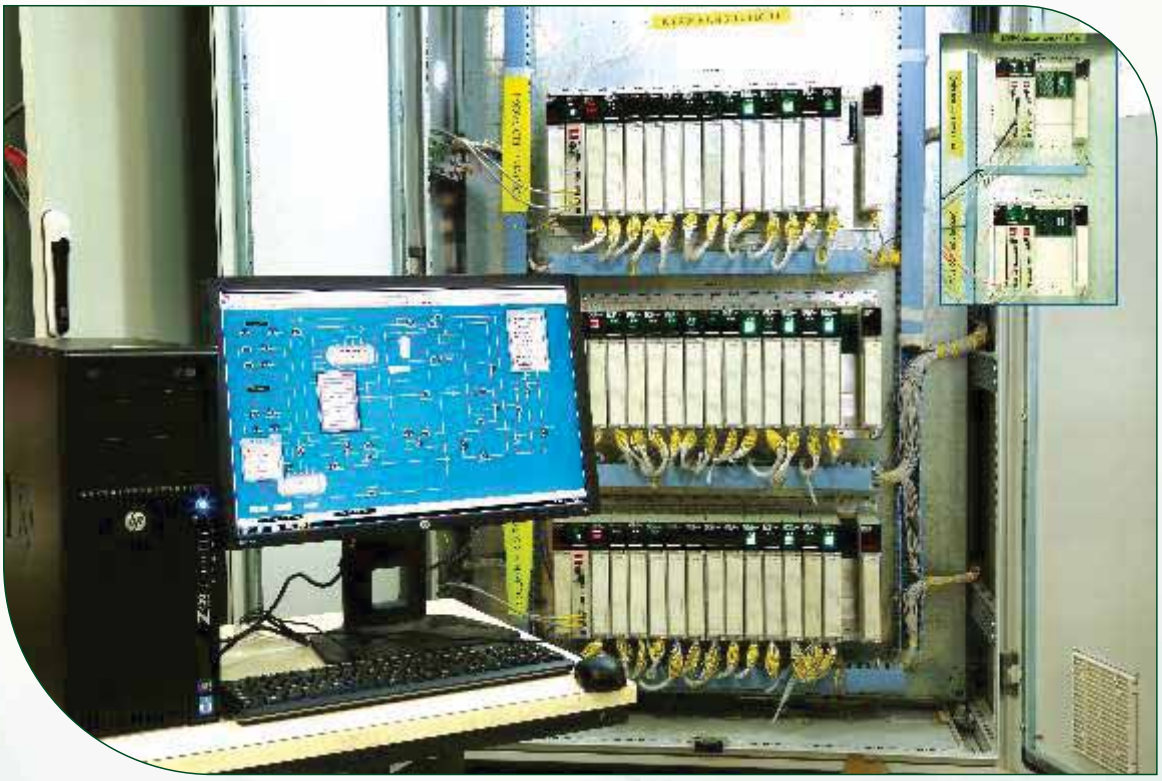
The incessant rains in the first fortnight of December, severely disrupted vital services and caused damage to the infrastructure at the DAE Township, Kalpakkam. About 1500 houses got inundated and people had to be evacuated to various safe dwelling places and were provided with basic amenities. The compound wall broke down in some places. Many lakes in and around Kalpakkam had breached away due to which the Buckingham Canal was over flooded. The water flow was enormous. The gushing water eroded the wing wall abetment of the Old Bridge at Sadras posing a serious safety hazard.

In order to drain out the flooded water, emergency drainage systems were created. The maintenance of the storm water drains, the Old Bridge, the roads and compound wall was taken up on a war footing to ensure safety and security.

CHAPTER-9

PUBLIC SECTOR UNDERTAKINGS

(FINANCIAL PERFORMANCE)



Secure Programmable Logic Controllers for Space Applications



Antenna Platform Unit for Tejas

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). 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 net Profit After Tax (PAT) for the year 2015-16 is about ₹ 2300 Cr. The net profit after tax for previous FY 2014-15 was ₹ 2201 Cr. NPCIL bonds continued to be rated at AAA (Highest Safety) by CRISIL and CARE.

URANIUM CORPORATION OF INDIA LTD.

The overall performance of the company during the year 2014-15 was satisfying. The total income of the Company during the year 2014-15 was ₹ 890.24 Cr. (Previous year ₹ 814.30 Cr.). The Company is consistently making profit year after year and the profit before tax during the year 2014-15 was ₹ 11.34 Cr. Performance of the Company in terms of MoU signed with DAE is expected to be "Good" .

INDIAN RARE EARTHS LTD.

During the year 2015-16, the Gross Sales Turnover anticipated is ₹ 434.64 crore (provisional) against ₹ 420.97 crore of previous year. Anticipated loss in 2015-16 is ₹ 22.67 crore (provisional) compared to profit before tax of ₹ 3.15 crore in 2014-15.

Production of Monazite Processing Plant (MoPP) and HPRE not materializing as envisaged and non-availability of sufficient raw material at Chavara and Manavalakurichi were the factors which affected the revenue generation of the company.

Depressed demand of titanium feedstock and titanium dioxide pigment globally due to reliance of Chinese Industries on local feed stock and accumulation of high level of inventory were attributed to reduction of prices in international market and were partially responsible for fall in profit.

Further, mandatory MDCC & licensing for customers sourcing minerals from OSCOM Unit by Odisha Government and Levy of Excise Duty on major minerals of IREL were also the main concern for revenue generation.

ELECTRONICS CORPORATION OF INDIA LIMITED

Electronics Corporation of India Limited (ECIL) is engaged in the design, development, manufacture, supply, installation and commissioning of electronic equipment for the Atomic Energy, Defence, Aerospace, Security, Information Technology and e-Governance sectors. The Company is a key player in the Strategic Electronics space in the country and has unique multi-disciplinary competencies. ECIL has been consistently paying dividends over the past few years and is poised to leverage the large growth in Strategic Electronics.

ECIL has built a strong technological base by associating itself with prestigious R&D institutions of DAE, DRDO, DoS, and academic institutions like IITs and others. The linkages with DAE laboratories have enabled ECIL to provide indigenous solutions for electronic equipment spanning the entire nuclear fuel cycle from ore processing to waste management including power generation and fuel reprocessing. These linkages have also enabled the company to build a strong product base in Defence Electronics, especially in the domains of Communications, Fuzes, Electronic Warfare and C4I. The Company's strong relationship with the Department of Space has resulted in ECIL executing technologically complex projects of national importance in the aerospace sector.

ECIL has emerged as a major player in providing integrated security solutions to the strategically vital installations in the country.

ECIL plays an important role in the General Elections with the Electronic Voting Machines (EVM) and the Voter Verifiable Paper Audit Trail (VVPAT)

printers. The EVMs are also being deployed by the states in the elections for local bodies and cooperative societies.

Performance

Against the MoU target of ₹1620 crore each for production and net sales, the Company achieved a production of ₹ 721 crore and a net sale of ₹ 690 crore upto December 2015.

The sector-wise significant achievements during the year 2015-16 are as follows:

Atomic Energy

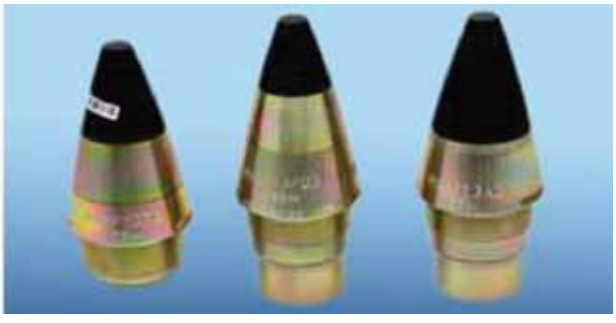
- Radiation Detection Equipment for Airports
- Neutron Detectors for Prototype fast Breeder Reactor
- Secure Programmable Logic Controllers for Space Applications
- Radiation and Gas Monitoring System for Advanced Technology Vessel Project

Defence

- Universal Electronic Fuzes for Indian Artillery
- Network Centric Systems for DRDO
- Secure Communication Systems for Indian Armed Forces
- Command and Control Systems for Missile Programmes
- Sensors and Actuators for Defence Programmes



Antenna Platform Unit for Tejas



Universal Electronic Fuzes



Combat Control Centre for Akash Missile

Aerospace

- Antenna System for Strategic Applications
- Weather Radar Systems



Secure Programmable Logic Controllers for Space Applications

Security

- Integrated Security Systems for strategic



Access Control System

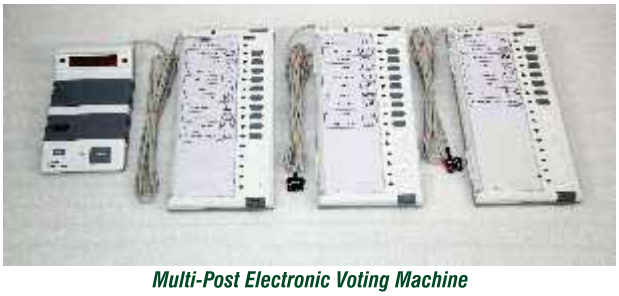


Limb Monitor

installations
- Mobile Communication Jammers
- Cyber Security Equipment

IT, e-Governance & OTHERS

- Multi-Post Electronic Voting Machines and VVPATs for the General, State and Local Body elections
- Smart Energy Systems
- Computerisation of Sales Tax Operations in Maharashtra
- IT Education



Multi-Post Electronic Voting Machine

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. Currently, work is going on in the areas of Modular PLC system for Strategic Applications, Smart Radiation Monitors, Flash X-ray System for Imaging high speed projectiles, Portal Monitoring Systems, Uranium Analyser, S-band Ground Telemetry Receiver System, Explosives detectors, Seekers, Multi-feed antenna system etc.

New Products Introduced

Following new products were introduced during the year:

- Uranium Analyser
- Solid State Digital Video Recorder System
- Radar Target Echo Simulator
- High Power Solid State Switches
- TDM Signal Analyser and De-multiplexer
- Linux based ECSCADA Server Software

Tie-ups and Agreements

· The company has entered into a Memorandum of Understanding with Bharat Dynamics Limited to work together for providing Missile Electronics and Weapon Support systems for the ongoing and upcoming major defence programs. This MOU enables both the organizations to enhance and harmonise their business opportunities in the area of Missiles and underwater weapon systems.

- The company has entered into a Memorandum of Understanding with Space Application Centre (SAC), Ahmedabad for the development of multi band composite feed systems required for Earth Stations.

- The company has also entered into a Memorandum of Understanding with IIT Hyderabad for Technical collaboration on upcoming technologies and joint R&D projects.

CHAPTER-10

OTHER ACTIVITIES



Distribution of prizes at the DAE Quiz Event during the 103rd Indian Science Congress, Mysuru



Winners of the 27th DAE All India Essay Contest

NATIONAL SECURITY

BARC continued implementation of the necessary research and development as well as manufacturing activities required for national security.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), a standing Committee of senior officials of DAE is responsible for ensuring emergency preparedness and response arrangements and also for coordination of the Department's response to any radiation emergency in the public domain.

An emergency could be due to events taking place either within a nuclear facility or at other facilities handling radioactive materials such as hospitals or industries, due to an accident involving the transport of nuclear material or even due to any deliberate attempt to cause disruption in public domain by involving radioactive material. With deployment of multiple safety systems and due to inherent design features, the possibility of any accident in a nuclear facility or during transport which might lead to a radiation emergency in the public domain is highly remote. 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 these activities are overseen by an independent regulatory authority, which ensures that all radiological safety issues are adequately addressed. Further, in case such an unlikely event does occur and 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 support facilities available to public officials who would be handling various types of emergencies related to radiation / radioactive materials in the public domain. The CMG also provides its expertise in various forums in the field of nuclear / radiological emergency management at both National and International levels.

The Crisis Management Group formally meets to review the crisis management plans at different facilities to discuss on 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 the recurrence of such incidence.

The Emergency Response System of DAE is also available to respond any request from public official in the event of the reported presence or suspected presence of radioactive material. For this purpose, guidelines have been circulated to all the State Governments and Union Territories. A significant component of the emergency response system of DAE is the availability of two Emergency Control Rooms at Mumbai which are manned on a round-the-clock basis throughout the year. These have multiple modes of communication and are in constant contact with various nuclear facilities in the country as well as with the International Atomic Energy Agency (IAEA) in Vienna.

During the year 2015, India not only ensured its participation in all IAEA conducted International exercises (popularly known as ConvEx exercises) but also successfully met all the convention requirements identified under the Early Notification and Assistance Conventions (ENAC). India's participation was facilitated by CMG of DAE and its Emergency Control Room (ECR) which is also the National Contact Point for nuclear and radiological emergency. Some achievement any described below:

- India's effective response during ConvEx-1a Exercise conducted on 28.07.2015 was duly acknowledged in official exercise report published by IAEA. India's name is appearing in the list of First Five Responses received by Incident & Emergency Centre (IEC) from National Warning Points.
- During ConvEx-2a exercise conducted on 18.03.2015, India could successfully meet all the requirements of IAEA's Convention on Early Notification.
- During ConvEx-2b exercise conducted during 25-27th August 2015, India successfully offered its assistance in real

time to the affected country and all necessary arrangements were made within the stipulated time-period.

- India has successfully participated in the International Exercise ConvEx-2c on 15.12.2015 and offered its assistances to all requesting countries in their requested domains. This was the very first time that India participated in ConvEx-2c Exercise.

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 a variety of emergency exercises. The numbers of exercises carried out during the year 2015 were Communication Exercises – 408 nos., Fire Emergency Exercises – 66 nos., Plant Emergency Exercises – 61 nos., On-Site Emergency Exercises – 14 nos. and Off-Site Emergency Exercises – 6 nos.

DAE effectively responded to the reports of suspected leakage of radioactive material from imported consignment at New Delhi International Cargo Terminus which was occurred on 29th May 2015. Subsequently, DAE along with Ministry of Home Affairs (MHA) has also conducted mock exercise on radiological emergency at Kolkata airport on 02.08.2015.

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.

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.

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 2015, India also actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combating Nuclear Terrorism and India's own Global Centre for Nuclear Energy Partnership (GCNEP).

Cooperation at the multilateral level in peaceful uses of nuclear energy was also promoted through the European Organisation for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER), and the Nuclear Energy Agency of OECD.

Significant achievements were made in India's bilateral international engagement in civil nuclear cooperation with major partners. This included signing of Administrative Arrangement with the U.S. in March 2015 to implement the India-U.S. Agreement for Cooperation Concerning Peaceful Uses of Nuclear Energy. With France, during Prime Minister's visit to Paris on April 10, 2015, a Pre-Engineering Agreement between NPCIL and the French reactor manufacturer AREVA NP was signed for detailed safety assessment for the French-designed nuclear power plant for the Jaitapur Nuclear Power Project in Maharashtra, along with a Memorandum of Understanding between M/s Larsen & Toubro and AREVA NP aimed at cost reduction by increasing localization for the Jaitapur project. With Russia, during Prime Minister's visit to Moscow on

December 22, 2015, a joint Programme of Action for Localization of Manufacturing in India for Russian-designed Nuclear Power Plants was signed.

Following the signing of a contract for long-term supply of uranium during Prime Minister's visit to Canada in April 2015, the first consignment of uranium reached India in December 2015. In addition, during Prime Minister's visit to Kazakhstan in July 2015, a contract for long-term supply of uranium from Kazakhstan was renewed. The civil nuclear cooperation agreement with Australia signed on September 5, 2014 was brought into force on November 13, 2015 along with the signing of the Administrative Arrangement for implementing the Agreement. The fuel supply arrangements with Canada, Kazakhstan and Australia will bolster energy security by supporting the expansion of nuclear power in India.

The reaching of agreement on a bilateral civil nuclear cooperation agreement with Japan during Prime Minister Abe's visit to India on December 12, 2015 brought to a close five years of negotiation on this issue.

Civil nuclear cooperation with neighbouring partners was also promoted. An Agreement on Cooperation in Peaceful Uses of Nuclear Energy was signed with Sri Lanka on February 16, 2015 to facilitate sharing of expertise and capacity building for societal applications of nuclear energy. With Bangladesh, in response to specific request of the Bangladeshi side, capacity building courses in civil nuclear energy were provided to two groups of Bangladeshi nuclear experts in Jan-Feb and Nov-Dec 2015 in Mumbai. During Prime Minister's visit to Mongolia in May 2015, India presented the indigenously developed and manufactured teletherapy equipment Bhabhatron-II with a digital simulator for treatment of cancer to Mongolia's National Cancer Centre.

India ratified the IAEA's Convention on Supplementary Compensation for Nuclear Damage (CSC) on January 14, 2016 and submitted the Instrument of Ratification to the IAEA on February 5, 2016. This marked a conclusive step in addressing of issues related to civil nuclear liability within the four corners of India's Civil Liability for Nuclear Damage (CLND) Act, 2010, following the release of FAQs on Civil Nuclear Liability by MEA and DAE in February 2015 and the launch of the India Nuclear Insurance Pool (INIP) by a group of Indian insurance companies in June 2015.

In an important legislative development, the passage of the Atomic Energy (Amendment) Act, 2015 by the Parliament in December 2015 created the legal basis to enable NPCIL to enter into joint ventures with other Indian PSUs, thus paving the way for new equity to meet the additional funding requirements for expanding India's nuclear power programme and augmenting the nation's nuclear power generation capacity.

Global Centre for Nuclear Energy Partnership (GCNEP) is being set up to enable India to establish leadership in the field of nuclear energy through research, training and international partnerships. GCNEP will help in capacity building in association with the interested countries and the IAEA, involving technology, human resource development, education & training and giving a momentum to R&D in enlisted areas.

The main objectives of the centre includes Development of enhanced nuclear safeguards to effectively and efficiently monitor nuclear materials and facilities; Promoting the development of advanced, more proliferation resistant nuclear power reactors; Training manpower in the field of Nuclear Security and Radiological Safety; Educating in the field of Advanced Nuclear Energy Systems, Isotopes and Radiation Technologies, Nuclear Forensics and Establishing accreditation facilities for radiation monitoring.

The site activities took off with selection, demarcation and mutation of land. A total area of approx. 230 acres -125 acres at Kheri Jasaur for the 'Campus' and approx. 105 acres at Jasaur Kheri for the 'Township', has been earmarked for the Centre. The two sites are separated by an approximate road distance of 1km. The acquired area has been secured by boundary wall which runs for a total length of approx. 10.5km.

Phase-I construction activities for the Centre are now in progress which account for an approx. built-up area of 7,600 sqm. Currently, work is in



A view of the under construction SNSS Building



A view of the under construction Guest House Block

progress for School of Nuclear Security Studies (SNSS) Building in the Campus site and Wing-A of Guest House in the Township site. It is proposed to supplement these buildings with the necessary services so that these can be operationalized as and when they are available by the end of FY2016-17.

For SNSS Building, slab casting has been done for the ground floor, and column raising is in progress for the first floor. At the residential site, nearly 70% brick works have been completed for Block-A of Guest House, and plastering and flooring works are also in progress in parallel.

GCNEP has also hired an office space in BSNL Building at Bahadurgarh. This office is being used for project management as well as a setup for soft-start of mandated GCNEP activities. The office is equipped with the required office infrastructure and has facilities for hosting meetings seminars, lectures, workshops by the visiting faculty. The office is connected to high speed broadband network-National Knowledge Network (NKN). It also has an earmarked Laboratory Area, DAE Outreach Area, in addition to the Staff & Faculty cabins. Process has also been initiated towards setting up of a demonstrative Model Emergency Response Centre at this office.

While the permanent infrastructure is being built, GCNEP has already taken up the task of conducting national and international training programs. GCNEP hosted trainees & visiting faculties from India and abroad as a part of collaborative research. During the period, April 2015 to December 2015, a total of 12 programs have been conducted so far under GCNEP.

In terms of international collaborations, in November, Department of Atomic Energy (DAE), Government of India, and Department of Energy and Climate Change (DECC), United Kingdom, announced the signing of a Memorandum of Understanding (MOU) between the two countries concerning cooperation on the Indian Global Centre for Nuclear Energy Partnership. It is understood that the agreement will provide a framework for further cooperation.

Memoranda of Understanding (MOU) have already been signed with USA, Russia, France, UK and the IAEA. Following this, exchange visits, training programs and seminars have been organized along with USA and IAEA.

The Third Meeting of Indo-US Joint Working Group (JWG) for GCNEP was held during August 05-07 2015, at Mumbai, Maharashtra. The US



US delegates on tour of Radiation Portal Monitors at JNPT, Navi Mumbai



Concluding the Third JWG Meeting, August 7th 2015, Mumbai

delegation was led by Honorable Anne Harrington, Deputy Administrator DOE/ NNSA, USA. The Indian side was headed by Dr. K. L. Ramakumar, Director RC&IG, Head NCPW DAE & Chairman Advisory Council- GCNEP.

The US delegation also visited JNPT Navi Mumbai and witnessed the demonstration of indigenously developed Radiation Portal Monitors installed by ECIL at the Port Complex. Both sides expressed satisfaction on the progress and agreed for a continued momentum in cooperation.

A four member Indian delegation, headed by Dr. Pradeep Kumar K. S. (Head SRSS GCNEP and AD, HS&EG, BARC) visited Sandia National Laboratories, Albuquerque, New Mexico, USA to participate in the Indo-US Technical Exchange on Simulation Technologies. During this period, experts from India Department of Atomic Energy (DAE) and U.S. National Nuclear Security Administration (NNSA) exchanged their views on Modelling and Simulation Tools & Methodologies. Both sides expressed a willingness to carry forward the cooperation on the subject matter, and participate in realizing the Modelling & Simulation facilities proposed at GCNEP Campus.



Delegates at Simulation Technologies Exchange Workshop



Indian delegates visiting Radiation Monitor Portal test station installation

During August 24-28 2015, an Indian delegation led by Shri L. R. Jangra (Head, Coordination Division, GCNEP) visited Rotterdam Port (Netherlands) & Pacific Northwest National Lab (PNNL) of DOE at Richland (USA), for a workshop under Technical Exchange on "Advanced Techniques for Special Nuclear Material (SNM) Monitoring Techniques and Detection Architectures".

NPCIL is a member of various international organizations such as World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), Institute of Nuclear Power Operations (INPO) and World Nuclear Association (WNA). NPCIL actively participated 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 at Tokyo and Moscow. All the 441 nuclear power plants operating in 30 countries of the world are its members. NPCIL representatives are in the governing board of WANO Tokyo and Moscow centres. During the year WANO Peer Review of RAPS-3&4 and WANO Follow-up reviews of KAPS were carried out by experts from various countries and found to be very useful in bringing out areas of improvement from international perspective. These reviews also provided NPCIL an opportunity to learn international good practices. Further, WANO Peer Reviews of KGS-1&2 is planned in February 2016. WANO also carried out the Corporate Peer Review of NPCIL HQ during May 25 to June 5, 2015.

WANO organized two Technical Support Missions (TSMs) on the topics for which NPCIL had requested specific assistance from WANO to learn from international practices and experience to strengthen its own programmes. Four more TSMs are planned before the end of the year. Several persons from NPCIL participated in the important meetings, seminars and workshops and gave presentations. A team from RAPS-3&4 visited Cernavoda NPP in Romania under WANO's Benchmarking programme. Many experts from NPCIL participated in the 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 also participated in the WANO Biennial General Meeting held in Toronto, Canada in October 2015.

NPCIL has been participating in some COG meetings held through audio and video conference. In addition COG representative visited NPCIL and discussed issues of mutual cooperation. Two experts participated in COG workshops held in Canada and China respectively. NPCIL participated in information exchange programme of COG and had access to its website where lot of useful operating experience information related to PHWR plants is available.

NPCIL is participating in INPO's (Institute of Nuclear Power Operations) International Participants Programme. Many senior officers at stations and HQ have been provided access to INPO website which contains high quality operating experience information and other documents. Further, with the possibility of Indo-US nuclear deal becoming operational soon, it is expected that there will be increased cooperation between NPCIL and US nuclear power plant vendors. Many persons from NPCIL participated in various meetings, workshops, seminars organized by IAEA. NPCIL continued to provide information for IAEA PRIS database. NPCIL is also benefitted from the membership of WNA as it provides detailed worldwide reports on fuel availability, utilization and forecast for future.

MANAGEMENT SERVICES

The Management Services Group (MSG) of DAE manages the Information Technology facilities in DAE headquarters. During the year a number of high end servers were procured. These servers would be configured as virtual machines to replace all the old and obsolete servers that are in operation. Security features on the network were enhanced with the installation of Secure Network Access System (SNAS) that would monitor user behavior and prevent unauthorized access. Near 100% uptime was achieved on all the services offered over the network including internet access and mail services. MSG operates a helpdesk in DAE Secretariat that enables delivery of all IT services to the users.

A DAE wide Integrated Management Information System named AnuSangrah was designed, developed and implemented during the year. This project was jointly developed by DAE, BARC, IGCAR, RRCAT, NPCIL and ECIL. The system has several modules including human resources, project management, information bank, finance etc. This information system aims to integrate data across all the Units of DAE including PSUs and Aided Institutions. Once fully implemented this system would act as an important decision making tool to the senior management. Under this project several applications have been developed for DAE Secretariat to manage its Parliament Question and Answers, monitor court cases, disseminate information through online circulars and an intelligent task management system.



MSG coordinates the functioning of the Computer and Information Security Advisory Group (CISAG) of the Department constituted for the purpose of overseeing IT security in DAE and its units. Quarterly IT security audits were conducted by units and reports were submitted to the group. In addition, audit groups were constituted to conduct detailed audits of certain units. As the nodal agency of the Department for cyber security, any alert received from external government agencies were communicated by MSG to the Chief Information Officers of all the Units for action.

DAE's web site is maintained by MSG. It has links to all DAE and its constituent units. DAE's website is a repository of Parliament Question and Answers, Press Releases, Acts, Rules, Agreements, Orders, Publications, Achievements of the Department and provides downloadable forms for

the benefit of the public. A new website is under development in collaboration with NIC and will be deployed soon.

MSG also manages various applications relating to administration and accounts activities in the DAE Secretariat.

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 Units and Aided Institutions 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 discharge these responsibilities.

During the year, the Vigilance section of DAE carried out various activities which included submission of 19 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 20 new cases of Disciplinary cases of Group 'A officers and retired Government servants that include issue of charge sheet, appointment of IO / PO. Besides, action was also taken on earlier cases by referring the matters to UPSC/CVC for advice and to the Prime Minister for approval of penalty etc. ; Processed 61 complaints that were downloaded from CVC portal and 4 complaints received through PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides, 11 complaints from CBI have also been processed. 33 cases have been closed with the approval of Competent Authority after necessary investigation and status uploaded onto the CVC portal. 65 complaints were received directly by the Department. After confirming the authenticity of the complainant, necessary investigation were carried out and with the approval of Competent Authority 55 complaints were closed. Vigilance clearances were given for various purposes to 1,875 Group 'A' officers as well as to staff of the Secretariat. Appointment of Vigilance Officer/ Chief Vigilance Officer of Constituent Units/ Aided Institutes and in the Department were done. Scrutiny of Annual Immovable Property Returns of DAE Secretariat was carried out. Co-ordination between CVC and Units for conducting of CTE (Chief Technical Examiner) examination was also done.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2015" was observed in DAE during October 26-31, 2015 on the theme of "Preventive Vigilance as a tool of Good Governance". The week commenced with administering vigilance pledge by Director (Administration), DAE to all officers and staff on 26/10/2015. During the week, various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were held in which officers and staff of DAE actively participated. Shri Keshav Kumar, IPS, Joint Director, CBI delivered a talk on 30/10/2015. The key note address was delivered by Shri Sanjeev Sood, Joint Secretary (I&M) and Chief Vigilance Officer, DAE. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 30.10.2015. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.



A glimpse of the "Vigilance Awareness Week" observed in DAE during October26-31, 2015

Vigilance awareness is one of the important parameters of good Corporate Governance. At NPCIL, 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 HQs are regularly organized by the Directorate of Vigilance.

A new initiative of organizing outreach programmes in Schools & Colleges was taken by

NPCIL as per directives of CVC in the months of October & November 2015. CVC assigned 'Mumbai' and 'Tirunelveli' district for conducting these activities to NPCIL. NPCIL conducted outreach activities in total nine colleges including three colleges in Mumbai and two colleges in Tirunelveli District. In addition, four more colleges located at other cities/ towns nearby NPCIL power plants were also covered. Total 29 schools were covered including six schools in Mumbai and five schools in Tirunelveli District.

Vigilance Awareness Week with the theme of 'Preventive Vigilance as a tool for good governance' was observed in NPCIL Headquarters in Mumbai and all the units located outside Mumbai during the week from 26.10.2015 to 31.10.2015. A number of programmes viz. seminars, debate competitions, quiz competitions, case study competition, short film competition, poetry recital competition, cartoon &poster drawing, mime etc. were organized during this period.

A short film competition was conducted at all the Units of NPCIL. Total sixteen groups participated in the competition. First prize winning film titled 'Dream House' was screened on October 29, 2015. The second and third prize winning short films titled 'Bhrastrachaar Mukt Bharat' and 'Diwali Ki Mithai' were screened on the opening day of VAW-2015 i.e. October 26, 2015. These films were screened at HQs & all units and were appreciated by everyone. The documentaries were produced in-house by employees of NPCIL. A vigilance magazine 'CHETNA' is published every year during the Vigilance Awareness Week. The 14th edition of CHETNA magazine was released on October 29, 2015.

An online 'System for Management of Vigilance Complaints (SMVC)' has been launched. This new system integrates all complaints (lodged on-line as well as the ones received by other means) and facilitates tracking and monitoring of complaints. The system facilitates the complainants to not only lodge their complaints on-line but they can also check the status of their complaint by logging into NPCIL website. Integrity Pact has been implemented in NPCIL during this year. Twelve vigilance officers of HQs and Units were imparted short duration training programmes in reputed institutes to increase their capability and skills.

OFFICIAL LANGUAGE IMPLEMENTATION

DAE and its Constituent Units including 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:

- Under the Official Language Rule 10(4), 40 offices have been notified so far.
- The Parliamentary Committee on Official Language inspected HARL; Srinagar; AMD, Shillong; NPCIL, Mumbai; NPCIL (Quality Assurance), Noida; ECIL, Hyderabad; Bhavini, Kalpakkam; Seismology Division, Delhi, BARC.
- DAE inspected NRL, Srinagar; HARL, Gulmarg; DPS, Mumbai; DCS&EM, Mumbai; AERB, Mumbai; BRIT, Mumbai; NPCIL, Mumbai; IRE, Mumbai; UCIL, Jharkhand; ECIL, Hyderabad; IMS, Chennai; AMD, New Delhi; NFC, Hyderabad; In addition to this, various Units/PSUs/Aided Institutions namely BARC, RRCAT, NFC, AMD, IGCAR, VECC, HWB, GSO, DCS& EM, AERB, NPCIL, IRE, ECIL, UCIL, Bhavini, TIFR, TMC, IPR, HRI and IOP inspected their Subordinate Offices and Sections.
- Total 50 Seminars and 43 Talks in Hindi on diverse 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 were furnished to the various Committees of the Parliament and the Agreements and MOUs were prepared bilingually.
- Total 2533 officers and employees were imparted training in Hindi Noting and Drafting in Hindi Workshops. 278 officers and employees under the Incentive Scheme for

doing original noting and drafting in Hindi, 16 Typists under the Incentive Scheme for Hindi Typing and 27 Stenographers under the Incentive Scheme for Hindi Stenography were awarded.

- Total 213 Officials, 13 Typists and 11 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.
- Hindi books worth ₹ 6,79,808/- were purchased.
- Quarterly meetings of OLICs were held regularly and the progress of implementation of Hindi was monitored regularly through Departmental OLIC meetings. The Quarterly Progress Reports and Minutes of the meetings of OLICs of all

  Units/PSUs/Aided Institutions were also reviewed regularly. Hindi Week / Fortnight / Month was organized in all offices.
- DAE and its 25 establishments have their Websites in bilingual form and these are updated regularly.
- Presently, there are total 24,749 bilingual computers in the Department.
- The Hindi Vigyan Sahitya Parishad, a voluntary organization of BARC continued to publish a popular Hindi quarterly bulletin "Vaigyanik". Pamphlets on various subjects related to DAE's activities were also prepared in bilingual form.
- Total 22 House Magazines and 12 News Letters were brought out by various establishments of DAE.
- The total strength of Hindi staff in DAE and its constituent Units, PSUs, and Aided Institutions is 130.

NPCIL continued its efforts in propagating and implementation of the provisions of Official Language Act, 1963, Rajbhasha Rules, 1976 and various order/guidelines issued by Govt. of India.

To encourage the officers/employees of NPCIL to do their official work in Hindi and allay their apprehensions regarding use of the language, around 20 workshops were organized during the period from April to December, 2015 and 550 officers/employees were trained in these workshops. During the period, total 72 Hindi monthly competitions were conducted to promote the use of Official Language which were attended by more than 1500 participants.

"Hindi Sevi Samman Yojana" and "Rajbhasha Bhushan Puraskar Yojana" are in-force in NPCIL to acknowledge the outstanding contributions of NPCIL officers/employees in the field of Official Language. Two employees of HQ were awarded under Hindi Sevi Samman Yojana during the period under report. Also, Rajbhasha Bhushan Puraskar was awarded for the first time to one of our employee from RR Site.

NPCIL HQ, Mumbai has organized a Hindi Scientific Seminar for all the member PSUs of Mumbai TOLIC (Town Official Language Implementation Committee) which consists of more than 60 PSUs in Mumbai.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resource facilities of BARC is equipped with the state-of-the-art infrastructure and technology to provide seamless access of information to BARC and DAE scientists and engineers in their day-to-day R&D activities. During the year, more than 330 books, around 1700 e-books for Central Library and around 400 books for various Divisional libraries were added to the resource. Various standards, codes, patents and complete sets of standards have been procured. Around 1800 scientific and technical reports and more than 500 bound periodicals have been added to the collection. BARC currently subscribes to 1058 periodicals and 11 Databases. Access has been provided for more than 3500 online journals through Lakshya and remote access facility for more than 1500 Science Direct Online journals to more than 750 scientists and engineers of BARC.

Designing, content management and maintenance of various knowledge portals namely BARC official website in public domain, online

information gateway for e-resources Lakshya, library portal Saraswati and SIRD portal on BTS have been carried out. In order to extend the online digital resources access in 24x7 mode from Home, Office or Anywhere (HOoA), a cloud based facility has been evaluated and tested. Reservation and renewal of books for BARC users has been continued through web-OPAC. A web based information technology tool has been evaluated for detecting the most subtle attempts at plagiarism and is under implementation. Institutional Repository of published articles and PhD thesis now holds more than 11000+ journal articles including 1650+ articles of the year 2015 & 210 Theses with full text. The registered users for the email based NUCNET facility have reached more than 250. A secure VPN based access of Saraswati for ANUNET users of BARC out-stationed employee has been implemented. RFID Tags for Bound have Volumes has been procured for implementation. Foreign Language Management software using PHP and SQL has been developed to enable authorized members to upload metadata of the translated documents and manage foreign collection. BARC Technologies module for BARC-CMS has been developed and implemented for generation of static webpage from database with RSS feed. Web-base application software for SIRD Central Dispatch Management System and No Demand Certificate for Library facilities are under development. E-books search facility has been developed with add-on search features. 30 Desktops for digital area in the central library have been installed for general users and a large number of library users are accessing digital resources on Intranet (SARASWATI) as well as Internet (LAKSHYA) in virtualized single desktop.
A new webpage with add-on smart search facilities has been developed for eBooks at Lakshya. Database for E-books has been created in LIBSYS and Bibliographic records in MARC21 formats of books have been imported to LIBSYS thus eliminating need to enter the records manually. As per the guidelines for managing the Indian Government Website Compliance matrix, BARC website has been audited by STQC Directorate, Department of Electronics & information technology. The mandatory information as per Dept. of AR&PG has been uploaded. A new layout for BARC Entrepreneur Corner has been designed and uploaded.

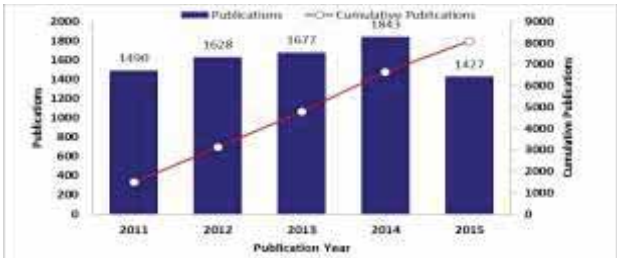
Under Apex project R&D-XII-N-49 "Enhancement of Digital Knowledge Resources and Human Resource Development" a subproject titled "Archival Centre for BARC and Enhancement of Infrastructural Facilities" is being executed with a total XII Plan Layout of Rs. 4.0 crores including spillover of Rs. 2.0 crores during XIII Plan.

SIRD is contributing in building authentic DAE resource collections and management programme under the banner of DMIS. BARC Newsletters from 2010 to latest issue has been uploaded to DMIS portal.

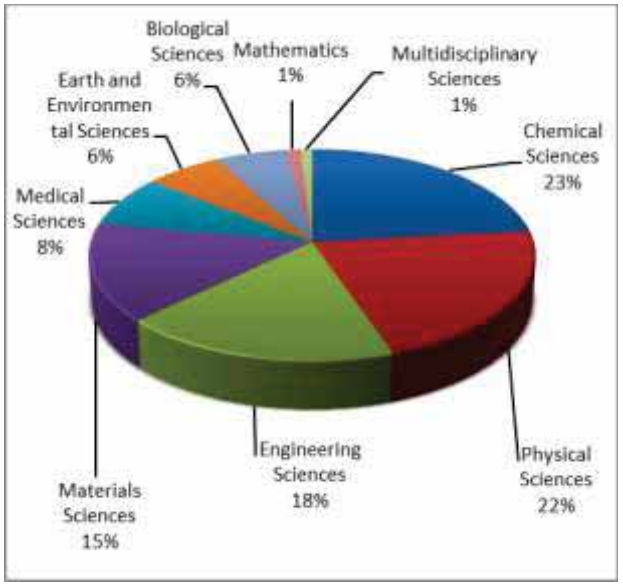
Photography & cinematographic services for various events including coverage to VIP visit, events in BARC (Scientific and social), International and National conferences & Seminars, industrial, security, strategic and landscape photography etc were provided. Annual Photo Exhibition was inaugurated by Dr. Sekhar Basu, Director, BARC with the theme "Flowering 60s" and more than 1000 footfalls were noticed during the exhibition.

Library Circulation Unit continued to provide user friendly services to scientists and engineers of BARC and other DAE units and interacted with other National and International organizations to identify and acquire the information needed by the scientists and engineers. Publications of BARC Scientists and Engineers are listed in the monthly publication 'Scientific Information Resource Bulletin' and the full text of these publications are made available on SARASWATI. Library continued to provide photocopy service to BARC Scientists and Engineers through self-operating photocopiers for the purpose.

A total of 8065 publications were published during 2011-2015 as per "Scopus" database. There were 1427 publications in 2015. The highlights are given below.



Publications of BARC during 2011-2015



Subject-wise Distribution of Publications of BARC in 2015

Regular publications printed included 49 BARC External and Internal Technical Reports and 7 issues of the BARC Newsletter including the Founder's Day Special Issue. BARC Pocket Diaries, BARC Pocket Calendars and BARC Desktop Calendars and several other publications were published for various Divisions of BARC during 'Engineers' Conclave', 'Thorium Energy Conference', 'Graduation Day' function and other scientific events conducted by BARC.

India has contributed 3013 bibliographic records to the INIS database of the IAEA. Document delivery services are provided to various member countries of INIS and 75 documents were sent in 2015. NEA Data Codes were procured for BARC Scientists and Engineers. The section identified 994 nuclear related news from daily newspapers and added to the news archives. Bibliographic sheets of 14 external technical reports were made and the digital copy was sent to INIS for including in the Non-Conventional Literature collection of IAEA.

The Foreign Languages Section provided specialized translations from sources such as scientific journals in foreign languages, technical guides and manuals and articles and documents of practical application to scientific and technological information. Translations are provided in French, German, Italian, Spanish and Russian. Interpretation services were also provided on demand. During the period over 1600 pages of translated texts were provided.

Printing and Binding Unit continued to provide printing of restricted reports, reprints, invitation cards, visiting cards etc., by using offset and screen printing processes. Binding of collected scientific publications of various Divisions, reprints, tender documents, restricted reports etc. was carried out.

The Scientific Information Resource Centre (SIRC) of DAE Secretariat continued to provide library & information services such as Circulation, New Arrivals Services, News Clipping Services, Reference & Information Services, Reprography Services etc. New books, Periodicals & Journals and other reading materials were added to the resource collection of SIRC. SIRC continued to provide the online access to Scientific Journals of Elsevier. The online subscription of "Thomson & Reuters" for access of international law journals were also catered. Publication and printing of statutory documents such as 'Annual Report', 'Outcome Budget' and internal publications such as 'Accounts at a Glance', 'DAE Diary', "DAE Essay Contest Announcement" etc. were handled and completed at SIRC. Publication and printing of various public information literature such as 'Nuclear India', 'Parmanu', 'DAE Perspective', etc. were also continued.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of public outreach programmes to alleviate unwarranted fears, to address apprehensions harboured against nuclear energy and to keep the public abreast with the contributions of atomic energy towards societal welfare. Towards achieving this, DAE participated in and organised a host of events comprising exhibitions, seminars, workshops, essay and quiz contests in different regions of the country which were well received by the target audiences.

The 103rd Indian Science Congress was held at University of Mysore, Mysuru during February 3 – 7, 2016. The focal theme was "Science & Technology for Indigenous Development in India".



Distribution of prizes at the DAE Quiz Event during the 103rd Indian Science Congress, Mysuru

DAE and other constituent units participated in the exhibition displaying all their activities. Nuclear quiz were conducted in English and Kannada on all the days which saw very enthusiastic participation by students and the general public. Prizes were given away to the winners in the quiz.

The 19th National Exhibition with the theme, "Make in India – Our Commitment to the Nation" was held at Netaji Maidan, Baranagar, Kolkata, West Bengal during September 9 - 13, 2015. DAE participated in this event and exhibited all the peaceful uses of atomic energy. Variable Energy Cyclotron Centre, Kolkata also participated and exhibited their R&D activities.

The 27th All India Essay Contest on Nuclear Science and Technology was held in October 2015. A total of 307 essays were received out of which the authors of twenty nine were selected for making an oral presentation at Mumbai. The selected participants visited various DAE facilities. Prizes, in cash were awarded on Founder's Day. The essays were received in Hindi, English, Tamil and Gujarati languages.



Winners of the 27th DAE All India Essay Contest

"Indian Technology Congress 2015", a two day exhibition with focal theme "Transforming India as a Global Engineering & Technology Hub – Prospects and Pathways" was organised at NIMHANS Convention Centre, Bangalore during July 29-30, 2015. Heavy Water Board put up an exhibition on its technologies and products developed and its role towards societal development. Members of the general public, students at the college level benefited from this event.

The "Vigyanene Tu Kausalam" exhibition was held at Jayapur, Varanasi, Uttar Pradesh during April 28 – 30, 2015. This was a Science, Technology and Engineering Exhibition. Members of the academic community, students visited the exhibition.

The International Conference on Science, Technology and Applications on Rare Earths (STAR-2015) was held at Trivandrum, Kerala during April 23 – 25, 2015. DAE put up exhibition on this occasion on its activities relating to rear earths, uranium exploration, mining and fuel fabrication.

National Association for Application of Radioisotopes and Radiation in Industry (NAARRI) organised a two day seminar on "Applications of Radioisotopes and Radiation Technology in Agriculture, Industry & Healthcare" at AISECT University, Bhopal during July 3 – 4, 2015. DAE put up an exhibition on relevant activities.

Department of Atomic Energy participated in the "11th Food & Technology Expo & Concurrent Show – Government Achievement & Schemes Expo 2015" at New Delhi during July 29 – 31, 2015. The main focus was Application of Radiation & Isotopes in Healthcare and Gamma Radiation Processing Services. DAE exhibited its activities in the area of agriculture and food processing. Experts from BARC were also present for interaction with the public that comprised mainly farmers, agriculturists and businessmen.

The University of Mysore (in its centenary year) and the INS, Mysore chapter jointly organised a seminar on "Benefits of Nuclear and Material Sciences in day to day life" at Mysore during August 21 – 22, 2015. DAE put up an exhibition on its contributions towards nuclear power, applications of radioisotopes, water, hydrology, advanced technologies etc.

DAE took part in a National Conference on Analytical Science and Technology that was held at Munnar, Kerala during September 24 – 26, 2015. The

theme of the conference was "Analytical Science for Technological Innovations and Environmental Sustainability".

Government Model Science College, Jabalpur organised the "Parmanu Urja Janjagruti Abhiyan" a three days exhibition of DAE during October 8 – 10, 2015. DAE put up an exhibition on its various activities. The exhibition was well received by professional college students and faculty.

BARC in collaboration with NPCIL and HBNI organised the International Conference "Thorium Energy Conference 2015 (ThEC2015). DAE put up Exhibition that was run parallel to the conference during October 12 – 15, 2015 at Nabhikiya Urja Bhavan, NPCIL, Anushaktinagar, Mumbai.

DAE organised the 7th International Exhibition and Conference, India Nuclear Energy 2015 at the Nehru Centre, Mumbai during October 15 - 16, 2015. National and International professionals in the Nuclear Power Industry participated in this event. In a concerted effort, DAE along with its other constituent units exhibited its activities specifically in the area of nuclear power and also applications of radioisotopes, advanced technologies etc.

The 35th India International Trade Fair 2015 organised by the ITPO, was held at the Pragati Maidan, New Delhi during November 14-27, 2015 with theme Make in India. DAE exhibited all its activities and achievements as in nuclear power, applications of radioisotopes in various areas, water and hydrology, advanced technologies etc through interactive multimedia display systems. The Atomic Minerals Directorate for Explorations and Research (AMD), Delhi also participated in the exhibition along with DAE. Members of the general public, students, and industrialists visited the pavilion.

DAE participated in the 9th National Seminar on Peaceful Uses of Atomic Energy that was organised by United Schools Organisation of India (USO) at New Delhi during November 16 – 17, 2015. Select teachers at the high school level and educators from all over India attended the seminar.

DAE participated in the India International Science Festival (IISF) held at IIT Delhi during



Visitors at the DAE pavilion during the India International Science Festival (IISF), IIT Delhi

December 4 – 8, 2015. Various government departments like ISRO, DRDO, CSIR, DBT, IITs etc. also took part in this event. DAE exhibited all its activities as in nuclear power, applications of radioisotopes, advanced technologies, international collaborations: CERN, ITER etc. The exhibition was visited by students, faculty members and scientists/technologists.

The 7th edition of AGROVISION was held at Reshimbagh Ground, Nagpur during December 11 - 14, 2015. The department's achievements and contributions in the area of nuclear agriculture especially for the benefit of farmers and applications in food processing were exhibited. A large number of farmers and other scientific professionals benefitted from this event.

DAE participated in the Acharya Satyendranath Basu Smarak Bijnan 'o' Prajukti Mela at Hedua (North Kolkata) during January 20 – 26, 2016. VECC, Kolkata also participated in the event. The exhibition was visited by students at the high school and college levels.

A conference on "Advances in Refractory and Reactive Metals and Alloys (ARRMA-2016)" was held at Convention Center, Anushaktinagar during January 27 – 29, 2016. The International Conference on Radiation Research: Impact on Human Health and Environment (ICRR-HHE 2016) and the First Biennial Meeting of Society for Radiation Research (SRR) was held at Convention Center, Anushaktinagar during February 11 – 13, 2016. DAE put up an exhibition on related activities.

The International Conference on Materials Science and Ionizing Radiation Safety & Awareness (ICMSIRSA – 2016) was organised by Shivaji University, Kolhapur on January 28 – 30, 2016. DAE put up an exhibition on its activities, members of the general public, students at the high school,



Dignitaries at the DAE exhibition during ICMSIRSA – 2016, Shivaji University, Kolhapur

professional college level and other academicians visited the pavilion.

Madhya Pradesh Council of Science & Technology in collaboration with Vigyan Bharati organised 5th Bhopal Vigyan Mela (BVM2016) at BHEL Dushehra Ground, Bhopal with the focal theme of "Swachh Bharat". DAE put up an exhibition on its various activities. The exhibition was visited by students and academicians and general public.

DAE participated in an exhibition organised by Goa Science Centre, a grand festival of Science & Technology called Science Fiesta. The Science Fiesta was held at Goa during February 26 – 29, 2016. Members of the general public, students at the high school, college level and academicians visited the pavilion. NPCIL also participated in this event.

DAE took part in an event organised by the Aravali Institute of Nursing a "Vigyan Mela" at M. L. Sukhadiya University, Udaipur during August 11 – 12, 2015. DAE participated in the Public Outreach Programme at Department of Physics, University of North Bengal on August 26, 2015 and Ananda Chandra College on August 27 – 28, 2015.



Dr. M.R. Srinivasan, former Chairman AEC, & Secretary DAE at the DAE pavilion during Engineers' Conclave 2015, Mumbai

DAE put up exhibition on all its activities during the "Engineers' Conclave 2015" held at Nabhikiya Urja Bhavan, NPCIL, Anushaktinagar, Mumbai during September 7 – 9, 2015. Various DAE units and members from the Indian nuclear industry participated in this event.

In addition to all these events, several public awareness lectures/workshops on atomic energy were conducted in different regions of the country throughout the year. Many of these were in the vernacular medium also.

To communicate undeniable merits of nuclear power to various sections of the society NPCIL has been carrying out a gamut of public awareness activities over a period of time conveying the facts on nuclear power in a simple and transparent manner. Public understanding of nuclear power and other associated aspects is one of the major goals of Nuclear Power Corporation of India Limited (NPCIL). To achieve this, a multipronged communication strategy has been adopted on public awareness. An action plan with clear set of objectives and timelines is in place for effective communication which also includes a review and monitoring mechanism.

NPCIL's public outreach includes regular interaction with the persons living nearby Indian 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 a number of nuclear galleries at the science centres across the country to allay the apprehensions of public on nuclear power and other associated aspects.

NPCIL has been scaling up its public outreach programme manifold in a structured manner through a multi-channel approach. Several innovative public awareness programmes have been conceived and implemented across the nation in this regard. Use of exhibitions, seminars, scientific meets, distribution of single-sheet publications, street plays, TV commercials, advertisements in print and

electronic media, radio jingles, innovative comic books and animated films in vernacular languages, enhanced interaction with press and media, e-public awareness campaigns to name a few that were adopted to scale up outreach activities.

NPCIL has also been partnering with several expert agencies like National Geographic Channel, National Council of Science Museums, Tamil Nadu Science and Technology Centre, PR agencies, PIB and Department of Science and Technology etc.

NPCIL has been reaching out to an average of around one and half lakh people per month as a result of these multi-pronged initiatives.

During the year, following public outreach activities were undertaken by NPCIL:

Web based Public Awareness

NPCIL web site has been providing large amount of information on nuclear energy and about the activities and achievements of the corporation. A link for public has been provided for seeking information on visit to a nuclear power station or for a visit to their premises for a presentation which is being utilized by a large number of people.

Publications

Several Lakhs copies of various informative & educative public awareness publications on various aspects of nuclear power are being distributed among general public, students, teachers, doctors, eminent persons etc. Thousands of copies of these publications were distributed in regional languages also in the state where NPPs are located.

Hall of Nuclear Power

The permanent exhibition on Nuclear Power "Hall of Nuclear Power" was recently inaugurated at New Delhi and the one in Chennai is at an advanced stage of completion. The already functional 'Hall of Nuclear Power' at Mumbai attracts around 10 Lakhs of visitors yearly. Creation of similar centres at Bhubaneswar, Ahmedabad and Jaipur are under process. General public particularly students visit this permanent gallery throughout the year. Many more such Halls of Nuclear Power are planned at various prominent locations across the country.

Multimedia and Short Films

To make aware common man about the working of nuclear power plant and its safety features, a 3-D walk through film is produced and screened in Hall of Nuclear Power located at various Science Centres. Besides, on account of COP 21 (Conference of Parties 21), two short films on climate change and ESP were produced in Hindi and English and telecasted in DD national, DD News and DD Delhi during the period 7.12.2015 to 13.12.2015.

Exhibitions

NPCIL participated in national/ regional/ local level exhibitions at various locations across the county to educate, inform and dispel myths associated with nuclear power and radiation. National level exhibitions like India International Trade Fair (IITF- 2015) held at New Delhi are one of the notable exhibitions where large number of visitors are attracted. Engineers' Conclave 2015 at Mumbai, International Thorium Energy Conference (ThEC – 2015 Mumbai), India Nuclear Energy (INE – 2015 Mumbai) were some of the other important exhibitions where NPCIL participated.



NPCIL pavilion in IITF - 2015, New Delhi

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

public awareness activities. Total 89 such lecture programs have been organized till end December 2015.

Awareness programmes in schools and colleges

NPCIL, in partnership with professional organizations, took several initiatives to reach out to students and teachers and educationalists.

KV Students and Teachers Adoption Programme

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 were launched in 3 states during this year covering over 25 Kendriya Vidyalayas.

Media Students Adaptation Programme (M-SAP)

NPCIL has always maintained excellent professional relations with press and media to provide valuable inputs to create story line for various sections of society. As a special initiative, NPCIL has devised an exceptional programme to nurture the young journalists from leading mass communication institutes and universities by arranging their visit to our nuclear power plants to have first-hand experience under the very unique programme M-SAP. So far 7 visits to various nuclear power plants by media students from various institutes and universities across the country have been organized and a detailed briefing on benefits of nuclear power has been done.

Capacity-building for outreach

Around 60 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 various sites. In addition, orientation training programme was organized for 7 resource-persons at New Delhi for conducting awareness in Kendriya Vidyalayas.

Newspaper In Education (NIE) programme with Times of India

To give the young students a right perspective on nuclear power, a special programme "Newspaper In Education (NIE)" in association with India's leading English daily 'Times of India' was launched. The programme helps students to better understand nuclear science and to learn factual information. Under the student connect programme, so far 96 workshops on nuclear energy have been organised in various schools and colleges across the country with its massive coverage. Under this programme a mega event on drawing competition "Color Splash" was also organized this year in which around 2200 students of more than 400 schools across Mumbai participated. The theme of this splendid event was" Nuclear Power: An Inevitable Option to Combat Climate Change".

Atom on Wheels (AoW)

Atom on Wheels Programme, a very unique public awareness activity, is specially designed for the villagers and people who are living near the upcoming nuclear power plants across 6 states in the country to allay prevailing apprehensions related to radiation and to develop the positive understanding on nuclear energy. Under this programme, around 1500 villages with approximately 50 Lakhs of people is targeted to be covered in the duration of two years.

Media / 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, pan India in 8 states. Lots of articles and positive news, focusing on multiple aspects of nuclear energy are planned to be published in newspapers across the nation.

At HWP, Manuguru, programs were organized in a grand way in nearby villages to create public awareness about the peaceful uses of Atomic Energy and to clear mis-conceptions by audio-visual presentations. A program on “DAE in the service of Society” by Shri S.K. Malhotra, Head, Public Awareness Division, DAE, Mumbai was organized for the Officials from HWP, Manuguru, State Government, M/s SCCL and Teachers from AECS. Information Centre at Colony for public was

inagurated. HWP, Manuguru organized Anu Vignan Exhibition at Khammam for 2 days during September 2015 and around 5200 students attended the exhibition.

At HWP, Kota, two Public Outreach Programmes and four Public Awareness Programmes were conducted covering 258 personnel belonging to nearby schools / colleges, villagers and others.

The HWP, Hazira carried out study tour to plant site for students, health awareness programme for township residents and public awareness program for people of Kavas village. A talk on "DAE in the service of the Society" was delivered by Director (Operations), HWB, Mumbai at KRIBHCO Auditorium for employees of KRIBHCO & HWP, Hazira.

At HWP, Thal programs were conducted for highlighting the societal benefit of nuclear energy and role of Department of Atomic Energy in nation building. Public lectures were organized by HWP-Thal at RCF complex and RCF colony. Scintillating talks were delivered and nuclear issues of public apprehensions were addressed by Outstanding Scientists of DAE as well as Heavy Water Board, Mumbai. The program was attended in huge numbers by RCF officials, school teachers and students. Strategy for long term energy security of the nation was discussed. A short film on organizational set-up, activities & performance of the DAE was premiered. The audience were enlightened with the applications of atomic energy in medical & health, agriculture, industry and other areas through production and use of radioisotopes and development of radiation technology applications. The issues of minimal environmental impact of the nuclear energy as compared to power generation through fossilized fuel and other conventional methods were highlighted by the speakers. Public were made aware of the cost-effectiveness as well as abundance of nuclear energy resource of the country.

Plant visit was organized at HWP, Tuticorin for about 1200 school students of 5 schools of Tuticorin. Lectures were also given to them on the activities & societal contribution of DAE. A colloquium was held with the theme "DAE in the service of society" covering college professors, school teachers and industrialists. Anu Vigyan exhibition and Anu Vigyan floor shows were organized. A DAE information centre was set up inside the HWP colony premises which is kept open for the public and students.

At RRCAT, under the Public Outreach Programme, several events were organized at various schools and colleges in Indore and in nearby cities and towns like Ujjain, Mhow, Dewas and Khargone. The events included an exhibition of specially developed working models, posters describing the DAE programs and R&D activities of RRCAT, lectures and interaction sessions with RRCAT scientists. About 1500 to 2000 students and teachers faculty members participated in each event leading to a total participation of over 12000 participants in various events.



Students being shown a working model of Indus-2

Public awareness programmes were continued by AMD in various cities as well as in remote field areas at 66 venues and a total of 125 events were organised for students, teachers and general public on the occasion of Anuvigyan week.

The Institute of Physics (IOP) conducted Public Awareness Programmes by spreading the awareness about the basic science among common people. As a part of the programme, various activities like Annual Science Quiz Competition and Annual Science Modelling Competition by Alumni Association of the Institute were carried out. Students from different schools/colleges across Odisha visited the Institute frequently.

Towards inculcating scientific interest and temperament among students at all levels. GCNEP organized eight such programs in the vicinity of Bahadurgarh where GCNEP is being set up. The target audience was XIth and XIIth class science students. A group of 45 students were invited to GCNEP Transit Office on 08th October in this connection. Dr B S Tomar Associate Director (RC&IG, BARC) and Head, SNMCS, GCNEP delivered a lecture on the occasion, followed by some experiments on radiochemistry. Students showed keen interest towards the program, especially the experiments part of it as it was their first hands-on experience with radioactivity.



School students visiting GCNEP Transit Office Bahadurgarh

SOCIAL WELFARE

Corporate Social Responsibility, Sustainability and Rehabilitation & Resettlement

NPCIL aims to harmonize its core values and business operations to meet the need of the local community in the best possible manner. From the inception of nuclear power programme in the county, the units of NPCIL have been implementing numerous social welfare activities for the benefit of local population. With issuance of DPE guidelines on Corporate Social Responsibility (CSR) for Central Public Sector Enterprises and enactment of the Companies Act 2013, NPCIL has re-invigorated the CSR programme in right earnestness.

During the financial year 2015-16, ₹ 55.38 Cr. was allocated for the CSR programme as against ₹ 52.54 Cr. in the last financial year. Unspent CSR funds were carried forward from the previous years. Using these funds, total about 100 projects were sanctioned in the FY 2015-16. Of these projects, 38 projects were in education, 21 projects were in healthcare, 24 projects were in infrastructure development, 5 projects were in skill development and 12 projects were in Sustainable Development area.

An additional CSR fund of ₹ 125 Cr. was sanctioned on account of silver jubilee year for initiating major CSR projects. From this fund, a major project titled 'Assisting Specially Abled Neighbors' (ASAN) is under implementation for providing assistive devices to the Persons with Disabilities (PwDs) living within 16 KM radius of all the fourteen Unit locations by making a Memorandum of Understanding (MoU) with Artificial Limbs Manufacturing Corporation of India (ALIMCO).

Under CSR programme, NPCIL is taking up the activities in the five identified thrust areas as education, healthcare, infrastructure development, skill development, and sustainable development. Support to education was extended through implementation of projects such as construction of school buildings and class rooms, scholarships to



School Building constructed by KAPS, NPCIL at Vadkul village



School Building constructed by KKNPP, NPCIL, near Kudankulam, Tamilnadu

students and development of Aganwadis. Educational items were provided to the school children for motivational purpose. Based on need, transport facility was provided for the school children and teachers.

Under healthcare category, primary health centres, mobile medical van services and medical camps were operated. Funds were provided for extension of hospital buildings. Construction of roads, community halls, bus stop sheds and drinking water facility etc. were taken up under infrastructure development.



Medical camps near Kaiga and Narora

Skill development programmes were implemented by imparting livelihood generation skills like welder training, masonry, computer skills, tailoring and stitching etc. Sustainable development initiatives were taken through implementation of projects like installation of solar street lights and biogas plant, conservation of turtles, rain water harvesting, artificial reefs for augmenting fish production etc.



Skill development: Welding Training at Rawatbhata, Rajasthan



Stitching and Industrial Training to women at Kaiga site

A comprehensive baseline survey has been completed at most of the Units of NPCIL. In addition to this, the unit CSR Committees at NPCIL sites assessed the needs for CSR projects requested by the local administration, surpanches, schools etc.

In the area of Rehabilitation & Resettlement, State Govt. authorities for Chutka site in Madhya Pradesh and MahiBanswara site in Rajasthan have declared the award as per RFCTLARR Act, 2013. The requisite fund has been deposited by NPCIL to both the state authorities for releasing to the Project Affected Families.

Swachha Bharat Mission

The Department of Atomic Energy (DAE) and its constituent units continued its activities for the "Swachha Bharat Mission".

As a part of "Swachha Bharat Mission", total 475 toilets and urinals have been constructed in nearby villages around NPCIL units and construction of another 53 toilets and urinals are expected to be completed by March, 2016. In addition to this, contribution amounting ₹ 10 Cr. to Swachha Bharat and ₹ 10 Cr. for Clean Ganga Kosh has also been made.



Toilet block inauguration at Ghivali village

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.

Healthcare facilities were provided to entire Mumbai based CHSS beneficiaries through the 390 bedded hospital, 13 zonal dispensaries, 3 occupational health centers and 24 hour casualty facility. All these units are computerized with unique Hospital Information System (HIS). The number of CHSS beneficiaries from the Mumbai based DAE units stood 85780 and the total number of CHSS beneficiaries registered was 100131. During the year, the BARC hospital has registered 2,52,088 patient visits in all the OPDs whereas 5,21,405 patients were attended through the zonal dispensaries. Total 34,292 casualty visits were also recorded.

Many new facilities such as Liquid Medical Oxygen, Advanced Ventilators, Audio-Visual Alarm for oxygen and nitrous oxide in the main OT complex etc. were installed and made operational.

A Dedicated Child Guidance clinic has been started at the Centre for Behavioral Sciences for catering to the maternal health needs of children. Pathological tests for Dengue, Malaria Antigen, Vitamin D, Homocysteine levels etc. were started in-house. Antibiotic Sensitivity Testing Unit, Automated Coagulation System, Genexpert for M.TB & Rifampicin resistance, Strip reader for Microalbuminurian & Urinary Albumin Creatinine ratio etc. was installed. An outreach program of Preventive Gynec checkup at dispensary level has been started. High risk pregnancy clinic has been started apart from normal antenatal checkup clinic. The work for setting-up of In-Vitro Fertility Clinic (IVF) and treatment has been initiated in Gynecology Unit. CBCT machine was installed for implant surgery planning, endodontic treatment and planning orthodontic treatment etc. Breast cancer screening at dispensary and hospital level for detecting breast cancers in early stage and reducing the morbidity and mortality in CHSS community was continued.

Dental OPD at BARC Hospital has been upgraded and commissioned for full-fledged operations which will help in substantial reduction of waiting period. New Dental Laboratory at BARC Hospital is also in the advanced stage of completion.



Upgraded Dental OPD

Conceptual plan has been prepared, designed and developed for a multi-specialty hospital building for BARC Hospital with new state-of-the-art operation theatres & other modern diagnostic facilities. Tenders were invited for civil works and quotations are being evaluated.

Children's Education

To meet the educational needs of the children of the employees of the Department of Atomic Energy and its constituent units, the Atomic Energy Education Society (AEES), an autonomous institution under the Department of Atomic Energy (DAE) was established in the year 1969. AEES currently administers 30 Schools/ Junior colleges at 15 centers located all over India and are imparting quality education to over 27,000 students. AEES provides education to economically backward children living around the Plant/Project area through its Talent Nurture Programme.

AEES achieved significant results in its pursuit of excellence in academic as well as non-academic fields, during the year. AEES continued to aim at the broader development of the complete personality of its students through modern and

technical educational infrastructure. In this regard AEES has launched several long-term key projects such as Application of Science and Technology for Educational Reforms (ASTER).

Board (Xth and XIIth) Exam results of AEES students

Total 2245 students appeared in the CBSE Board examination (Class-X) in March, 2015 and the pass percentage was 98.17. Overall 315 students secured CGPA 10 points and 517 students secured CGPA 9 point or more. Total 1834 students appeared in the Class XII board examination in March, 2015 and the pass percentage was 92.91 and the overall Excellence Index stood at 74.32. The pass percentage of AECS-1, Tarapur, AECS-3, Tarapur, AECS, Mysore and AECS, Kudankulam was 100%.

Co-scholastic Achievements of AEES students

Total 136 students secured admission to various engineering colleges and 5 students secured admission into MBBS. 70 students were awarded the National Talent Search Scholarships for the NTSE conducted by National Council of Educational Research and Training (NCERT). In the 57th Annual All India UN Information Test, 45 students have secured good ranks in all India level. Two Students of AECS, Turamdih have secured 1st position in national level of "Hindi Vigyan Prashna Manch", conducted by Hindi Vigyan Parishad, BARC. Two Students from AECS-4, Mumbai, 2 Students from AECS, Kakrapar and 1 student each from AECS, Indore, AECS, Kaiga and AECS-1, Tarapur were qualified for Kishore Vaigyanik Protsahan Yojana Fellowship Award instituted by Indian Institute of Science, Bangalore. 58 students of Class IX of various AEC Schools participated in Junior Science and Mathematics Olympiad organized by AEES (in collaboration with HBCSE) at AECS-2, Mumbai along with 15 mentor teachers.

Achievements of Students in Art, Music and Dance

Total 278 students from AEC schools of Mumbai qualified in the Elementary Level and 25 students qualified in the Intermediate Level Drawing Grade Examination conducted by Directorate of Art, Maharashtra State Board. All India Inter AECS Art Exhibition was held at AECS, Kaiga. Spectacular paintings by students of AEC schools all over on different topics were brought for the final display and Prizes for the best entries were given to the winners. The All India Inter AECS Cultural Meet in Dance was organized at AECS, Kaiga from 5th to 7th November, 2014.

All India Inter–AECS Basketball, Volleyball and Badminton Tournament

All India Inter AECS Volleyball, Basketball and Badminton Tournaments were held at AECS-1, Tarapur, AECS, Anupuram, AECS, Narora and AECS-2, Mumbai respectively in 2014.

Summer Sports Coaching Camp for Students

Atomic Energy Education Society in collaboration with the Department of Atomic Energy Sports and Cultural Council organized Summer Sports Coaching Camp for school children in various games such as Football, Volleyball, Basketball, Lawn Tennis, Table Tennis, Badminton and Athletics.

All India Inter AECS/AEJC Science, Social Science, Mathematics and Teaching Aids Exhibition-2014

The above event was held at AECS, Indore in August, 2014. More than 100 projects in the said subjects were presented and best three projects were exhibited in NCERT/Jawaharlal Nehru National Science Exhibition in November, 2014.

ASTER Programme

Nine Live programmes on ASTER were telecasted which included two live programmes by the Nobel Laureates Dr. Jean Marie Lehn and Dr. Harold Krotto and other seven programmes by well-known Scientists and other dignitaries such as Dr. S. Banerjee, Ex-Chairman, AEC & Secretary, DAE, and Dr. R. Chidambaram, Former Chairman AEC, Dr. Sekhar Basu Director, BARC, Dr. B. Venkataramani, Dr. Pankaj Chaturvedi, TMC, Dr. Rajan Badwe, Tata Memorial Center and Shri Anil Kumar, IPS, IG (Security), DAE.

Workshops, Seminars and Orientation Programmes

Orientation programmes were organized by AEES for the PRTs, TGTs and PGTs with a view to empower them to plan and execute various classroom activities to be used for better evaluation.

Rolling Trophies

Dr. Homi Bhabha Rolling Trophies for the Best Overall Performance among AEC Schools and Junior Colleges were awarded to AECS-4, Rawatbhata and AEC-Indore respectively for the academic year 2013-2014.

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. Considering that the mandate of sustainable nuclear power needs the inculcation of positive attitude, team work, nurturing of excellence and building up of competitive spirit amongst the employees, DAE S & CC's thrust has been to encourage facilitation of activities towards these themes. In addition, programs are also designed to develop positive health and attitude towards achievement of excellence amongst family members of employees.

A brief summary of activities undertaken by DAE S&CC during the year 2015-16 are as follows:

About 1000 employees participated in the Inter DAE meets which aim at encouraging healthy competition amongst DAE employees in various sports and cultural events to facilitate inter as well as intra-unit synergy, constructive team work and sportsman spirit among employees.. The playing facilities at various units have been upgraded so that these improved DAE events can be conducted in the best traditions of the Department. As per tradition, DAE S&CC procured and gave mementoes as token of the Department's appreciation to all participants



Table Tennis event at PTAA, Anushaktinagar, Mumbai

and volunteers who contributed to the success of this meet. Teams to participate in National events like, Kabbadi, Bridge, Table Tennis &, Badminton etc. were also selected during the meet. Participation of all DAE units are through eight leader groups (Ajanta, Dwaraka, Ellora, Golkonda, Konark, Nagarjuna, Pushkar and Rameswaram). Selection trials are conducted by each leader group at various DAE units to represent the leader group. Three event Table Tennis at Mumbai (DCSEM), Volleyball at Manuguru (HWP-M) and Basketball at Jaduguda (UCIL) have been so far completed successfully by participation of all 8 leader groups as per games and financial guidelines of the Council. The Council allotted events to units and made arrangements for the trophies and mementoes. DAE S&CC also supported the participation of these players in National Championships by payment of affiliation fees, provision of kit allowance and arrangement of training camp.

DAE S&CC organized summer coaching camps (coaching in various games and sports like Athletics, Swimming, Cricket, Football, Basketball, Table Tennis, Badminton, Lawn Tennis etc.) for DAE school children for four weeks jointly with AEES at various DAE Schools located at different units of DAE. The Council shares one third of the cost of summer camp and frames the camp guidelines. More than 2750 students participated in the preliminary camp and 1500 students participated in the main camp. Selection for advanced coaching was done based on performance of the players in summer coaching camps.

The New Community Centre, Anushaktinagar was renovated during the year, 2015 by DCSEM. All the halls have been provided with acoustic resistant wall panelling, new flooring and air-conditioners. The LED lighting has been provided to save electricity consumption. The renovated sports facilities have started functioning from 15th Jan ,2016.



New Renovated Badminton Hall cum auditorium at Anushaktinagar

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. Yoga Magazine, for updating the latest techniques etc. in Yoga Science, were supplied to all the schools and different units of DAE. To further encourage Yoga and Fitness, units of DAE were encouraged and financially supported to set up fitness centers for their employees and family members. "Healthy Living" Programmes and regular yoga activities as well as camps were organized at different centers e.g.Vrindavan,NCC etc for employees as well as for their family members. Monthly Yoga magazines (2 Nos) are supplied for updating the latest techniques in yoga Science, to all the schools and different units of DAE. DAE S&CC provided financial support to BARC YOGA Summer camp organised by BARC Staff Club. Supported for fitness centre equipment in Shantiniketan and Purnima Building, Mumbai. A Yoga workshop has been planned at RRCAT, Indore during Feb 2016.

Under Nature and adventure related activities, 5th DAE S & CC Nature and Adventure Camp for the children of DAE employees was organized during Dec 24-27, 2015 at Van Vihar Camp, Karjat. A total of 75 Children (45 girls and 30 boys) between age group of 9-13 yrs have participated in this camp. The objective of the camp



Participants of Nature and Adventure Camp -2015

was to promote the spirit for adventure among the youngsters.

Seventh All India DAE Himalayan Trekking Expedition (Trek the Himalaya-7) was organised in Hamta Pass region near Manali, Himachal Pradesh from 2nd--09th October, 2015. All the participants successfully completed the trek.



Participants of 7th DAE Himalayan Trekking Expedition at Manali

DAE S&CC organised an annual all India trekking programme "Girisanchar-27" with the approval of the Indian Mountaineering federation.

Some of the promotional activities undertaken by DAE S&CC included participation of DAE teams in National Level inter institutional tournaments supported by national federations (Table tennis, Kabaddi, Badminton, Bridge & Ball Badminton); Support to Sports, fitness, cultural cum community centre (New Community Centre) at Anushaktinagar as a demonstration model community center on a self-supporting basis as an example to all other units. ; Support to district level promotional tournaments at Anushaktinagar to facilitate advanced coaching for children in Table Tennis , Tennis, Cricket & Badminton; Financial subsidy to welfare groups of various units (ARWA for sports, BARC Hospital, BARC Staff Club Yoga Circle, etc.) and new community centre for Annual

competitions SPLASH-2014 and Shantiniketan &Purnima Residents for setting up of Gym Facility and Subsidy to Special children for conducting sports camp Shoushilya at Anushaktinagar.

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.

DAE received a total of 1147 RTI applications and 137 Appeals during the year 2015. All applications have been responded to within the stipulated time frame by the CPIOs. Appeals have been disposed off as per the provisions of RTI Act, 2005.

The provisions contained in RTI Act, 2005 were fully complied by IGCAR with Suo moto disclosure under Section 4 of RTI Act 2005 and updated information were uploaded in the website. During the year, 142 applications were received, 4 applications were transferred to other PIOs and information was provided to all the remaining 138 applicants within the prescribed time limit.

At AMD, the RTI related issues were dealt efficiently. A total of 171 RTI applications were received, out of which 165 were replied, 4 transferred and 2 rejected. 29 first appeals were received and 2 CIC hearing on second appeal were attended.

At NPCIL, an elaborate mechanism exists with 7 Central Public Information Officers (CPIOs) and 7 Assistant Public Information Officers (APIOs), one at each site and one CPIO, one central APIO and an Appellate Authority at Headquarters to deal with the requests received under the RTI Act, 2005. The mandatory information required under the Act under Section 4(1) (b) has been posted on NPCIL website and the information was updated. Presentations/ lectures were organised in NPCIL for creating awareness about the importance and ways to implement the Act. During the financial year 2015-16, 594 nos. of RTI applications and 147 nos. of appeals were received under the RTI Act 2005 and they were disposed off.

During the year, IREL received 103 RTI queries out of which 100 RTI queries were replied to.

SINP received 30 RTI Applications out of which 28 RTI Applications were replied and it received 5 Appeals and all of them were replied.

AWARDS & PRIZES

NPCIL and its sites won several awards in the areas of safety and performance, public outreach activities, CSR and Official Language.

TAPS-1&2 won the National Safety Council of India (NSCI) award “Prashansa Patra” and National Safety Council Maharashtra chapter awarded a plaque for "Factories Working over One Million Man-Hours under Scheme-I – Lowest Accident Frequency Rate for the year 2014-15”. TAPS-3&4 won the first prize in power generation industrial group in the “Best safety practices award-2015”, awarded by National Safety Council Maharashtra chapter and Directorate of Industrial Safety & Health Maharashtra state jointly. National safety award for the year-2013 for outstanding performance in industrial safety based on lowest average accident frequency rate.



NSCI award for TAPS-3&4 for the year-2013 for outstanding performance in industrial safety based on lowest average accident frequency rate

RAPS-3&4 won Bronze shield award in “SURAKSHA PURASKAR” by NSCI under Category-C “Manufacturing Sector of Power Generation” for the year-2014. RAPS-3&4 has bagged this award consecutively for the last four financial years. Silver shield was awarded in “JEWEL OF INDIA AWARD” to RR SITE by Indian Solidarity Council New Delhi for outstanding achievements in

the field of "Manufacturing of Nuclear Power Generation Sector" for the year-2015. RAPS-5&6 won "Suraksha Puraskar" (Bronze Trophy) award for the Calendar year-2015 from NSCI based on past 3 years safety performance. RAPS-5&6 won "Jewel of India Award" from Indian Solidarity Council for outstanding achievements in the field of nuclear power generation. Maharashtra safety award-2014 for achieving longest accident free period in power generation, transmission and distribution category by National Safety Council Maharashtra chapter.

NAPS won "Industrial Safety Award" of AERB for the year 2014 jointly with Madras Atomic Power Station in production unit group (NPPs & HWPs).

KAPS-1&2 won PRASHANSA PATRA-2014, award from the fourth level National Safety Council of India safety awards–2014 in category-c under the manufacturing category for the assessment period of three years-2012 to 2014 for achieving the most outstanding performance in safety and health management system. "Gold shield" award in the category of performance of Nuclear Power Stations for the year 2013-14, conferred by Central Electricity Authority (CEA), Ministry of Power, Government of India. "National Safety Award" for outstanding performance in Industrial safety as runner-up during the performance year 2013 in achieving Accident Free Year by Minister of State for Labour & Employment, Government of India. "Environment Protection Award" of AERB for the year-2014 in operating units/operating mines group. For the first time in Indian nuclear industry, KAPP-3&4 has won the prestigious "Sarvsrestha Suraksha



National Award for Meritorious performance of KAPS-1&2 for the year 2013-14



National Award for Meritorious performance of KGS for the year 2013-14

Puraskar" in the construction sector, from National Safety Council for the performance in three consecutive years in 2012, 2013 & 2014.

KAIGA site won National Award for Meritorious Performance in Power Sector for the year 2013-2014 in the performance of Nuclear power plants Category. KGS-1&2 won "Unnata Suraksha Puraskar" (Silver trophy) for the year 2013 and 2014 from National Safety Council, Bengaluru; bagged runner up Award in the Lowest Average Frequency Rate category for the performance year 2013. KGS-3&4 bagged national safety award "Shreshtha Suraksha Puraskar" (Silver) from National Safety Council of India for the year 2014. Bagged safety award "Utthama Suraksha Puraskar" from National Safety Council, Karnataka Chapter for the performance year 2013 & 2014.

NPCIL was awarded third prize for outstanding work done in the field of Official Language implementation among PSEs of Govt. of India by Ashirwad Sansthan, an NGO. The house magazine of NPCIL HQ "URJASWI" also bagged the second best magazine award among all the magazines published by the member PSUs of Mumbai PSU TOLIC (Town Official Language Implementation Committee). For the year 2013-2015, MAPS received first prize from TOLIC, Chennai for the excellent implementation of Official Language in the PSU group. The coffee table book on flowers found in and around NPPs "The Realms of Flowers" won the first prize for best coffee table book in the Public Relations Society of India (PRSI), national awards 2014. Madras Atomic Power station (MAPS) has won the "Gold Award" from Green Tech

Foundation, New Delhi, under "4th Annual Green Tech CSR Awards 2015" in Nuclear Power sector for outstanding achievement in CSR.

During the year 2015-16, UCIL received many accolades for its outstanding activities in different domains such as Udyog Ratan Award -2015 by Institute of Economic Studies, Excellence Award - 2015 by Institute of Economic Studies, Greentech HR Award -2015 by Greentech Foundation, New Delhi, Greentech Safety Award -2015 to Turamdih Mill by Greentech Foundation, New Delhi and Outstanding Leadership Award -2015, Mining Engineers Association of India.

ECIL won the prestigious Governance Now PSU Research and Innovation Award for the year 2015 in recognition of its unparalleled contribution to Research and Development as well as assimilation of new technologies in Electronics and allied fields. ECIL received SKOCH Order of Merit Award 2015 for EVMs and related products and Cancer Hospital Information Management System. ECIL received "Rajbhasha Shield" for the year 2014-15 in Big Organizations category for excellent implementation of Official Language.

The HWP, Manuguru received two Indian Chemical Council Awards for the year 2014 for Excellence in Management of Health/Safety/Environment and Excellence in Energy Conservation & Management. HWP, Kota was awarded with “RAJ BHASHA SHIELD” by Nagar Rajbhasha Karyanwayan Samiti-Kota for the period Jan to Jun'2015. Certificate of Appreciation from National Safety Council (Manufacturing Sector) under Group-B was awarded to HWP, Hazira for the year 2013.

AMD officers have been conferred with Outstanding Service Award – 2014 of Indian Nuclear Society, N.N. Chatterjee Award - 2015 of Geological Society of India, Bengaluru, Prof. S.M. Ramananda Setty Award – 2013 of Mineralogical Society of India, DAE Hindi Sevi Samman 2013-14, Dr. G.R. Udas – Dr. K.K. Dwivedy Medal – 2014 and 2015 by Indian Society of Applied Geochemists (ISAG), DAE Group Achievement Award – 2014 and DAE Meritorious Service Award (MSA) - 2014.

AT BRIT, the Scientific and Technical DAE Excellence Award 2014 was awarded to Mr. Tariq Saeed Anwar, Head, Regional Centre, RAPPCOF, Kota, for 'Development of Indigenous High Intensity Co-60 Teletherapy, Irradiator Sources and Sealed Sources Fabrication'. Another Scientific and Technical DAE Excellence Group Achievement Award 2014 was conferred on Dr. V.N. Yelgaonkar and Dr. A.K. Kohli, Group Leaders of the team of Scientists/Engineers/Technical Personnel for their contribution for successfully accomplishing the activity titled, 'Design and Development of Indigenous Co-60 Based Blood Irradiator and Innovative Technique for the Benefit of Industries'.

Scientists from TIFR have won prestigious national awards during the report period. The Shanti Swarup Bhatnagar Prizes for excellence in scientific research were awarded to Professor Mandar Deshmukh for Physics, Professor K Sandeep and Professor Ritabrata Munshi for Mathematics and Professor Vidita Vaidya for Medical Science. The Infosys Science Foundation Prize was awarded to Professor Mahan Mj for Mathematics, and Professor G. Ravindra Kumar for Physics.

Prof. R. Gopakumar of HRI was awarded the J. C. Bose fellowship this year.

CHAPTER -11

IMPLEMENTATION OF PERSONS WITH DISABILITIES (EQUAL OPPORTUNITIES, PROTECTION OF RIGHTS & FULL PARTICIPATION) ACT, 1995

The Department of Atomic Energy has a mandate to develop peaceful uses of nuclear energy in areas like power generation and basic research in frontier areas of science and technology. In view of the nature of activities carried out by the Scientific and Technical persons in various Research Centres, Public Sector Undertakings, Industrial Units and Aided Institutions of the Department, this Department is not in a position to implement the provisions of reservation of posts fully as required under the "Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act, 1995". Therefore, this Department has already sought exemption for the Units like Heavy Water Boards and Nuclear Power Corporation of India Ltd. From the provisions of the said Act. No specific scheme under plan projects for the benefit of persons with disabilities has been introduced in the Department. In-spite of the constraints, all the Units/PSUs/Aided Institutions have attempted to identify posts, where persons with disabilities could be employed without impairing the activities or causing inconvenience.

The sanctioned strength and number of persons with disabilities in various posts in Group A, B, C & D against 3% vacancies to be reserved for them under Section 33 of the said Act is indicated in the pages that follow.

For the purpose of DAE Annual Report 2015-2016 (PWD Report - I & II merged)

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2016 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 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	8233	0	2	39	0	1	3	227	0	0	7	NIL	NIL	NIL	28	0	0	0
Group B	9821	5	7	64	2	1	2	177	0	0	10	NIL	NIL	NIL	109	0	0	2
Group C	11030	15	32	112	4	13	12	404	0	9	27	0	1	0	178	0	0	2
TOTAL	**29084**	**20**	**41**	**215**	**6**	**15**	**17**	**808**	**0**	**9**	**44**	**0**	**1**	**0**	**315**	**0**	**0**	**4**

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

For the purpose of DAE Annual Report 2015-2016 (PWD Report - I & II merged)

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2016 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 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	1286	1	1	5	5	5	5	9	0	1	0	NIL	NIL	NIL	0	0	0	0
Group B	2854	6	1	19	2	3	5	5	0	1	2	NIL	NIL	NIL	0	0	0	0
Group C	2486	4	10	37	6	4	5	21	0	0	4	0	0	0	0	0	0	0
TOTAL	**6626**	**11**	**12**	**61**	**13**	**12**	**15**	**35**	**0**	**2**	**6**	**0**	**0**	**0**	**0**	**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

For the purpose of DAE Annual Report 2015-2016 (PWD Report - I & II merged)

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 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	6834	6	3	41	2	4	1	49	0	0	0	NIL	NIL	NIL	9	11	0	0
Group B	5937	13	6	57	4	2	1	34	3	2	1	NIL	NIL	NIL	8	0	0	0
Group C	8525	9	7	56	5	3	3	69	1	0	0	0	0	0	44	26	0	0
TOTAL	**21296**	**28**	**16**	**154**	**11**	**9**	**5**	**152**	**4**	**2**	**1**	**0**	**0**	**0**	**61**	**37**	**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

CHAPTER -12

CITIZEN'S CHARTER



I) OUR VISION

The vision of the Department of Atomic Energy is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

II) 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.

III) OUR ACTIVITIES

The Department is engaged in the design, construction and operation of nuclear power / research reactors and the supporting nuclear fuel cycle technologies covering exploration, mining and processing of nuclear minerals, production of heavy water, nuclear fuel fabrication, fuel reprocessing and nuclear waste management. It is also developing advanced technologies which contribute to the national prosperity. The human resource developed and technical services being rendered by the Department have been greatly helping the Indian industry.

The Department is also developing better crop varieties, techniques for control/eradication of insects thus protecting the crops, radiation based post harvest technologies, radiation based techniques for diagnosis and therapy of disease particularly cancer, technologies for safe drinking water, better environment and robust industry.

IV) 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.

V) DAE PROGRAMMES RELATING TO THE NATIONAL COMMON MINIMUM PROGRAMME

High potential domains for developmental applications

- **Agriculture**

  Enhanced production of oilseeds and pulses

- **Education, Health**

  Homi Bhabha National Institute (HBNI)
  National Initiative on Undergraduate Science (NIUS)
  Countrywide Services in Cancer through Telemedicine

- **Food & Nutrition Security**

  Radiation Processing of Food & Agro Products

- **Water Resources**

  Desalination in water scarcity areas along the sea coast

- **Energy Security**

  Electricity supply in near and long term ensuring long term sustainable development
  Rule of Nuclear Power as Primary Energy Source in the years to come.

VI) WHOM TO CONTACT

I. Public Grievance and complaints

Smt. Chitra Ramachandran, Additional Secretary &
Public Grievances Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22022816
Email I.D. - as@dae.gov.in

II. Vigilance Complaints

Shri Sanjeev Sood, Joint Secretary (I&M) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22840309
Email I.D. - jsim@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 SPEHERES OF LIFE. WE SHALL REMAIN VIGILANT AND WORK TOWARDS THE GROWTH AND REPUTATION OF OUR ORGANISATION. THROUGH OUR COLLECTIVE EFFORTS, WE SHALL BRING PRIDE TO OUR ORGANISATIONS AND PROVIDE VALUE BASED SERVICE TO OUR CONTRYMEN. WE SHALL DO OUR DUTY CONSCIENTIOUSLY AND ACT WITHOUT FEAR OR FAVOUR.

THIS OFFICE IS THUS COMMITTEED TO MAINTAINING THE HIGHEST LEVEL OF ETHICS IN ITS WORKING TOWARDS ACHIEVING THE ABOVE OBJECTIVE, ALL ARE REQUESTED :

- NOT TO PAY BRIBE
- IF ANYBODY IN THIS DEPARTMENT OR ITS OFFICES ASKS FOR BRIBE : OR
- IF YOU HAVE ANY INFORMATION ON CORRUPTION: OR IF YOU ARE A VICTIM OFCORRUPTION IN ANY OF OUR OFFICES.

YOU MAY COMPLAIN TO:

Smt. Chitra Ramachandran, Additional Secretary &
Public Grievances Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22022816
Email I.D. - as@dae.gov.in

YOU CAN ALSO COMPLAIN TO:

THE CENTRAL VIGILANCE COMMISSION,
SATARKTA BHAWAN, BLOCK 'A',
GPO COMPLEX, INA,
NEW DELHI – 110 023.

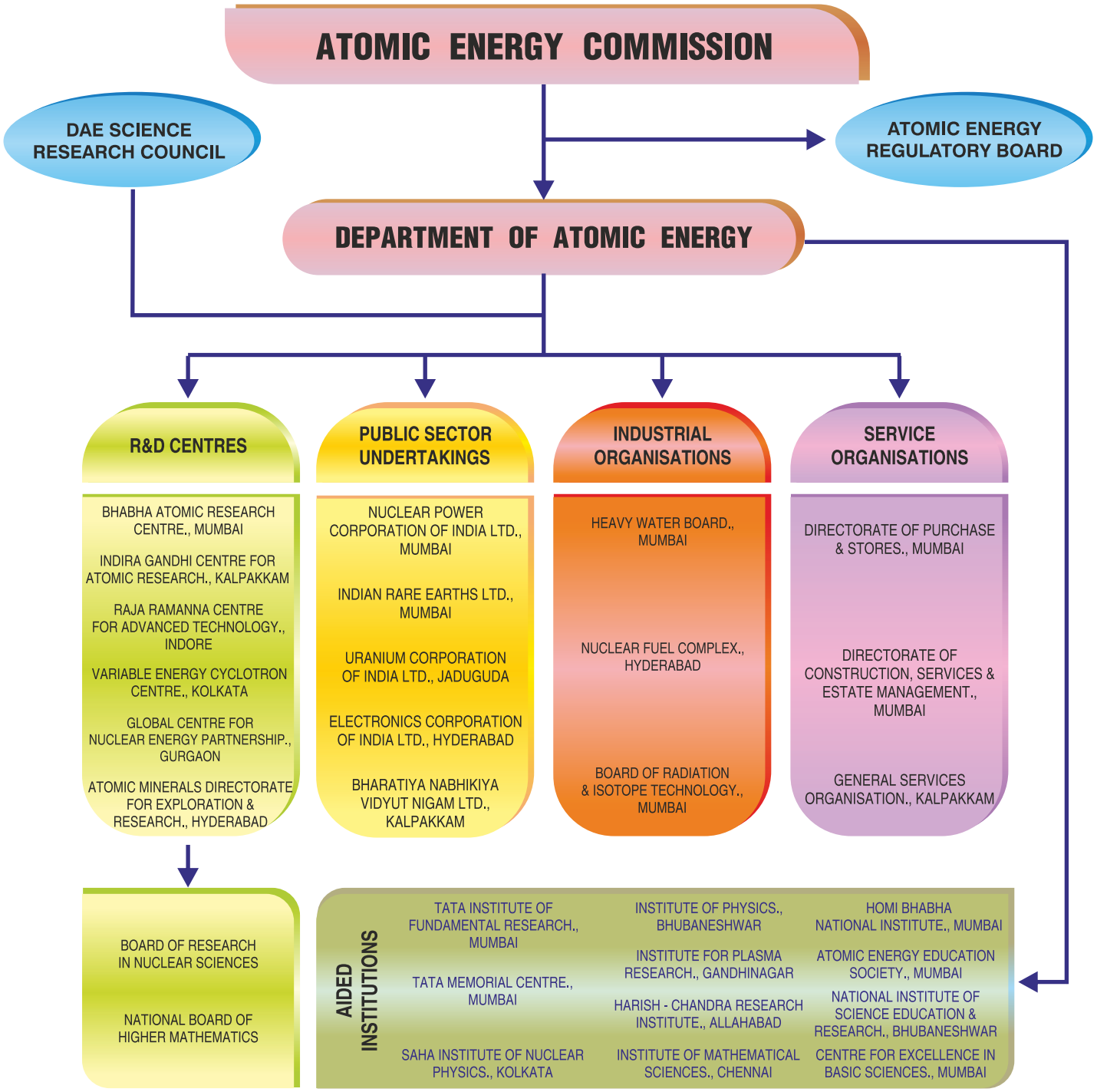
ANNEX-I

THE ORGANISATION

The Department of Atomic Energy (DAE), that came into being on August 3, 1954, has been engaged in the development of nuclear power technology, applications of radiation technologies in the fields of agriculture, medicine, industry, and basic research.

An integrated group of organizations, the Department comprises six Research Centres, three Industrial Organisations, five Public Sector Undertakings and three Service Organisations. It has under its aegis two Boards for promoting and funding extra-mural research in nuclear and allied fields, and mathematics, and a national institute (deemed university).

It also supports ten institutes of international repute engaged in research in basic sciences, astronomy, astrophysics, cancer research and education, etc., and a society that provides educational facilities to the children of DAE employees.


ATOMIC ENERGY COMMISSION
DAE SCIENCE RESEARCH COUNCIL
ATOMIC ENERGY REGULATORY BOARD
DEPARTMENT OF ATOMIC ENERGY
R&D CENTRES
BHABHA ATOMIC RESEARCH CENTRE., MUMBAI
INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH., KALPAKKAM
RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY., INDORE
VARIABLE ENERGY CYCLOTRON CENTRE., KOLKATA
GLOBAL CENTRE FOR NUCLEAR ENERGY PARTNERSHIP., GURGAON
ATOMIC MINERALS DIRECTORATE FOR EXPLORATION & RESEARCH., HYDERABAD
PUBLIC SECTOR UNDERTAKINGS
NUCLEAR POWER CORPORATION OF INDIA LTD., MUMBAI
INDIAN RARE EARTHS LTD., MUMBAI
URANIUM CORPORATION OF INDIA LTD., JADUGUDA
ELECTRONICS CORPORATION OF INDIA LTD., HYDERABAD
BHARATIYA NABHIKIYA VIDYUT NIGAM LTD., KALPAKKAM
INDUSTRIAL ORGANISATIONS
HEAVY WATER BOARD., MUMBAI
NUCLEAR FUEL COMPLEX., HYDERABAD
BOARD OF RADIATION & ISOTOPE TECHNOLOGY., MUMBAI
SERVICE ORGANISATIONS
DIRECTORATE OF PURCHASE & STORES., MUMBAI
DIRECTORATE OF CONSTRUCTION, SERVICES & ESTATE MANAGEMENT., MUMBAI
GENERAL SERVICES ORGANISATION., KALPAKKAM
BOARD OF RESEARCH IN NUCLEAR SCIENCES
NATIONAL BOARD OF HIGHER MATHEMATICS
AIDED INSTITUTIONS
TATA INSTITUTE OF FUNDAMENTAL RESEARCH., MUMBAI
TATA MEMORIAL CENTRE., MUMBAI
SAHA INSTITUTE OF NUCLEAR PHYSICS., KOLKATA
INSTITUTE OF PHYSICS., BHUBANESHWAR
INSTITUTE FOR PLASMA RESEARCH., GANDHINAGAR
HARISH - CHANDRA RESEARCH INSTITUTE., ALLAHABAD
INSTITUTE OF MATHEMATICAL SCIENCES., CHENNAI
HOMI BHABHA NATIONAL INSTITUTE., MUMBAI
ATOMIC ENERGY EDUCATION SOCIETY., MUMBAI
NATIONAL INSTITUTE OF SCIENCE EDUCATION & RESEARCH., BHUBANESHWAR
CENTRE FOR EXCELLENCE IN BASIC SCIENCES., MUMBAI

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

ATOMIC ENERGY ESTABLISHMENTS IN INDIA



ANNEX-II

REPLIES TO AUDIT OBSERVATIONS

Report no. 30 of 2015: Compliance Audit - Union government, Scientific Ministries/ Departments

Implementation of Performance Related Group Incentive Scheme

Department of Atomic Energy introduced group incentives under Performance Related Incentive Scheme in May 2009. Review of implementation of the scheme in three units of Department of Atomic Energy, in which payment of group incentives of ₹ 32.19 crore was madeduring 2010-14, revealed instances of relaxation of targets, inflation of achievements and improper assessment of performances that not only defeated the purpose of awarding incentives for higher performances but also resulted in irregular payment of incentives. (Paragraph 2.1 of Report no. 30 of 2015)

ACTION TAKEN -

Preliminary replies have already been submitted to Audit. Action Taken Note is under submission.

POSITION OF ACTION TAKEN NOTES ON AUDIT PARAS OF C&AG REPORTS

Sr. No.	Year	No. of paras / PA report on which ATNs have been submitted to PAC after vetting by Audit	Details of the Paras / PA reports on which ATNs are pending		
			No. of ATNs not sent by the Ministry even for the first time	No. of ATNs sent but returned with observations and Audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by audit but have not been submitted by the Ministry to the Audit
1	1999	1			
2	2001			1	
3	2002				1
4	2006			1	
5	2008-09	2		1	
6	2010-11			1	
7	2013	4	2	3	
8	2014	3	2	5	
9	2015	6	13		
TOTAL : -		16	17	12	1

ANNEX-III

REPRESENTATION OF SCs, STs AND OBCs

For the purpose of DAE Annual Report 2015-2016

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2016 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2016)				Number of appointments made during the calendar year 2015									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	8233	599	130	703	257	21	3	30	327	30	6	5	1	0
Group B	9821	1809	790	2057	200	17	10	87	328	59	11	7	2	0
Group C	11030	2307	1050	3216	431	45	35	173	414	92	45	3	1	1
TOTAL	**29084**	**4715**	**1970**	**5976**	**888**	**83**	**48**	**290**	**1069**	**181**	**62**	**15**	**4**	**1**

For the purpose of DAE Annual Report 2015-2016

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2016 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2016)				Number of appointments made during the calendar year 2015									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	1286	64	7	101	49	2	2	17	48	3	0	2	0	0
Group B	2854	421	100	445	34	5	6	10	117	16	2	0	0	0
Group C	2486	772	157	474	56	10	7	17	23	4	1	1	0	0
TOTAL	**6626**	**1257**	**264**	**1020**	**139**	**17**	**15**	**44**	**188**	**23**	**3**	**3**	**0**	**0**

For the purpose of DAE Annual Report 2015-2016

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2016 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2015 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2016)				Number of appointments made during the calendar year 2015									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	6834	732	215	935	49	10	3	7	221	12	1	1	0	0
Group B	5937	952	446	1439	35	5	2	27	600	99	40	3	1	0
Group C	8525	1365	2301	1638	66	12	2	46	466	120	58	4	0	0
TOTAL	**21296**	**3049**	**2962**	**4012**	**150**	**27**	**7**	**80**	**1287**	**231**	**99**	**8**	**1**	**0**

ABBREVIATIONS

ACE	Angiotensin Converting Enzyme
ACM	Acceleration Cryo Module
ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADU	Aammonium Di-Uranate
ADXRD	Angle Dispersive X-ray Diffraction
AEDA	Aroma Extraction Dilution Analysis
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AFFF	Advanced Fuel Fabrication Facility
AFM	Atom Force Microscopy
AFMTF	AHWR Fuelling Machine Test Facility
AGPS	Acceleration Grid Power Supplies
AHWR	Advanced Heavy Water Reactor
AKRUTI	Advanced Knowledge & RUral Technology Implementation
ALARA	As Low as Reasonably Achievable
ALICEA	Large Ion Collider Experiment
ALIMCO	Artificial Limbs Manufacturing Corporation of India
ALIP	Annular Linear Induction Pump
ALM	Augmented Light Metal Plant
AMA	Anti Michrosomal Antibodies
AMD	Atomic Minerals Directorate for Exploration & Research
AMOS	Atomic, Molecular and Optical Science
AMTEC	Alkali Metal Thermal to Electric Converter
ANURIB	Advance National facility for Unstable and Rare Isotope Beams
AOE	Antioxidant Enzymes
AOO	Anticipated Operational Occurrences
AoW	Atom on Wheels
APDDC	Annular Pulsed Disc and Doughnut Column
APIO	Assistant Public Information Officer
APPJ	Atmospheric Pressure Plasma Jet
APPLE	Advanced Planar Polarized Light Emitter
APSPC	Annular Pulsed Sieve Plate Columns
ARDC	Asymmetric Rotating Disc Contactor
ARGT	Adjusted Rod Guide Tube
ARPES	Angle Resolved Photoelectron Spectroscopy
ASAN	Assisting Specially Abled Neighbours
ASE	Atomstroyexport
ASFSF	Additional Spent Fuel Storage Facility
ASS	Austenitic Stainless Steel
ASTER	Application of Science and Technology for Educational Reforms
ATI	Administrative Training Institute
ATM	Advanced Training in Mathematics
ATTF	AHWR Thermal Hydraulic Test Facility
ATU	Alarm & Trip Unit
AVS	Advance Vitrification System
AWTF	Additional Waste Tank Farm
AWTSF	Alpha Waste Transit Storage Facility
BARC	Bhabha Atomic Research Centre
BBCI	Dr. B. Barooah Cancer Institute
BDBA	Beyond Design Basis Accident
BEXD	Boron Enrichment Exchange Distillation
BEP	Boron Enrichment Plant
BER	Base Excision Repair
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BNHS	Bombay Natural History Society
BoG	Board of Governors
BOMAB	Bottle Manikin Absorption
BPCL	Bharat Petroleum Corporation Limited
BPR	Burnable Poison Rod
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BSOI	Beach Sand and Offshore Investigations
BUU	Boltzmann-Uehling-Uhlenbeck
BWR	Boiling Water Reactor
BWRO	Brackish Water Reverse Osmosis
CAAQMS	Continuous Ambient Air Quality Monitoring Station
CBI	Central Bureau of Investigation
CBS	Centre for Excellence in Basic Sciences
CBS	Computer Based System
CBM	Compressed Baryonic Matter
CCE	Centre for Cancer Epidemiology
CCIM	Cold Crucible Induction Melter
CCL	Carbon Tetrachloride
CCR	Closed Cycle Ccryostat
CCU	Catalyst Cracking Unit
CDW	Charge Density Wave
CEA	Central Electricity Authority
CERN	European Organisation for Nuclear Research
CFD	Computational Fluid Dynamics
CFVS	Containment Filtered Venting System
CHTR	Compact High Temperature Reactor
CICC	Cable In Conduit Conductors
CIP	Cold Isostatic Pressing
CISAG	Computer and Information Security Advisory Group
CLOE	Corrosion Loop Experiments
CLND	Civil Liability for Nuclear Damage
CMG	Crisis Management Group
CMPAPP	Chutka Madhya Pradesh Atomic Power Project
CMR	Custom Made Sources
CMS	Compact Muon Solenoid
CMTS	Cryo Module Test System
CNT	Carbon Nanotubes
CoARs	Cobalt Absorber Rods
COF	Coefficient of Friction
COG	Candu Owner's Group
CORAL	Compact Reprocessing facility for Advanced fuels of Lead cells
CPIO	Central Public Information Officer
CPL	Clear Pregnant LiquorCPMCharge Particle Monitor
CPSE	Central Public Sector Enterprise
CPT	CamptothecinCRCClinical Research Centre
CRDM	Control Rod Drive Mechanisms
CRGT	Control Rod Guide Tubes
CRI	Cancer Research Institute
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRS	Clinical Research Secretariat
CRZ	Coastal Regulation Zone
CSP	Core Sub assembly Plant
CSR	Corporate Social Responsibility
CSRS	Cone Shell Raman Spectroscopy
CSRDM	Control & Safety Rod Drive Mechanism
CTCB	Cryoplant Termination Cold Box
CTE	Chief Technical Examiner
CTS	Cobalt Teletherapy Sources
CVC	Central Vigilance Commission
CVD	Carbon Vapour Deposition
CVD	Chemical Vapour Deposition
CVL	Copper Vapour Laser
CVO	Chief Vigilance Officer
CWMF	Centralised Waste Management Facility
CZTI	Cadmium Zinc Telluride Imager
DAC	Diamond Anvil Cell
DAE	Department of Atomic Energy
DAF	Dissolved Air Floatation
DBI	Design Basis Information
DBTT	Ductile Brittle Transition Temperature
DCCP	DC Conduction Pump
DCSEM	Directorate of Construction Services & Estate Management

ABBREVIATIONS

DDU	Deep Depleted Uranium
DEBT	Diethyl Benzoyl Thiourea
DF	Decontamination Factor
DFRP	Demonstration Fast reactor fuel Reprocessing Plant
DFT	Density Functional Theory
DG	Diesel Generator
DGFS	DAE Graduate Fellowship Scheme
DIGIDOSE	Digital Pocket Radiation Dosemeter
DLP	Data Loss Prevention
DLLRF	Digital Low Level RF
DLX	Double Layer Experiment
DMRIT	Diploma in Medical Radio Isotope Techniques
DMRL	Defence Metallurgical Research Laboratory
DMW	Dissimilar Metal Weld
DNB	Diagnostic Neutral Beam
DND	Delayed Neutron Detection
DNM	Delayed Neutron Monitoring
DOF	Degree Of Freedom
DoPT	Department of Personnel and Training
DoS	Departemnt of Space
DOX	Doxorubicin
DPE	Department of Public Enterprises
DPPH	Diphenyl-1-Picryl Hydrazyl
DPS	Directorate of Purchase & Stores
DPSS	Diode Pumped Solid State
DPSSGL	Diode Pumped Solid State Green Laser
DRDO	Defence Research Development Organisation
DRM	Diploma in Radiation MedicineDSBDouble Strand Breaks
DSRC	Design Safety Review Committee
DSSC	Dye Sensitized Solar Cell
DTA	Differential Thermal Analysis
DTDDF	DAE Technology Display and Dissemination Facility
DTL	Drift Tube LINAC
DWBA	Distorted Wave Born Approximation
EBA	Electron Beam Accelerator
EBM	Electron Beam Welded
ECCS	Emergency Core Cooling System
ECF	Electrochemical Filter
ECIL	Electronic Corporation of India Limited
ECR	Emergency Control Room
ECRH	Electron Cyclotron Resonance Heating
EDPIS	Electronics Differential Pressure Indicating Switch
EDS	Energy Dispersive X-ray Spectroscopy
EED	Electro-Electrodialysis
EIA	Environmental Impact Assessment
EMI	Electromagnetic Interference
EMS	Environmental Management System
EMTR	Emergency Transfer
ENAC	Early Notification and Assistance Conventions
EPP	Extrusion and Piercing Plant
ESCADA	Electrical Supervisory Control and Data Acquisition
ESCIA	End Shield Calandria Integral Assembly
ESI-MS	Electro Spray Ionisation Mass Spectrometry
ESP	Environment Stewardship Programme
EVM	Electronic Voting Machine
EXAFS	Extended X-Ray Absorption Fine Structure
FAIR	Facility for Antiproton and Ion Research
FBG	Fiber Bragg Grating
FBTR	Fast Breeder Test Reactor
FBG	Fiber Bragg Grating
FBR	Fast Breeder Reactor
FCC	Future Circular Collider
FCIPT	Facilitation Centre for Industrial Plasma Technology
FESEM	Field Emission Scanning Electron Microscopy
FMBCA	Fueling Machine Bridge and Carriage Assemblies
FMHA	Fueling Machine Head Assemblies
FMTF	Fuelling Machine Test Facility
FOFB	Fast Orbit Feedback
FOTIA	Folded Tandem Ion Accelerator
FPC	First Pour of Concrete
FPDW	First Priority Design Works
FPE	First Priority Equipment
FPGA	Field Programmable Gate Array
FPI	Food Package Irradiator
FRENA	Facilities for Research in Experimental Nuclear Astrophysics
FRFCF	Fast Reactor Fuel Cycle Facility
FRIDM	Fuelling machine operated Remote pressure tube Inside Diameter Measurement
FROG	Frequency Resolved Optical Gating
FRVG	Full Range Vacuum Gauge
FTIR	Fourier Transform Infrared
FWHM	Full Width at Half Maximum
FZP	Fresnel Zone Plates
GCMS	Gas Chromatography-Mass Spectrometry
GCNEP	Global Centre for Nuclear Energy Partnership
GDR	Giant Dipole Resonance
GEM	Gas Electron Multiplier
GFA	General Framework Agreement
GHAVP	Gorakhpur Anu Vidyut Pariyojana
GIXRD	Grazing Incidence X-Ray Diffraction
GLAD	Glancing Angle Deposition
GMRT	Giant Metrewave Radio Telescope
GRB	Gamma Ray Burst
GRPS	Gamma Radiation Processing Services
GUI	Graphics User Interface
HAP	Hydroxyapatite
HBCSE	Homi Bhabha Centre for Science Education
HBNI	Homi Bhabha Nationa Institute
HD-VSFG	Heterodyne Detected Vibration Sum Frequency Generation
HEDP	Hydoxy Ethylene Diphosphonate
HEMA	Hydroxyethyl Methacrylate
HFU	Horizontal Flux Unit
HIS	Hospital Information System
HKED	Hybrid K-edge Densitometry
HOM	Higher Order Modes
HPCL	Hindustan Petroleum Corporation Limited
HPU	Health Physics Unit
HRI	Harish-Chandra Research Institute
HRG	Hadron Resonance Gas
HRTF	Hydrogen Recombiner Test Facility
HWB	Heavy Water Board
HSCMS	Hydrogen and Steam Concentration Measurement System
HTSC	High Temperature Super Conductor
IAEA	International Atomic Energy Agency
IARI	Indian Agriculture Research Institute
IAS	Isotope Application Services
IASCC	Irradiation Assisted Stress Corrosion Cracking
ICAR	Indian Council of Agricultural Research
ICGC	International Conferences Genome Consortium
ICIAM	International Congress of Industrial and Applied Mathematics
ICM	Injector Cryo-Module
ICT	Integrated Cold Trap
ICT	Institute of Chemical Technology
ICTS	International Centre for Theoretical Sciences
ICW	Inner Containment Wall
IDCT	Induced Draft Cooling Towers
IEC	Incident & Emergency Centre
IFL	Initial Fuel Loading
IFRT	Integrated Facility for Radiation Technology

ABBREVIATIONS

IFSB	Interim Fuel sub-assembly Storage Building
IGCAR	Indira Gandhi Centre for Atomic Research
IHTR	Indian High Temperature Reactor
IICHEP	Inter-Institutional Centre for High Energy Physics
IIFC	Indian Institute Fermilab Collaboration
IIT	Indian Institute of Technology
IITF	India International Trade Fair
ILW	Intermediate Level Waste
IMD	India Meteorological Department
IMO	International Mathematics Olympiad
IMSBR	Indian Molten Salt Breeder Reactor
IMSc	Institute of Mathematical Science
INE	India Nuclear Energy
INIP	India Nuclear Insurance Pool
INMO	Indian National Mathematics Olympiad
INO	India-based Neutrino Observatory
INPO	Institute of Nuclear Power Operations
INPRO	Innovative Nuclear Reactors and Fuel Cycles
INRP	Integrated Nuclear Recycle Plant
InStem	Institute of Stem Cell Biology and Regenerative Medicine
IOCL	Indian Oil Corporation Ltd
IOP	Institute of Physics
IPR	Intellectual Property Rights
IPR	Institute for Plasma Research
IPWR	Indian Pressurised Water Reactor
IREL	Indian Rare Earths Limited
IR-FEL	Infra-Red Free Electron Laser
IRMA	Immunoradiometric Assay
IRSIS	Infrared Spectroscopic Imaging Survey
ISI	In-service Inspection
ISNS	Indian Spallation Neutron Source
ISOCAD	Integrated System of Computer Aided Dosimetry
ISODIMM	Interactive Software of Drawing Interfaced Maintenance Management
ITER	International Thermonuclear Experimental Reactor
ITFT	Integrated Thermal Hydraulic Test Facility
ITL	Integral Test Loop
IVPD	In Vitro Protein Digestion
IVT	Initial Varietal Trial
IWMS	Integrated Work Management SystemIWSIn-Wall Shielding
JET	Joint European Torus
JHR	Jules Horowitz Reactor
JNPP	Jaitapur Nuclear Power Project
JNPT	Jawaharlal Nehru Port Trust
KAMINI	KAlpakkam MINI Reactor
KAPP	Kakrapar Atomic Power Project
KAPS	Kakrapar Atomic Power Station
KARP	KAlpakkam Reprocessing Plant
KGS	Kaiga Atomic Power Station
KKNPP	Kudankulam Nuclear Power Plant
LAM	Laser Additive Manufacturing
LANL	Los Alamos National Laboratory
LAXPC	Large Area X-ray Proportional Counter
LBB	Leak Before Break
LBE	Lead Bismuth Eutectic
LBNE	Long Baseline Neutrino Experiments
LCW	Low Conductivity Water
LEBT	Low Energy Beam Transport
LEED	Low Energy Electron Diffraction
LEHIPA	Low Energy High Intensity Proton Accelerator
LEU	Low Enriched Uranium
LHC	Large Hadron Collider
LHCD	Lower Hybrid Current Drive
LIBS	Laser Induced Breakdown Spectra
LLCB	Lead-Lithium Cooled Ceramic Breeder
LLCS	Lead Lithium Cooling System
LLNL	Lawrence Livermore National Laboratory
LLRF	Low Level Radio Frequency
LMCE	Long Manufacturing Cycle Equipment
LOCA	Loss of Coolant Accident
LPIU	Liquid Poison Injection Unit
LVPD	Large Volume Plasma Device
LZCU	Liquid Zone Control Unit
MAA	Macro Albumin Aggregates
MACE	Major Atmospheric Cerenkov Experiment Telescope
MACS	Multiple Alpha Counting System
MALDI-TOFMS	Matrix Assisted Laser Desorption/Ionization Time of Flight Mass Spectrometry
MaPLE	Magnetized Plasma Linear Experimental
MAPS	Madras Atomic Power Station
MBE	Molecular Beam Epitaxy
MCF	Medical Cyclotron Facility
MCS	Mist Cooling System
MEBT	Medium Energy Beam Transport
MECOS	Metallic Component Margins under High Seismic Loads
MED-TVC	Multi Effect Distillation-Thermal Vapor Compression
MEE	Major Equipment Erection
MEE	Multiple Effect Evaporator
MEK	Methyl Ethyl Ketone
MGEF	Mouse Genetic Engineering Facility
MHA	Ministry of Home Affairs
mIBG	meta Iodo Benzyl Guanidine
MIVOC	Metal Ions from Volatile Compounds
MLC	Multi Leaf Collimator
MLP	Multiple Layer Perception
MoEFCC	Ministry of Environment, Forest and Climate Change
MOIS	Medical Oncology Information System
MONSTER	Modular Neutron SpecTER
MOPA	Master Oscillator Power Amplifier
MoPP	Monazite Processing Plant
MOT	Magneto Optical Trap
MoU	Memorandum of Understanding
MOVPE	Metal Oxide Vapour Phase Epitaxy
MPGD	Micro Pattern Gas Detectors
MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
M-SAP	Media Students Adaptation Programme
MSF	Multi Stage Flash
MSG	Management Services Group
MSLB	Main Steam Line Break
MSSM	Minimal Supersymmetric Standard Model
MULLaRP	Mungbean, Urudbean, Lentil, Lathyrus, Rajmash and Pea
MYT	Multilocation Yield Trial
MWPF	Metallurgical Waste Processing Facility
NAAC	National Assessment and Accreditation Council
NAPS	Narora Atomic Power Station
NBHM	National Board of Higher Mathematics
NCCCM	National Centre for the Compositional Characterization of Materials
NCERT	National Council of Educational Research and Training
NCRA	National Centre for Radio Astrophysics
NDA	Non-Destructive Assay
NDCT	Natural Draft Cooling Towers
NDDP	Nuclear Desalination Demonstration Plant
NDT	Non Destructive Testing
NEA	Nuclear Energy Agency
NEC	North Eastern Council
NER	North Eastern Region
NEXAFS	Near Edge X-ray Absorption Fine Structure

ABBREVIATIONS

NFC	Nuclear Fuel Complex
NIE	Newspaper in Education
NIMHANS	National Institute of Mental Health and Neurosciences
NISER	National Institute of Science Education & Research
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NRB	Nuclear Recycle Board
NSCI	National Safety Council of India
NSPCL	NTPC Sail Power Corporation Ltd
NSSS	Nuclear Steam Supply System
NTO	Natural Transition Orbital
NTPF	Niobium Thermit Production Facility
NTTF	NPCIL Thermal Hydraulic Test Facility
OCES	Orientation Course for Engineering Graduates & Science Post-Graduates
ODS	Oxide Dispersion Strengthened Steel
OECD	Organization for Economic Co-operation and Development
OHSMS	Occupational Health and Safety Management System
OIT	Oxidation Induction Time
ONERS	Online Nuclear Emergency Response Decision Support system
OPO	Optical Parametric Oscillator
OSCOM	Orissa Sand Complex
PADS	Passive Auto Depressurization System
PAT	Profit After Tax
PAS	Positron Annihilation Spectroscopy
PBTF	Pebble Bed Test Facility
PCP	Primary Coolant Pump
PCR	Polymerized Chain Reaction
PCRD	Passive Catalytic Recombiner Devices
PCT	Patent Co-operation Treaty
PDB	Protein Data Bank
PDDC	Pulsed Disc and Doughnut Column
PDHRS	Passive Decay Heat Removal System
PEA	Pre Engineering Agreement
PEEM	Photo Emission Electron Microscopy
PEGDA	Polyethylene Glycol Diacrylate
PET	Positron Emitting Tomography
PFBR	Prototype Fast Breeder Reactor
PGU	Pulse Generator Unit
PHT	Primary Heat Transport
PHWR	Pressurised Heavy Water Reactors
PIE	Post Irradiation Examination
PKM	Parallel Kinematic Mechanism
PLIS	Performance Linked Incentive Scheme
PMD	Photon Multiplicity Detector
PMMA	Polymethyl Methacrylate
PREFRE	Power Reactor Fuel Reprocessing
PRSI	Public Relation Society of India
PRTRF	Power Reactor Thorium Reprocessing Facility
PSAR	Preliminary Safety Analysis Report
PSF	Pressure Sand Filter
PSI	Pre-service Inspection
PSPC	Pulsed Sieve Plate Column
PSS	Primary Shut down System
PTFE	Poly Tetra Fluro Ethylene
PVA	Polyvinyl Alcohol
PVD	Physical Vapour Deposition
PVT	Polystyrene, Polyvinyl Toluene
PwD	Persons with Disabilities
PWFA	Plasma Wake Field Accelerator
PWT	Plane Wave Transformer
QCD	Quantum Chromo Dynamics
QMS	Quadrupole Mass Spectrometer
QTL	Quantitative Trait Locus
RAFMS	Reduced Activation Ferritic Martensitic Steel
RAL	Radioanalytical Laboratory
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RCC	Regional Cancer Centre
RCR	Regional Centre for Radiopharmaceuticals
RECAPP	Regional Centre for Accelerator-based Particle Physics
RFCTLARR	The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement
RFID	Radio Frequency Identification
RFQ	Radio Frequency Quadrupole
RHIC	Relativistic Heavy-Ion Collider
RIA	Radioimmunoassay
RIB	Radioactive Ion Beam
RMC	Radiation Medicine Centre
RMO	Regional Mathematics Olympiad
RMRE	Rare Metal and Rare Earth
RNP	Radionuclidic Purity
ROH	Reactor Outlet Header
RPC	Resistive Plate Chamber
RPhP	Radiopharmaceuticals Production
RPP	Radiation Processing Plant
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RSPCB	Rajasthan State Pollution Control Board
RTC	Ready to Cook
RTD	Residence Time Distribution
RTE	Ready-to-Eat
RTLS	Reactor Trip Logic System
RUP	Reprocessed Uranium Oxide Plant
SAC	Space Application Centre
SANS	Small Angle Neutron Scattering
SBA	Strong Base Anion
SBF	Simulated Body Fluid
SBF	Stuffed Baked Food
SBN	Strontium Barium Niobate
SBO	Station Blackout
SCADE	Safety Critical Application Development Environment
SCC	Super Conducting Cyclotron
SCC	Stress Corrosion Cracking
SCMM	Surgical Coordinate Measuring Mechanism
SCRF	Super Conducting Radio Frequency
SDE	Simultaneous Distillation Extraction
SDU	Sodium Di Uranate
SEM	Scanning Electron Microscopy
SEM-EBSD	Scanning Electron Microscope-Electron Backscatter Diffraction
SER	Site Evaluation Report
SGDHR	Safety Grade Decay Heat Removal
SHE	Super Heavy Elements
SIMS	Simulation Information Management System
SINP	Saha Institute of Nuclear Physics
SLD	Stroke Limiting Device
SMD	Standard Magnet Dewar
SMES	Superconducting Magnetic Energy Storage
SMVC	System for Management of Vigilance Complaints
SNAS	Secure Network Access System
SNP	Silver Nanoparticles
SOD	Superoxide Dimutases
SOEC	Second Order Elastic Constants
SOFC	Solid Oxide Fuel Cell
SPE	Solid Phase Extraction
SPF	Specific Pathogen Free
SPME	Solid Phase Micro Extraction
SPND	Self Powered Neutron Detector

ABBREVIATIONS

SPP	Solvent Production Plant
SPT	Shielded Pin Tray
SQUID	Super Conducting Quantum Interference Device
SRC	Safety Review Committee
SRGT	Shut off Rod Guide Tube
SSC	Systems, Structures & Components
SSO	Single Sign On
SSR	Single Spoke Resonator
SSR	Simple Sequence Repeat
SSR	Self Study Report
SST	Steady-state Superconducting Tokamak
SSTP	Stainless Steel Tube Plant
SSWBC	Shadow Shield Bed Whole Body Counter
STP	Special Tube Plant
SULS	Start-Up Logic System
SUT	Startup Transformers
SVD	Silicon Vertex Detector
SWRO	Sea Water Reverse Osmosis
SXT	Soft X-ray imaging Telescope
SYMPLE	SYstem for Microwave PLasma Experiments
TACTIC	TeV Atmospheric Cerenkov Telescope with Imaging Camera
TANSPEC	TIFR-ARIES Near Infrared Spectrograph
TAPS	Tarapur Atomic Power Station
TBM	Test Blanket Module
TBP	Tributyl Phosphate
TCF	Technical Cooperation Fund
TCIS	TIFR Centre for Interdisciplinary Sciences
TDC	Technology Development Council
TD-OCT	Time Domain Optical Coherence Tomography
TDP	Technology Demonstration Plant
TEM	Transmission Electron Microscope
TFS	Tritium Filled Self-luminous
TGP	Turbine Generator Package
THM	Total Heavy Mineral
TIFR	Tata Institute of Fundamental Research
TIG	Tungsten Inert Gas
TIMS	Thermal Ionization Mass Spectrometer
TLD	Thermo Luminescence Dosimeters
TLD	Tuned Liquid Damper
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TMIS	Training Management Information System
TOEC	Third Order Elastic Constants
TOF	Time of Flight
TOLIC	Town Official Language Implementation Committee
TOPO	Tri-Octyl Phjosphine Oxide
TOR	Terms of Reference
TPLC	Trombay Programmable Logic Control
TRISO	TRIstructural ISOtropic
TRIUMF	TRI University Meson Factory
TRIX	Tank Remediation by Ion Exchange
TRLFS	Time Resolved Laser Induced Fluorescence Spectrometer
TSM	Technical Support Mission
TSO	Trainee Scientific Officers
TVC	Total Viable Count
UCIL	Uranium Corporation of India Limited
UMRT&EH	Upgradation of Metal Reduction Technology & Effluent Handling
UTS	Ultimate Tensile Strength
VECC	Variable Energy Cyclotron Centre
VFD	Variable Frequency Drive
VFU	Vertical Flux Unit
VHE	Very High Energy
VSSC	Vikram Sarabhai Space Centre
VSSP	Versatile Solvent Synthesis Pilot Plant
VVPAT	Voter Verifiable Paper Audit Trail Printers
VWSF	Vitrified Waste Storage Facility
WANO	World Association of Nuclear Operators
WFI	Water for Injection
WIP	Waste Immobilization Plant
WLCG	Worldwide LHC Computing Grid
WNA	World Nuclear Association
WRF	Weather Research and Forecasting
WTF	Waste Tank Farm
XPS	X-ray Photoemission Spectroscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
XMCD	X-ray Magnetic Circular Dichroism
YAS	Yttria Alumina Silica

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