

Government of India
Department of Atomic Energy

ANNUAL REPORT

2014-15

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Front cover: DAE Tableau in the 66th Republic Day Parade 2015 at Rajpath, New Delhi (Left)
Kudankulam Nuclear Power Projects Units 1 & 2 - Plant view (Right)

Back cover: A collage of pictures portraying DAE activities in the field of Nuclear Science & Technology

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EXECUTIVE SUMMARY

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

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

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

The DAE has technologies in place which are relevant to the 'Swachcha Bharat Abhiyan' and the 'Clean Ganga Project'. Their implementation can help achieve the objectives of these national mission.

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 2014-15, the programmes of the Department achieved impressive growth in all the segments and domains. These are described below.

NUCLEAR POWER PROGRAMME: STAGE 1

PRESSURISED HEAVY WATER REACTORS

Nuclear Power Corporation of India Ltd. (NPCIL), a public sector undertaking of DAE and dividend paying company with AAA credit rating by CRISIL and CARE is responsible for 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. Of these reactors, the Kudankulam Nuclear Power Project-1 (KKNPP-1) of 1000 MWe commenced commercial operation from December 31, 2014. The second unit KKNPP-2 is also in advanced stage of commissioning. First pair of indigenously designed 700 MWe Pressurised Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat followed by second pair at Rawatbhata in Rajasthan are under construction.

Power Generation

During the calendar year 2014 NPCIL recorded highest ever generation of 37146 MUs (including 2984 MUs infirm power from KKNPP-1) which was 10% higher than the last year's generation.

During the financial year 2014-15, the overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 81% and 89% respectively till December 31st, 2014.

During the year, the Rajasthan Atomic Power Station (RAPS)-5 recorded continuous run of 765 days which is best in Asia and second best in the world. In addition, KGS-1, KGS-2, KAPS-2 & MAPS-2 also achieved continuous run of more than a year. So far, this feat has been achieved seventeen times by various reactors operated by NPCIL.

Projects under Commissioning

Kudankulam Nuclear Power Project (KKNPP) Unit-1&2 (2x1000 Mwe)

The Unit-1 of the Kudankulam Nuclear Power Project has been declared in commercial operation from 00:00 hrs of December 31, 2014. It has generated 3.348 MUs infirm power and 24 MUs commercial power up to December 31, 2014 since its first synchronization to the grid in October 2013. In Unit-2, all the construction and equipment erection are almost completed and commissioning of the systems was in advanced stage. Important commissioning milestone "Hydro test and Circular Flushing of Primary Circuit" was achieved in July 2014. The application for clearance of Hot Run is currently under review by Atomic Energy Regulatory Board (AERB).



KKNPP-1&2: Plant view

Projects under construction

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

Civil work for the nuclear building, control building, other auxiliary and common buildings are almost completed. The finishing activities were in different stages of completion for Unit-3 and common buildings and work fronts were released progressively. The works related to inner containment wall of reactor building-3 are completed and work related to IC dome has been started. Piping, mechanical, electrical, ventilation and instrumentation works progressed in full swing in Unit-3 & common buildings. End shields and Calandria erection and welding were completed and preparation for Calandria tube installation for Unit-3 was in progress. Both main buses in 220 KV switchyard have been successfully charged. In Unit-4, concreting of inner containment wall lift-8B (EL 129-131.5 M) was completed in record time of 8 days. Control building slab at EL 106 M was completed. Manufacturing and progressive delivery of equipments/components were in progress.

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

Civil works on many fronts were in progress. In Reactor Building-7, Inner Containment (IC) wall has been constructed up to 126.7 M elevation and 109M elevation floor slab has been constructed. Ball filling has been completed in both End Shields of Unit-7 and are ready for erection. Major equipment erection clearance was under review by AERB. In Unit-8, concreting of Calandria Vault up to 5th lift (out of 6) and IC Wall up to 101.7M Elevation has been completed. Erection of Fuelling Machine Bridge & Column in Unit-7 was completed in November 2014. 220KV switchyard has been energized successfully. Manufacturing and progressive delivery of equipment/components were in progress.



RAPP-7&8: Main plant view

New Projects

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

Government administrative approval and financial sanction of the project exists. General Framework Agreement (GFA) for setting up of KKNPP Units-3&4 was signed with M/s. Atomstroyexport and made effective. First supply contract for implementation of the project "Supply of Long Manufacturing Cycle Equipment & First Priority

Equipment" has been signed. First priority design activities for which a contract already signed with M/s. Atomstroyexport, are in advanced stage. Clearance for consent to establish KKNPP has been obtained from Tamilnadu Pollution Control Board (TNPCB).

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

Government Administrative approval and financial sanction exist for the project. Environmental clearance from Ministry of Environment and Forest (MoEF) has been obtained for the plant site and clearance for the township is awaited. Haryana State Pollution Control Board (HSPCB) has granted Consent in October 2014 to establish GHAVP. Report for siting clearance was prepared and submitted to AERB and it was under review. Issue of movement of 11 families (landowners of 28.5 acres of land), who did not accept the compensation and moved to court against the land acquisition is on hold for siting consent for the project from AERB. Application for excavation consent has been submitted to AERB. Technical evaluation is in progress for End Shields, Calandria, Steam Generators and Reactor Headers. Issues raised by vendors related to Civil Liability for Nuclear Damage (CLND) Act clauses are awaiting to be resolved.

Jaitapur Nuclear Power Project (JNPP) Units-1&2 (2x1650 MWe LWRs)

Review of technical assignment Part-I by working group was completed and the observations were forwarded to M/s AREVA. Review of technical assignment Part-II was in progress. An application for siting consent was submitted to AERB and it was under review. Construction of site office-cum-core storage, concrete testing laboratory at JNPP plant site was completed. The techno-commercial discussion with AREVA/ALSTOM was in progress.

New Sites

Land acquisition, environmental studies, public outreach activities, various site studies etc. were continued at new sites namely Chutka and Bhimpur in Madhya Pradesh, Mahi Banswara in Rajasthan, Mithi Virdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga 5&6 in Karnatka and Haripur in West Bengal. Sections-9 notification was issued by State Govt. authorities for Chutka site in Madhya Pradesh and Mahi Banswara site in Rajasthan. Public hearing was organised at Chutka on February 17, 2014. Section-11 award was in advanced stage of issuing for Chutka. NPCIL made a fresh application for acquisition of project land Kovvada in Andhra Pradesh as per the new RFCTLARR Act, 2013 as the period of Section-4 notification issued got lapsed. The Gujarat Government acquired land as per the new RFCTLARR Act, 2013 for the project.

Quality Assurance

Quality Assurance / Surveillance activities were carried out expeditiously for projects and stations by NPCIL. Pre-service inspection of KKNPP Unit-2 has been taken up. Corporate QA audits of KAPP-3&4 and RAPP-7&8 projects were completed in a planned way. Corporate reviews of operating stations were conducted based on WANO guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO. Directorate of Engineering, Quality Assurance, Procurement, Reactor Safety & Analysis, Health, Safety & Environment and Directorate of HR (Knowledge Management functions) are ISO: 9001 certified. Surveillance audits of these directorates by the certifying body were successfully completed.

FRONT END FUEL CYCLE

Front-End Fuel Cycle comprises operations such as mining, milling and processing of ore, and fabrication of fuel. In addition, production of heavy water, used as moderator and coolant in pressurized heavy water reactors, also 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 reactors. 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 (HWB), a constituent unit of DAE in its Industries Sector continued its contributions 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.

HWB, emerged as the largest global producer and a trusted supplier of Heavy Water. Realizing the large potential for non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology areas, HWB also nurturred R&D activities in this area.

Performance of the Board during the year was very good with respect to heavy water production, specific energy consumption and safety & environment performance. HWB surpassed the targeted production during the period.

The Heavy Water Board achieved more than 104% of targeted production for the financial year 2014-15 and the specific energy consumption was more than 28 GJ/Kg.

Diversification Activities

HWB continued to make major progress on its extended mandate in the field of development, demonstration and deployment of technologies for various in-core and out of core material for the nuclear fuel cycle, mainly centering around three broad areas, i.e. (i) Solvents for front and back end hydrometallurgical operations of nuclear fuel cycle application, (ii) demonstrating Solvent Extraction (SX) technology for extraction of various rare materials, (iii) producing stable isotope like ^{11}B for Fast Breeder Reactors (FBR) and ^{18}O for societal applications.

Solvent Technology

In the area of Solvents, both the newly installed industrial facilities at HWP, Baroda and Talcher for production of TBP and D2EHPA performed very well enabling HWB to meet the requirements of NFC, NRB and all other units. Developmental efforts were in place at HWP, Tuticorin in the Versatile Solvent Synthesis Pilot Plant (VSSP) in campaign mode for special and futuristic Solvents like D2EHPA-II and TiAP and DHOA for collection of data for industrial level production of these solvents. HWB has initiated setting up of Solvent Production Plant (SPP) at HWP, Tuticorin for production of these solvents with an objective to achieve self-reliance in special solvents.

HWB demonstrated the solvent extraction technology in industrial proto-type scale at its Technology Demonstration Plant for various nuclear hydrometallurgical operations. Process and equipment developments are the current thrust areas.

Boron Enrichment

In consonance with the material input for second stage of NPP based on FBRs, HWB, with its decades of experience of Heavy Water production 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 operated very well. HWB has acquired comprehensive capability in this area achieving enrichment levels beyond 95% in multiple chemical forms. To support the second stage of NPP, HWB successfully delivered the entire quantity of enriched Boron for the 1st core of PFBR. India has thus found a place in the few handful countries possessing such capability.

Sodium Metal

Sodium is another important input for FBRs, used as coolant in the reactor. HWB has undertaken development of indigenous technology for production of nuclear grade Sodium. Networking with the Indian R&D organizations, it has developed closed electrolytic cells of successively larger size with the ultimate intent of an industrial scale set up. A 2000 Amp closed cell for production of nuclear grade sodium has been developed and it was successfully operated for extended period. Based on these inputs, a 600 MT per annum plant is proposed to be set up at HWP, Baroda.

Mineral Exploration and Mining

The Atomic Minerals Directorate for Exploration and Research (AMD) continued the accelerated pace of exploration activities during the year. This resulted in the establishment of over 16,535 tonnes of additional Uranium Oxide (U_3O_8) reserves in the areas of Andhra Pradesh, Meghalaya and Jharkhand. The country's uranium resources were updated to over 2, 14,158 tonnes of Uranium Oxide.

Significant uranium anomalies were located in the parts of Andhra Pradesh, Uttarakhand, Rajasthan, Chhattisgarh and Odisha. About 1,76,660 m of drilling was carried out to establish additional uranium reserves in the known occurrences and subsurface continuity of mineralisation in the new promising areas. Significant mineralised intercepts/bands were identified in boreholes drilled at Andhra Pradesh, Karnataka, Rajasthan, Jharkhand and Meghalaya. Potential blocks were also identified at Rajasthan, Chhattisgarh, Haryana, Uttarakhand, Tamil Nadu, Andhra Pradesh and Arunanchal Pradesh.

AMD carried out Geochemical surveys (2,720 sq km), Ground Geophysical investigations (288 sq km), Airborne survey and Remote Sensing survey anomalies was carried out over 11,355 line km.

Rare Metal and Rare Earth investigations resulted in location of significant concentrations along the Pikkli hills-Hogenkal tract, Dharmapuri district, Tamil Nadu; riverine placers of Chorwana-Tejagarh, Panchmahal and Baroda districts, Gujarat; Siwana-Ramaniya-Mawdi, Barmer and Jalore districts, Rajasthan.

Beach Sand and Offshore Investigations surveys resulted in establishing potential heavy mineral zones mainly along the east coast. Significant zones of Total Heavy Mineral (THM) concentration were located at Odisha, Andhra Pradesh and Tamil Nadu.

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 Earth Limited (IREL) is a Mini Ratna (Category-I) Company and it is engaged in mining and production of beach sand minerals and rare earth compounds.

The overall performance of UCIL during the year was satisfying. First phase of surface exploration for extension of ore lenses in deeper levels of Jaduguda Mine beyond Tirukocha fault was completed by AMD. Twelve boreholes were drilled and assay results of eight boreholes gave positive indication of additional low grade lenses. Second phase of exploratory drilling will start soon.

A project for modernization of Bhatin Mine has been taken up for capacity augmentation. Work on seven new projects were initiated towards strengthening the existing operations in Jharkhand and ongoing project at Tummalapalle.

Tummalapalle uranium project is readying for commissioning in 2015-16. The mine has achieved the desired ore production capacity and adequate ore has been stockpiled. Efforts at finding safe procedure for mining of Hang-Wall (HW) lode are in progress.

UCIL continued its spirited neighborhood development programme around its operating units in Singhbhum and Tummalapalle. In addition, drinking water supply and mobile medical camp around Gogi uranium project, infrastructure development around KP M project in Meghalaya etc. continued to generate goodwill towards uranium mining.

UCIL has proposed for restarting of exploratory mining at Gogi uranium Project. The same is under consideration of AMD. Proposal to start exploratory mining at Rohil in Rajasthan is also under consideration of AMD.

The major achievement of the mineral processing plant at Indian Rare Earths Limited (IREL) included the filing of three international patents which were development of a modified High Tension Roll Separator (HTRS) for electrostatic

separation of minerals based on their electrical resistivity, development of an improved Electrostatic Plate Separators (ESPS) for mineral separation based on difference in electrical resistivity & size of minerals and development of a method & equipment for separating non-conducting non-magnetic minerals.

The above works have resulted in various benefits such as premium grade Garnet production at OSCOM, process optimisation in mineral separation plant in OSCOM, 25% reduction in specific consumption of power & furnace oil, up-gradation of Monazite plant at Manavalakurichi and Chavara, online production of Leucoxene at IREL, Chavara and Xenotime production flowsheet.

The major achievement of the chemical plant at IREL included the production of nuclear grade uranium at RED, Alwaye from uranium bearing metallic radioactive waste from BARC; Design, erection and commissioning of HPRE plant at RED, Alwaye to produce high purity separated rare earths; process for Neodymium (Nd) metal production using induction furnace and Samarium (Sm) metal production with high purity Nd fluoride and Sm oxide powders produced at RED; Value addition of Monazite-MoPP at OSCOM and value addition of ilmenite & zircon-high purity TiO_2, ZrO_2 and HfO_2.

At BARC a phosphate precipitation based method to recover uranium from Tumalapalle ore carbonate leach liquor was developed and tested with more than 99.95% recovery of uranium. Production of Uranium metal ingot was continued to meet the requirement of research reactors. A process was developed for recovery of uranium values from legacy wastes and the recovered uranium was utilized for metal ingot production.

Upgradation of Metal Reduction Technology & Effluent Handling (UMRT&EH) facility was commissioned for production of nuclear grade Aammonium Diuranate (ADU) from scrap generated during fuel fabrication for research reactors.

Fuel Fabrication

Nuclear Fuel Complex (NFC) manufactures and supplies fuel bundles for Pressurised Heavy Water Reactors (PHWRs) and Boiling Water Reactors (BWRs) of NPCIL. During the report period, a record production of PHWR fuel bundles, PHWR fuel tubes, Zirconium Sponge, Niobium metal and SS tubes & job orders was achieved and the name plate capacity surpassed to 140%.

All critical components and various sub-assemblies to meet the commissioning schedule of 500 MWe PFBR were manufactured and supplied. Balance quantity (11 nos.) of fuel sub-assemblies were under various stages of completion.

Production of pressure tubes of 700 MWe PHWRs through new route of two stage radial forging of billets was undertaken on mass scale for meeting commissioning schedule of forth coming KAPP-3 & 4 and RAPP 7 & 8 reactor. Till the report period, production of about 1300 nos. of pressure tubes were completed and first consignment of pressure tubes were supplied to RAPP-7.



Flagging off of first consignment of pressure tubes to RAPP-7

NFC launched 19 new projects during the XII plan and 3 new projects during MTA. These projects are 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 to 900 tpy, in line with the demand from M/s NPCIL.

New Zirconium Oxide & Sponge Project at Zirconium Complex was successfully completed. The project "DWPFC-LWR" was also completed. Financial sanction was obtained for setting up of NFC-Kota a green field project of NFC.

Activities were in progress for establishing Niobium Thermit Production Facility (NTPF) to meet the Niobium requirement of VSSC (Dept. of Space) indigenously.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

PREFRE-2 at Tarapur has set a new performance record in the back-end fuel cycle program by achieving 122% of its rated capacity. Post refurbishment, Kalpakkam Reprocessing Plant (KARP) achieved close to 100% capacity fuel for the first loading of Prototype Fast Breeder Reactor (PFBR) and was supplied to Fuel Fabrication Facility.

Design of various systems for Integrated Nuclear Recycle Plant (Tarapur), Additional Spent Fuel Storage Facility, Uranium Oxide Facility (Kalpakkam) and Power Reactor Fuel Reprocessing - 3A (Kalpakkam) was underway.



Laser Assisted Single Pin Chopper for PRTRF

The first of its kind industrial-scale facility in the world PRTRF crucial for the 3rd stage Indian Nuclear Program for reprocessing power reactor irradiated thoria was built in Trombay. A heterogeneous catalysis route using hydrogen as reducing agent was developed for near total conversion of uranyl nitrate into uranous nitrate with fast kinetics.

Using Calyx Crown-6 solvent, ^{137}Cs was selectively recovered from HLLW and immobilized in borosilicate glass as radiation pencils which are viable alternatives to ^{60}Co for γ - irradiation. This technology developed by BARC was awarded US patent (Patent No.: US 8,828,532 B2, Sep.9, 2014).

Advanced Vitrification System, Tarapur (Joule Melter) completed vitrification of 72 m^3 of High Level Waste. Other back-end fuel cycle facilities such as Tank Remediation by Ion Exchange, Liquid Waste Treatment Plant, Tarapur Rad-Waste Augmentation Plant and Solid Waste Management Facility operated satisfactorily to meet the waste management requirements at Tarapur. Waste Immobilization Plant, Kalpakkam processed more than 500 m^3 of Intermediate Level Waste. The hot commissioning of Uranium Separation Process using depleted Uranium is completed and processed High Level Waste from KARP - Waste Tank Farm. In recognition of its contribution, Centralised Waste Management Facility (CWMF) received an Award for Volume Reduction and Safe Disposal of Pressure Tubes from Enmasse Coolant Channel Removal Campaign in MAPS-I.

R&D SUPPORT TO POWER SECTOR

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

An upgraded fuelling machine operated tool developed by BARC to measure inside diameter of a coolant channel pressure tube was deployed in KAPS-2. A similar tool developed for remote repair of end fitting E face of 220 MWe PHWR's resulted in a significant saving of reactor shut down time and man-rem. A customised tool was developed to retrieve self powered neutron detectors from the carrier tube in TAPS-4.

A new hot cell facility to evaluate the performance of irradiated LWR fuel bundles, PHWR pressure tubes and structural components was commissioned in BARC. The Q-10 pressure tube made of imported material was removed after 14 Effective Full Power Years of reactor operation to study the effect of irradiation on zirconium alloys and understand deformation mechanisms. Fractographic examination of Zr-2.5Nb alloy pressure tubes of IPHWR revealed that the alloy is less susceptible to hydride embrittlement. Further, fracture toughness is much higher while cooling (during reactor shutdown) from peak temperature of 400°C compared to that during heating from ambient temperature.



The new hot cell facility at BARC

Design of the 900 MWe Indian Pressurised Water Reactor was optimised by incorporating differentially enriched fuel assembly for enhanced fuel utilization. An Integrated Test Facility to validate the Control & Instrumentation systems of Compact LWR was setup. Two independent systems, an underwater manipulator BARC Vessel Inspection System BARVIS and Multi Ultrasonic Sensor InspeCtion (MUSIC) system were developed for ultrasonic testing of welds of TAPS-1 & 2 pressure vessel (PV). A digital reactivity meter using neutronic signals developed for online measurement of core reactivity of nuclear reactor was deployed in Experimental Reactor Critical Facility for physics experiments.

HEALTH SAFETY & ENVIRONMENT

NPCIL recorded about 400 reactor years of safe operation of reactors by the end of November 2014. The review of safety of operating stations was carried out on a regular basis. The individual and collective occupational exposures of radiation workers at various Nuclear Power Plants (NPPs) were maintained within the budget approved by AERB by following the principle of ALARA (As Low as Reasonably Achievable) and maintaining the highest standards of safety within the NPPs. The radioactive effluents from NPPs to the environment were maintained very low in comparison to the 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



Automated system for biological sample analysis

and Occupational Health and Safety Management System (OHSMS) as per IS-18001: 2007 were maintained and regular audits (internal & external) & management were carried out for continual improvement.

Assessment of internal exposure of occupational workers from various BARC facilities in Mumbai and Tarapur was carried out by whole body/lung counting and bio-assay analysis. An automated system to estimate radionuclides like Thorium, Uranium, Plutonium, Americium and Strontium in Urine/Fecal samples of radiation workers was developed. An online spot air sampler is developed for in-situ measurement of long lived alpha air activity. An indigenous radiation monitoring system was developed for long term environmental surveillance. Geochemical analysis using radiotracer technique was developed to establish substance specific concentration pattern and history of environmental pollutants.

Online Radon Monitoring Network (ORMoN) coupled with noxious gas sensors was developed and installed at Turamdih mines.

All plants of Heavy Water Board were 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, and other The Fast Breeder Test Reactor (FBTR), operating at Kalpakkam for over 25 years, also caters to technology development related to fast reactor

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

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

Prototype Fast Breeder Reactor

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.

The entire civil structural work for nuclear island buildings has been completed. The horizontal tunnel and vertical shaft of the sea water intake structure has been connected.

Supply and erection of all major critical



Erection of Inclined Fuel transfer Machine

reactor components and Nuclear Steam Supply System (NSSS) were completed. Core sub-assembly handling machine such as Transfer Arm and Inclined Fuel Transfer Machine were erected and tested successfully in reactor.

The project has achieved an overall physical progress of 97.635% at the end of November-2014.

Site selection committee constituted by DAE has approved Kalpakkam site for FBR 1&2. The pre-project activities for FBR 1&2 are under progress. Geotechnical investigation, site evaluation reports were completed. Environmental impact assessment report was finalized and submitted to Tamil Nadu Pollution Control Board (TNPCB) for approval.

Fast Breeder Test Reactor

During 2014-15, Fast Breeder Test Reactor (FBTR), the flagship of IGCAR continued to play a significant and critical role as a test bed for various materials including fuels. The twenty third irradiation campaign was successfully completed during November 2014 and for the first time the reactor power was raised to the highest ever level of 24.5 MWt, generating an electrical power of 5 MWe. The total operating time of the reactor and turbo generator was 669 hours and 481 hours respectively and the total thermal energy and electrical energy generated was 12937 MWt and 1.973 MU respectively. During this period, as a part of post-Fukushima retro-fits, entry points to the building were elevated to take care of the revised design basis flood level of 1000 years return period as per current safety norms.

FBR Fuels

The reactor core has three different types of fuels - U,Pu mixed carbide, U,Pu mixed oxide and sodium bonded U-Pu-Zr metal alloy. A capsule containing two sphere-pac Mixed Oxide (MOX) fuel pins and a reference pellet fuel pin was test irradiated for 300 hours and the post-irradiation examination of these pins were commenced at IGCAR.

As per requirement, the uranium-plutonium mixed carbide fuel pins for FBTR at Kalpakkam were supplied by BARC. Fabrication of (U-Pu)O2 mixed oxide (MOX) fuel pins for 500 MWe Prototype Fast Breeder Reactor (PFBR) of BHAVINI continued and target of fabrication and supply of fuel pins for zero power criticality is completed. Setting up of fourth fabrication line under XII plan is in progress. Nearly one ton MOX was recycled using wet and dry recycling techniques. One more microwave system is commissioned at AFFF, BARC, Tarapur to enhance the recycling of the Clean Reject Oxide (CRO).

As a part of quality assurance of FBTR fuel, fifty nine (U,Pu)C samples were analysed for Pu, U contents and isotopic compositions of Pu and Am by using biamperometry, thermal ionisation mass spectrometry and alpha spectrometry.

Fast Reactor Fuel Reprocessing

Compact Reprocessing facility for Advanced fuels of Lead Cells (CORAL), the pilot plant facility for reprocessing the FBTR fuel continued to perform satisfactorily. The rich experience of reprocessing of short cooled carbide fuel has enhanced the confidence in the flow sheet and equipments. Demonstration Fast Reactor Fuel Reprocessing Plant is in an advanced stage of construction.

FBR Related Technologies

Towards research and development on Fast Breeder Reactors, a first of its kind, sodium submersible annular linear induction pump with a capacity of 2 m3/h flow rate at 4 kg/cm2 pressure was indigenously designed, manufactured and successfully tested in the sodium facility.

Towards the development of pyroprocessing technology, studies were continued on U-Gd-Zr and U-Pu-Zr alloys. A new facility comprising of a High Temperature Electro Refiner, a Vacuum Distillation and Melting system with requisite in-cell crane and remote handling equipments is being established to demonstrate the molten salt electrorefining process.

A 100 tonne shake table was commissioned which is a unique national facility that would contribute to seismic evaluation of components and systems for various programmes. VME64x based CPU and I/O cards, Compact PCI bus based diversified Real Time Computer have been developed for the use in safety systems of FBRs. Wireless sensor networks for nuclear reactor applications were also developed. For detection of ultra-trace of explosives, an ion mobility spectrometer was developed.

Future FBRs

Significant contributions were made in the conceptual design of FBR 1&2 along with the detailed design of the reactor assembly. Several optimizations studies were carried out towards safety features, improvement in the breeding ratio, reduced material consumption cost and time of construction. Based on these elaborate optimization studies and plant dynamics studies, the capacity of FBR 1&2 was increased from 500 to 600 MWe.

The Integrated Cold Trap (ICT) consisting of an economiser, cold trap, sodium pump, sodium flow meter and associated systems was conceptualized as an in-vessel purification system for future FBRs. In order to demonstrate the functioning of the ICT, a full scale model was fabricated.

Health, Safety & Environment

During the year, effective and efficient radiological surveillance and health physics services were provided for the radioactive facilities of IGCAR. TLD personnel monitoring services, covering about 2300 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 and contract workers engaged by active facilities and bioassay services for over 200 occupational workers were also provided.

IGCAR participated in the international intercomparison exercise organized by EURADOS for the evaluation of the TLDs used for personnel dose monitoring and also in a national intercomparison exercise for the plutonium estimation in body through urine matrix.

NUCLEAR POWER PROGRAMME: STAGE 3

THORIUM BASED REACTORS

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.



Radial Sealing Plug



Seal Element

Advanced Heavy Water Reactor

The physics and thermal-hydraulic coupled iterations were carried out from the onset of refuelling to the attainment of equilibrium state of the AHWR-LEU core. Possibility of off power refuelling of the equilibrium core of AHWR-LEU was studied for cycle lengths of 3, 6, 9, 12 and 18 months. A scheme was worked out to irradiate (Th- LEU) MOX fuel in the 19 element PHWR fuel cluster. An innovative seal plug for AHWR was designed. Prototype shut-off rod drive mechanism designed for AHWR was fabricated and function tested on full-scale test facility in BARC.

Other Thorium Reactor Systems

Integral and differential reactivity worth of control rods; Primary Shutoff Rods (PSR), Secondary shutdown System (SDS-2) and individual rods were computed in hot operating condition of 55% HEU fuelled CHTR with thicker PSRs and B4C particle based SDS-2. The Kilo Temperature Loop was commissioned to study the thermal hydraulic and material compatibility of Nb-1%Zr-0.1%C alloy at operating temperature CHTR.

The Innovative High Temperature Reactor (IHTR) 10 MWth reactor is designed as a technology demonstrator of IHTR-600MWth pebble bed reactor for the commercial hydrogen production. To estimate the self-shielding effect in TRISO particles in Pebble Bed HTR, a fast Monte Carlo algorithm called Randomisation of Face Centred Cubic Lattice (RFCCL) has been developed. A facility was built to test thermoelectric devices between 40°C water cooled junction and electrically heated molten salt junction upto 500 °C. Physics simulation of the Pool-type design with natural circulation in the proposed Indian Molten Salt Breeder Reactor was completed.

A new analytical method has been adopted to calculate effective delayed neutron fraction correction factor for circulating to static fuel conditions. The Monte Carlo code M3C developed for criticality calculations using continuous energy cross section data is ready for release. The code has been benchmarked with several published results and used for simulation of PHWR, AHWR and CHTR infinite lattices.

KAlpakkam MINI (KAMINI) Reactor

The KAMINI reactor was in regular operation up to a maximum power of 30 kW for neutron radiography of pyro-devices for Vikram Sarabhai Space Centre (VSSC), ISRO for calibration of neutron detectors from ECIL and activation analysis of samples from users and for neutron radiography of fuel elements.

Research Reactors

APSARA reactor is in partially decommissioned state with pool structure under protective cover. Remaining building space is utilized for experiments on modified APSARA & High Flux Research Reactor (HFRR). Up-gradation of APSARA reactor to 2 MW is underway. The fabrication of fuel plates for modified core of APSARA with U3Si2 (LEU-Low Enriched Uranium based) fuel dispersed in Al matrix and clad in Al-alloy was completed.

AHWR Critical Facility was operated on 63 occasions. It was used to test 23 nuclear detectors and irradiation of 8 large volume samples for Neutron Activation Analysis. Renewal of authorization to operate the facility for another ten years was obtained from regulatory authorities after Periodic Safety Review.

CIRUS reactor has been permanently shut down since 31st December 2010 with de-fuelled core. 2.6 Tons of chloride laden degraded heavy water was purified using a mixed bed ion-exchanger. Reactor systems were maintained in preservation mode and services including ventilation were kept in operation in truncated mode. Recovery trials of useful material settled on floor of spent fuel storage bays for reprocessing and safe disposal were underway.

DHRUVA is the only facility for radioisotope production and it is the national facility for neutron beam research. DHRUVA operated with a high level of safety at 80 MW power till October 2014 and at the rated capacity of 100 MW since November end, resulting in enhanced utilization and radio-isotope production. Researchers from institutions across the country through UGC-DAE Consortium for Scientific Research utilized the reactor and performed experiments with neutron beams.

Preliminary Design Basis Reports (DBRs) on major systems of High Flux Research Reactor (HFRR) was completed. Construction of research reactors, nuclear fuel cycle facilities and allied facilities in the Vizag campus was in progress. Engineering details for all the facilities were worked out. Physics design of 125 MW Thermal Research Reactor (ThRR) using natural uranium fuel cluster with & without flow tube was completed. Consolidated report is being prepared for site clearance from MoEF.

ADVANCEDTECHNOLOGIES

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

At RRCAT, a pulsed 476 MHz, 10 kW RF power amplifier with digital low level RF system for the sub-harmonic pre-buncher cavity of free electron infra-red laser was developed. A 16 kW 32-Way RF Power Combiner and 1 kW RF Power Divider at 650 MHz has also been developed. Five-cell, 1.3 GHz Superconducting Radio Frequency (SCRF) niobium cavity was fabricated, characterized and pre-qualified at 77 K at RRCAT. A semiautomatic cavity tuning machine has been developed to correct the frequency and field flatness of 1.3 GHz, nine-cell superconducting radio-frequency cavity. A tuning methodology for multi-cell superconducting radio-frequency cavity has also been developed. A new X-link tuning mechanism has been designed and developed for SCRF cavities. A horizontal electro polishing setup has been developed for polishing of five-cell 650 MHz SCRF cavities. An innovative process based on laser welding technique of niobium based superconducting radio-frequency cavity has been conceptualized and developed at RRCAT for the first time in the world.

This year saw several significant developments in the RIB project at VECC. Radioactive ion beam (RIB) of ^{111}In (Indium-111) was accelerated with factor of ten enhanced intensity and utilized for first user experiment that was aimed at studying variation of nuclear beta-decay rates in various matrixes such as gold and silicon. Also, using ion-beams from the RIB facility, a new technique was demonstrated for broad ion beam based, mask less, low cost and fast nano-patterning with potential



The world's first laser-welded 1.3 GHz niobium SCRF cavity developed at RRCAT



VECC engineer participating in assembly of injector Cryo Module at TRIUMF

applications in electronic, magnetic, optical and mechanical nano-devices. In a separate experiment, role of electron momentum re-distribution in Fe-based superconductors was studied for the first time using positron annihilation spectroscopy. In another interesting study, p-type conductivity in arsenic doped dilute magnetic semiconductor zinc oxide (ZnO) was examined. On the technology front, the main emphasis was on indigenous technology development related to superconducting electron linear accelerator and heavy-ion linear accelerator components.

At BARC, first segment of Radio frequency quadrupole (RFQ) accelerator was fabricated for the 20 MeV, 30 mA Low Energy High Intensity Proton Accelerator (LEHIPA). Vacuum Control Interlock and Information system for LEHIPA was developed. A high power coaxial coupler for 50 kW continuous wave, 350 MHz operation was developed in collaboration with CEERI-Pilani and a 325 MHz RF amplifier developed indigenously was tested at 7.5 kW. 1 GeV, 30 mA LINAC with superconducting cavities with 16 MV/m accelerating gradient was designed. Several users performed experiments on 6 MV Folded Tandem Ion Accelerator for a variety of Basic Science, Biological, Material, Environmental and Archaeological studies.

Laser Technology Development and Applications

At RRCAT, different types of fiber lasers were developed for material processing applications. Different types of Nd: YAG, intra-cavity frequency



Fiber Bragg grating inscription set up

doubled, diode-pumped green lasers were also developed. Semiconductor laser diodes array structures were grown using Metal-Organic Vapour Phase Epitaxy (MOVPE) technique and their operation has been demonstrated in the pulsed mode with a total integrated output power of 11W. Fiber Bragg Grating (FBG) temperature sensor was developed for use in high temperature measurement upto 800° C. An Nd: phosphate glass based rep-rate regenerative was developed using diode pumping instead of flash lamp pumping. Acceleration of negative hydrogen ions was observed for the first time in the interaction of ultrahigh laser intensity (10^{19} W-cm^{-2}) laser with transparent solid matter.

The Technology developed at RRCAT for various applications included in-situ cutting of triangular blocks of shock absorber assembly in RAPS-3 reactor; Gas assisted underwater laser cutting of coolant channel pressure tube stubs in high radiation field; Laser shock peening for reducing the stress corrosion cracking in stainless steel; Growth of CdS nanowires using template assisted electro-chemical deposition method; Microvasculature Imaging using Optical Coherence Tomography (OCT); Polarized Raman spectroscopic studies on ordering of hemoglobin molecules inside red blood cells; Design and development of OCT probe for in-vivo imaging of oral cavity; Micro-turning lathe for micro-fluidic stamp fabrication; Development of



Laser cutting of triangular fixing block of shock absorber assembly and the triangular cut piece

Cobalt-free hard surfaces for tribological applications and Laser additive manufacturing of Ti-SS transition joints.

For the studies relating to the shock velocity & particle velocity and for the spectroscopic method study a time resolved Raman spectroscopy of the shocked material using pump-probe technique was set up employing a 2J/8ns Nd:YAG laser system at BARC.

Electronics & Instrumentation

For providing a solution for dependable, secure video surveillance network, ECR series switch routers was developed and integrated jointly by IIT-B, ECIL and BARC. BARC has developed the stabilization system of the Active Radar Seeker which is being integrated by ECIL for DRDO. Development and integration of Servo controllers with the 2-axis gimbal mechanisms for the 0.73 M SATCOM terminal was completed. Stereoscopic Visualization System of microscopy for Neurosurgery training and education was designed, developed and deployed at AIIMS, New Delhi. Solenoid focusing lens for J-band klystron has been developed for use in RF Seekers. Walkthrough software useful for training security and response forces has been developed which provides a virtual 3D tour of the premise including external façade and internal details.

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



Airborne SATCOM Terminals for UAVs and AEWCS

Technology and e-Governance sector, ECIL has emerged as a major player in providing integrated security solutions to the vital installations in the country. New products introduced by ECIL during the year included Weather Radar System, Smart Energy Meters, Secure mobile communication systems, Ultra stable Power Converters, Long stroke length LVDTs and Actuators for missile programs.

Robotics

A compact four wheeled robotic vehicle along with a remote controlled telescopic assembly carrying a sensor capable of measuring 1000mR/hr at a max. height of 5.0m has been specifically developed by BARC for remotely mapping the radiation levels of HEPA (High Efficiency Particulate Attenuator) filter banks at radiological labs. A customized suspendable servo manipulator has been developed for remotely picking active small size glass pieces from the floors of the waste management process cell.



Robot with Teletector carrying Radiation Sensor

Cryogenics

An integrated closed loop testing facility for cryogenic turboexpanders of sizes ranging from 6.5mm to 45mm has been developed by BARC for studying detailed thermal and rotor dynamic behaviour of new turboexpanders before final assembly in actual cryogenic plant. A full-fledged closed loop cryogenic heat exchanger test facility has been developed to characterize the performance of high effectiveness cryogenic heat exchangers of various types (up to 4 streams) and a range of sizes (height up to 1.5m) at different pressure, temperature and flow conditions. An experimental He refrigerator/liquefier was fabricated. After steady state cycle simulations, some modifications were incorporated to achieve 200 W refrigeration capacities.



Closed loop heat exchanger test facility

A new buffer tank (BT-4) of 60 m3 W.C. at 25 bar(g) maximum operating pressure was installed and commissioned to maintain sufficient inventory of helium gas for continuous operation of the cryogenic system of Superconducting Cyclotron (SCC) at VECC.

RADIOISOTOPES & RADIATION TECHNOLOGY AND THEIR APPLICATIONS

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

Radioisotopes are produced in the research reactors at Trombay, accelerator at Kolkata and the various nuclear power plants of NPCIL. A wide variety of radioisotopes for medical, industrial and research applications are produced and supplied by BARC. The Board of Radiation and Isotope Technology (BRIT) produces and supplies 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 continue to offer services to medical and agro-industry. BARC received an award from IAEA for outstanding contributions in mutation breeding for crop improvement.

Agriculture

A high yielding Fusarium wilt resistant pigeonpea variety Trombay Akola Red Arhar (PKV-TARA) was released and Gazette notified for commercial cultivation in Maharashtra. Black gram selection TU-18, Mungbean selection TMB-45 and Cowpea genotype TC have been promoted from initial varietal trials (IVT) to advanced varietal trials (AVT-I) in All India Coordinated Research Project on Mungbean, Urudbean, Lentil, Lathyrus, Rajmash and Pea. Fifty three new selections were evaluated for seed size, seed yield per plant. Yellow Mosaic Disease (YMD) reaction in field conditions showed resistance to YMD along with large seed size and high yield. Breeder seed multiplication of released varieties TU94-2, TU-40, TAU-1, TAU-2 and TPU-4 was carried out. 538 quintals breeder seed of Trombay groundnut varieties TAG 24, TG 37A, TG 38, TDG 39, TG 47 and TG 51 were multiplied and distributed to 20 seed growing agencies. A high yielding widely adapted groundnut variety TG 37A was field demonstrated in neighbouring villages of KAPS Gujarat and Open Air Jail in Tamil Nadu. Using real time polymerise chain reaction (RT-PCR) and SYBR green dye, a technique was developed that does not require post-PCR agarose gel electrophoresis and can save time and money in marker assisted selection in a large population. Two rice selections BARCKKV10 and 11 were found superior in western Maharashtra in Advanced Variety Trial quality of Maharashtra State Rice Coordinated Trials. A rapid molecular method for detection of gliotoxin producing Trichoderma strains was developed.

Food Technology

A combination process including radiation treatment for hygienization and shelf life extension of shelled sweet corn kernels upto 30 days at 4C was evaluated at laboratory scale. Composite PVA-



Wheat samples irradiated with electron beam at different doses

gelatin films containing tomato pulp were prepared and characterized. The technology for Fruit Vegetable Dip Treatment Machine for processing of Litchi and other Fruits and Vegetables was developed. Litchi processing technology was transferred to SCRIMAD, Madagascar.

A large number of samples such as soya, kodou rice, kutki rice, maize seed and flour, and lauki seeds were irradiated at RRCAT using electron beam from linear accelerator for agricultural products and materials research.

Nuclear Medicine and Healthcare

More than 200 patients were treated using ^{177}Lu-labeled DOTA-TATE supplied by BARC. 129 ^{125}I-brachytherapy seeds were supplied to three oncology centres for treatment of eye cancer. Another 65 seeds (14 MBq) were supplied to Hinduja Hospital for prostate cancer treatment. About 3.9 KCi of medical radioisotopes ^{131}I, ^{99}Mo, ^{153}Sm, 177Lu, ^{131}I and ^{32}P were supplied to BRIT for radiopharmaceutical formulations. About 280 freeze-dried HYNIC-TOC kits were supplied through BRIT to various hospitals and nuclear medicine centres for the preparation of ^{99m}Tc-HYNIC-TOC for the diagnosis of various types of neuroendocrine cancers.

More than 23,000 consignments of ready to use radiopharmaceuticals of Na^{131}I for diagnosis and therapy of thyroid disorders, ^{131}I MIBG for neuroendocrine cancers, ^{32}P, ^{153}Sm and ^{177}Lu for bone pain palliation were supplied to various nuclear medicine centres and hospitals all over India by BRIT. Milestone production of 3Ci per batch of Na^{131}I could be achieved with the product of denomination of 25mCi, 50mCi, 100mCi and 125mCi. Total number of therapeutic treatments based on supplies, are estimated to be 18,960. This included therapeutic doses of Na^{131}I for the treatment of thyroid cancer and hyperthyroidism.

More than 73,500 cold kits for formulation of ^{99m}Tc radiopharmaceuticals (15 Products; BRIT Code-TCK) were supplied to nuclear medicine centres. A separate GMP compliant cold storage facility for in-vivo TCK cold kits was commissioned at RPhP, BRIT in June 2014.

Approx. 195 Ci of ^{99}Mo, in the form of Sodium Molybdate solution for solvent extraction generator and ^{99}Mo-^{99m}Tc Gel Generator were supplied. Approximately 400Ci of ^{99}Mo (1150 generators) in the form of Sodium Molybdate were supplied as alumina column generator (COLTECH). COLTECH generator of 1Ci capacity is also introduced.

More than 2,08,245 in-vivo diagnostic investigations were carried out this year with varied diagnostic radiopharmaceuticals. The among them were ^{99m}Tc based on cold kits and ^{99}Mo-^{99m}Tc generator systems.

Medical Cyclotron Facility (MCF), Parel continued the supply 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. Approximately 14,444 patients benefitted with PET investigations.



Module for sterile, injection grade [F-18]NaF

Around 5575 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits amounting to carry out about 5, 72,000 in-vitro investigations were supplied to various hospitals, research centres and immunoassay laboratories throughout India. RIA products and RIA Laboratory are certified for ISO 9001:2008 and ISO 13485:2008 from United Kingdom Accreditation Services (UKAS).

Around 700 routine radiopharmaceuticals samples were analysed by QC. Cold kits for preparation of ^{99m}Tc-DMSA, ^{99m}Tc- MAA, ^{99m}Tc-Myoview and ^{99m}Tc-Exametazime were analysed for outside agencies M/s DraxImage and GE Healthcare.

Ninety four batches of TCK products were released after scrutiny of production & quality control documents before their despatch.

Regional Centres of BRIT at Delhi, Bengaluru, Kolkata, Jonaki Hydrabad continued supply of radiopharmaceuticals to surrounding Nuclear Medicine hospitals.

Towards societal applications of radio-technology, VECC has collaborated with BRIT, Kolkata to develop an economic semi-automated PC controlled module ^{99m}Tc-TCM-AUTOSOLEX for preparation and use of [99mTc] pertechnetate using (n,g)^{98}Mo in hospital and has started clinical trials of the product also. The collaboration has also developed a PC controlled semi-automated ^{99m}Tc-TCM-AUTODOWNA for preparation of pharmaceutical grade ^{99m}Tc by anion exchange (Dowex-1) column and alumina column using nitric acid as part of the IAEA Coordinate Research Project (CRP) on direct production of ^{99m}Tc in cyclotrons.

Alternative Applications of Heavy Water

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 were developed at HWP, Baroda in laboratory scale. Process optimization was also done to minimize the consumption of Heavy Water used for synthesizing these molecules. A MoU signed between HWB & BRIT, BRIT has already started marketing these solvents to various reputed research institutes in the country. Board has further taken actions to restart supply of Deuterium gas to Indian manufactures. Two parties have come forward for manufacture of duterium based gas mixtures which will be used for curing optical fibers, calibration of analytical instruments and other R&D works.

Realizing the potential requirements of ^{18}O having application in nuclear medicine and bio-chemical research, HWB has successfully accomplished technology development for enrichment of O^{18} at HWP, Tuticorin. The technology development for enrichment of O^{18} reached an advanced stage of industrial deployment at HWP, Manuguru.

Cancer Diagnostics & Treatment Services

During the year, new equipments such as X-Ray Machine C-arm, Portable DR System, Robotic Surgery, Digital Radiofluroscopy, Ultrasound system with Portable Colour Doppler etc. were commissioned. Installation of equipments such as Steam Sterilizer, Cryostat Microtome, Water Purification system and Blood Collection Monitor was carried out. Medical Oncology Information System (MOIS) software has been implemented for Breast and GI Disease Management Groups. Introduction of smart card services for all services and all categories of patients has been done. Browser based Software has been implemented for Admission/Discharge/Transfer & Operation Theatre. Advanced imaging facility with Super-resolution imaging ready Laser Confocal Microscope, Spinning disk laser confocal microscope and Multi-photon ready high sensitivity spectral Confocal Microscope has been established. Cancer Registry at Vishakhapatnam has been established. For establishing of cancer hospital in Andhra Pradesh, retender is being issued for finalising contractor for construction. OPD activities have commenced and approximately, 150 patients have been treated so far. For cancer hospital in Chandigarh, procurement of high value equipments such as Telecobalt, Brachytherapy, X-ray C-Arm CT Simulator, Tissue Processor, Iseries Main Server, OT equipment i.e. OT light, Operation table etc for the Satellite Centre in Sangrur was in progress. During the year, 10 clinical trials were funded through DAE-CTC funds.

Industrial Applications of Radioisotopes & Radiation

Contract with Los Alamos National Laboratory, USA for identification of source to

repatriate US origin sources was completed for the five institutes in India. More than 1200 Ir-192 and Co-60 Radiography sources were supplied to NDT user. Sc-46 and Cs-137 CMR sources were supplied to various organisations. Irradiator sources with total activity of around 1259 kCi were supplied and exported in nine consignments to various processing plants within the country. Eight absorber rods were unloaded and transferred to RAPPCOF pool for irradiators and teletherapy sources. RAPPKOFF, Kota continued processing, production and transportation of Cobalt-60 sources. Total activity of Co-60 processed in the year 2014 was 63.52 PBq (1717KCi).

BARC prepared and sent about 445 nos. of ^{60}Co Polymer film sources of activity 37 kBq to users for their use as Position Identification of Perforation (PIP) sources in offshore procedures of oil-well explorations.

Radiation Processing

During the year, the ISOMED facility acquired the OHSAS 180001: 2007, EMS 14001:2004 and WHO-GMP certifications. It has designed and validated bar-coded GMP complaint computerised application package for commercial products from BRIT. Cumulative volumetric figures for the current fiscal was 7370 Cubic Mtrs from the contract radiation processing services for terminal sterilization of healthcare products.

About 2700 MT of spices and other products like nutraceuticals and colour pigments were processed at Radiation Processing Plant, Vashi. This facility has processed 30,550 tons of products since its inception. A facility for calibration of Nuclear Radiation Survey Meters and portable radiation monitoring of instruments approved by AERB has been set up at Vashi Complex.

MoU's were signed with M/s Raghuvansh Agrofarms Ltd and M/s Archon Healthcare Pvt. Ltd, for setting up Radiation Processing plant at Indore and Bavla, Ahmedabad respectively.

Two Radiation Processing plants, namely M/s Impartial Agro Tech (P) Ltd., and M/s Gujarat Agro Industries Corporation Ltd (GAIL), were



Inauguration of M/s GAIL, Bavla, Gujarat by Chief Minister, Gujarat

commissioned at Unnao, Lucknow and Bavla, Ahmedabad in 2014.

Total number of Radiation Processing Plants commissioned in the private sector in the country under MoU with BRIT is now 12.

Radiation Technology based Equipment & Services

Three Gamma Chamber-5000 and three Blood Irradiator 2000 were supplied to different universities and hospitals for various applications. Sixty radiography cameras, ROLI-2 and ROLI-3 were supplied.

BRIT participated in construction of Blood Irradiator for IAEA's Southern Tsete Fly Eradication Project (STEP) at Addis Ababa, Ethiopia jointly with M/s. Symec. BRIT supplied 60 kCi Co-60 source and provided other services such as dosimetry, source loading pattern design etc.



Southern Tsete Fly Eradication Project (STEP), Ethiopia

Order from IFRB, Bangladesh was executed for supply of 55 kCi Co-60 source for PANBIT Irradiator and expert services provided for refurbishment of plant.

Four units of Cobalt Teletherapy Machines 'Bhabhatron' built indigenously at BARC were commissioned one each at Guwahati, Bathinda, Mungeli and Zambia taking the total number of operating units to 30. Liquid Target Cavity for producing 16.5 MeV proton beam for Medical Cyclotron was developed as an alternative to silver target cavity.

Supply of 60 new indigenous radiography camera model ROLI-2 & model ROLI-3, and servicing and inspection of BRIT manufactured as well as imported ROLI cameras were the highlights during the reported year.

Water Purification, Water Desalination & Isotope Hydrology

DAE is participating as a technology provider/adviser in water analysis aspects of 'National Mission for Clean Ganga'. An additional RO system (15 m^3/hr capacity) was installed and commissioned as second stage in the existing Seawater Reverse osmosis plant of NDDP to cater to the needs of boiler feed make up water of MAPS. A series of Thin Film Composite charged nano-filtration membranes bearing fixed negative charge (-SO-3H+) have been developed indigenously using innovative chemical compositions through in-situ interfacial polymerization technique. A three dimensional CFD model of the spray drying process used for Zero Liquid Discharge desalination was developed.

Isotope hydro chemical investigation for understanding the hydrology of Pilikula Lake, Mangalore, Karnataka concluded that the Pilikula Lake is receiving large amount of groundwater due to agricultural activities in its catchment which improved the groundwater recharge. Isotope hydrological investigation to assess the groundwater salinity in and around Kelwa and Mahim villages of Palghar Taluka, Maharashtra concluded that majority of groundwater salinity is due to seawater intrusion;



Characterization of NF charged membranes in Test Cell

however, at few places salt pans also contribute to increased salinity in groundwater. Isotope technology for evaluating utility of tanks for enhanced groundwater recharge in hard rock zones of Nalgonda district, Telangana revealed rejuvenation of tanks could aid significantly in groundwater recharge.

BASIC & APPLIED RESEARCH

Basic and applied researches relevant to DAE's programme are carried out in the research centres of the department. The autonomous research institutes 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

A nodal domain theorem for non-separable quantum systems in two dimensions is proved at BARC. This presents novel connections between the theory of difference equations, partial differential equations and quantum ergodicity, a property of the quantization of classical mechanical systems that are chaotic.

The School of Mathematics of TIFR made substantial progress in the context of GL(3) and GL(2)×GL(2) sub-convexity. Studies on semilinear elliptic equations in the hyperbolic space were continued and new results on sign changing solutions were obtained. Existence of a maximizing function for a singular Moser-Trudinger inequality was established. Novel entropy conservative and kinetic energy consistent schemes for compressible Euler equations were constructed and their efficiency was established. A mathematical model for the epidemiology of tuberculosis in India has been proposed so as to study the differences in private and public sector treatments.

Important advances in number theory, group representation and differential equations were made in the course of the year at HRI. Work on interpolation of two real analytic curves by piecewise minimal surfaces was completed. A question of S. Bocherer concerning differential operators on Jacobi forms was answered positively. An intermediate modular relation between various zeta-functions has been proven which gives rise to many arithmetical Fourier series as a consequence of its functional equation.

The Institute of Mathematical Sciences (IMSc) remained involved in the various projects with national and international institutes on Mathematical Sciences without Walls; Developing tools for dynamical modelling of C elegans neuronal network activity; INO Project; Algebraic Problems; Provably Efficient Re-processing Algorithms; Potential Theory on Infinite Networks and Trees; DST-IMPECS Project on "Exact Geometric Computation for Non-Linear Problems"; DST-SERB Project on "National Network for Mathematical and Computational Biology"; Mechanisms of active intra-cellular transport: connecting theory and experiment and Non-Commutative geometry of quantum homogeneous spaces, the local Index formula & associated invariants.

Physics

Various sub-assemblies including Compound Parabolic Concentrator (CPC) Housing Sub-assembly, Main Frame Sub-assembly, PMT Housing sub-assembly and Drawer cage Sub-assembly were designed and manufactured for



MACE Camera

MACE telescope. The TACTIC telescope at Mt Abu was deployed for TeV (1012 eV) -ray observation of extragalactic objects. Design of 50 kiloton Iron Calorimeter electromagnet and 1/8 scaled engineering prototype module of 2.2 kiloton for India based Neutrino Observatory has been completed. A position sensitive multi-wire cathode strip gas detector was developed at BARC for the detection of fission fragments. A technique for characterizing deeply curved precision machined metallic surfaces was developed using the home-built Time Domain Optical Coherence Tomography setup. A compact portable neutron generator capable of producing 107-109 neutrons per sec in both DC and pulsed modes was developed. Stereoscopic visualization microscopy system designed for neurosurgery training and education was developed and deployed at AIIMS, New Delhi.

A regular stratospheric balloon manufactured and flown with 7 kg payload from TIFR Balloon Facility, Hyderabad reached a record altitude of 51.83 km and penetrated through Mesosphere for the first time. World record manned balloon flight was made using balloons fabricated at TIFR Balloon Facility. Laboratory model of Infrared Spectroscopic Imaging Survey (IRSIS) payload for an Indian Satellite was fabricated and being assembled. Discovery of a few new and interesting pulsars from follow up observations of the Fermi-LAT sources was made. With the aim of providing seamless frequency coverage of the GMRT, new wide-band radio frequency feeds and receiver systems were developed. The design and fabrication of new 130-260 MHz & 250-500 MHz receivers were completed. About 10 antennas of GMRT were upgraded with

broadband fiber optic link. A prototype of GPU based hybrid back-end system was developed. A new optical floating zone furnace to be used to grow oxide single crystals and other intermetallic compounds is expected to be installed in February 2015. A method to determine the change in chemical composition using intensity variation of a HAADF-STEM image at any point within a wedge shape sample of multilayer thin films containing two elements intermixed within the layers was developed. First microscopic demonstration of size induced 4f localization in CePd3 was carried out. Ultrafast laser pulses were used to write optical devices like splitters and waveguides inside glass. External tuning of random lasers has been experimentally achieved.

The experimental nuclear physics programs were carried out extensively during this year using the light ion beams from K-130 cyclotron at VECC with different state of the art new detection system available at the centre. The critical behavior of Giant Dipole Resonance (GDR) in mass A100 region was probed up to very low temperature using alpha beams from K=130 cyclotron and Large Modular BaF2 detector array (LAMBDA), developed in-house.

During the period, the Institute of Physics (IoP) achieved many milestones in the research in accelerator based sciences, surface science, nano materials and low-dimensional systems. The 3 MV Pelletron Accelerator at the Institute was used for a variety of experimental research programmes. In high energy phenomenology, cross section



Dr. R.K. Sinha, Chairman, AEC & Secretary, DAE inaugurating the newly established Advanced Materials Processing Laboratory in IoP, Bhubaneswar

processes of one loop, which are important for analysis of LHC data were studied. Newly discovered superheavy nuclei and a new mode of fission decay for neutron-rich heavy nuclei was also studied. Newly established Advanced Materials Processing Laboratory in the Institute Campus was inaugurated by Dr. R.K. Sinha, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy on 27th June, 2014.

HRI scientists working in the field of condensed matter made significant advances in the area of correlated quantum systems. Density matrix scattering theory for a two-component quantum liquid in a spin dependent quantum potential has been set up. Real space approach to correlated quantum systems has yielded tangible new results. The neutrino physics group worked on models to explain some of the properties of neutrinos and studied their signals at various experiments. Other important results include work on the fluxes of ultra-high energy neutrinos in the presence of physics beyond the Standard Model. 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). New production modes and decay channels for the KK top quark have been predicted and relevance for LHC explored. A new extension of the SU(2)L gauge symmetry in the standard model by a SU(2)R gauge symmetry has been proposed. This new mirror symmetry leads to the prediction of a new set of fermions whose existence can be tested in the LHC. A new protocol for the weak measurement of any observable with pre and post selection was established. A relation between time energy uncertainty relation and multiparticle entanglement was found. A general strategy for calculating physical quantities in string theory and quantum field theories at intermediate values of the coupling constant was devised.

The School of Physical Science, NISER continued to offer the five year integrated Master of Science (M.Sc.) programme in Physics which included courses such as Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics and Mathematical Physics. In addition,

elective courses based on upcoming areas in physical sciences were also offered for final and pre-final year students.

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 at 450 MeV energy, 100 mA current and Indus-2 at 2.5 GeV energy and up to 150 mA operated in the round-the-clock-mode. A major milestone was reached in Indus-2 on 19th June, 2014 when a current of more than 200 mA was achieved at 2.5 GeV energy.

At RRCAT, a global fast orbit feedback system was developed, integrated and tested in Indus-2 storage ring to further improve electron beam orbit stability.

An online booking portal for beam-time on Indus Synchrotron Radiation Source (SRS) beamlines which enables Indus SRS users to plan their experiments by checking the operation schedule and book the required beam-time slot in advance was launched on the RRCAT website.

X-ray lithography beam line was used for the development of different types of microstructures which include array of Compound Refractive X-ray Lens (CRLs) and high aspect ratio comb drive actuator. An x-ray focused spot size of 4.5 micron was obtained using these CRLs made in SU-8 polymer. High aspect ratio comb-drive actuators fabricated in acrylic with aspect ratio of 32 were fabricated by one-step deep X-ray lithography process.

The facilities at the Scanning EXAFS beamline were augmented with a low temperature cryostat for making measurements on samples down to a low temperature of 5K.

The protein crystallography beamline was used extensively by researchers from different laboratories all over the country. Several protein



The low temperature cryostat commissioned at BL-09 for carrying out low temperature EXAFS measurements.

crystals were synthesized in the Bio-Chemistry laboratory.

X-ray diagnostic beamline on Indus-2 is used for online measurements of transverse beam parameters of electron beam such as beam size, beam emittance and beam position. The ARPES beamline on Indus-1 was upgraded with a state of the art electron energy analyzer (Pholbos-150). The major parameters of this beamline available at present for the users included energy range of operation-12 eV to 200 eV and overall electron energy resolution of 140 meV at 21 eV photon energy. High temperature stability studies of multilayers of C/B4C and W/B4C were made using the soft X-ray reflectivity beamline on Indus-1.

Indus-2 synchrotron radiation source was upgraded by incorporating five insertion devices (undulators and wigglers) in the long straight sections of Indus-2 storage rings. These will enhance brilliance of the synchrotron radiation by 2 - 3 orders of magnitude. The first milestone in this direction was



Planar undulator for Atomic, Molecular and Optical Science (AMOS) beamline

accomplished by installation of two planar undulators in the straight sections, LS-2 and LS-3, respectively of the Indus-2 storage ring in December, 2014. Undulator, U-1 is for Atomic, Molecular and Optical Science (AMOS) experiments which will generate photons having a maximum flux between 6eV to 250eV. Undulator, U-2 is for Angle Resolved Photoelectron Spectroscopy (ARPES) experiments which will generate photons having a maximum flux between 30 eV to 600 eV. Work was underway on the development of front-ends and beamlines for these two undulators.

A new time resolved Extended X-ray Absorption Fine Structure (EXAFS) facility was setup at BL-8 beamline in Indus-2 to study in-situ growth of nano particles. A beamline was commissioned in Indus-1 synchrotron for Fourier transform infrared absorption/reflection spectroscopy. A Fourier Domain Optical Coherence Tomography system was developed indigenously for depth resolved tomographic imaging of scattering samples for material science research.

Fusion and Other Plasma Technologies

The Steady-state Superconducting Tokamak-1 (SST-1) experiment progressed well with spectacular milestone achievements at The Institute of Plasma Physics (IPR). Plasma start-ups with ITER relevant electric fields of 0.3 V/m, plasma formations with both second harmonic and fundamental electron cyclotron assisted pre-ionizations, superconducting magnets with Two Phase cooling are some of the science and technology milestones achieved. Discharges duration beyond 230 ms with plasma current in excess of 145 kA were obtained with repeatable characteristics in the Aditya tokamak. The toroidal magnetic field was raised up to 1.125 T to maintain edge safety factor (qedge) 3. The best base vacuum of the order of 3x10-8 Torr was achieved after successful baking of Aditya vacuum vessel at 110 °C. In Aditya tokamak, using the Ion Cyclotron Resonance Heating (ICRH) system, experiments were carried out to have plasma heating at second harmonic, disruption mitigation and also wall conditioning in presence of toroidal magnetic field. In the superconducting magnet technology, various prototypes were tested successfully with all components made from Indian industries and institutes.

For Large Scale Cryogenic systems, a steering committee with national technical and administrative experts was formed to discuss various ways to progress in this ambitious national project. Exploration of societal benefits from plasma technologies was continued vigorously through the Facilitation Center for Industrial Plasma Technology (FCIPT). Various projects were done through national sponsorships and though international collaborations.

At the Center for Plasma Physics, Guwahati the theory and experimental activities were beefed up in line with the goals of the Institute. The development of a neutron source based on inertial electrostatic confinement fusion scheme and its application in damage study of fusion materials progressed well.

At BARC, an innovative space saving online fabrication facility has been set up 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. This has enabled the fabrication of long length Cable-In-Conduit-Conductor (CICC) in the existing facility. Towards fabrication of 200m long Nb-Ti based 30kA superconducting CICC, required length of final stage cable was fabricated and wrapped with 25 micron SS foil.

Chemistry

A low cost wound care product based on controlled release of nitric oxide was developed at BARC and transferred to M/s. Cologen Healthcare Pvt Ltd, Tamilnadu. A point-of-use drinking water disinfection technology involving in-situ ClO_2 production is developed. Under incubation development project, a turmeric extract based formulation Turbovita containing all active Curcuminoids was developed. Palladium-platinum based catalyst supported on SS wire gauze was developed for mitigation of hydrogen generated in nuclear reactor during loss of coolant accident conditions. A portable and high sensitive sensor with



Turbovita, a novel Curcumin formulation developed by BARC

electronic alarm working at ambient conditions is developed for detection of toxic H_2S gas (1 ppm level) based on the surface conductivity of hydrogenated diamond films. Plastic scintillator detector technology based on polymers like polystyrene/polyvinyl toluene along with organic fluorescence additives was developed. A new methodology based on Energy Dispersive X-ray Fluorescence (EDXRF) was developed to detect level of elements using thin specimens of the sample deposited on thin scotch tape supports. A new pore-filled anion-exchange membrane has been developed for acid recovery from waste streams.

At TIFR, new NMR methods were developed for applications in both solution and solid state, especially for systems related to Malaria and Alzheimer's diseases. A new theoretical framework to describe charge transport across organic molecules was developed. New computational measures based on protein electrostatics to determine quality of protein structures was proposed. Zebrafish larval model was developed for manganese induced neuronal disorder. Spectroscopic techniques were developed which combine with NMR to derive structures of disease-causing, metastable proteins.

The School of Chemical Sciences at NISER continued to impart high quality undergraduate and postgraduate level of knowledge. In addition to traditional organic, inorganic, physical and theoretical chemistry areas, the school embarks on teaching and research activity in the interface areas of Biology, Material Sciences and Medicine.

Biology

A new fish facility was constructed at TIFR, Colaba campus. Geldanamycin, an anti-mitotic drug was tested and found to cure malaria in mice. A novel assay system to characterize motor proteins in vitro and in vivo was developed. The critical role for plasmodium p-proteins in nuclear division and in host invasion was elucidated. A stem cell population that forms muscles in the fruitfly was identified. Notable studies on learning and plasticity in stress, on mechanisms for associative learning and on human adaptation to throwing were carried out. At SINP, 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. NISER continued the research and teaching programmes with harmonious synthesis of classical and modern biology - always promoting scholarship, original thinking, innovative ideas and cutting edge research.

Materials Science

At BARC, reaction conversion process was optimized to transform carbon fibre directly into silicon carbide fibre for developing SiCf-SiCm and SiCf-MAX phase ceramic composites. Aluminium oxynitride (ALON) (9Al2O3.5AlN) ceramics was synthesized from Al2O3 and AlN by solid state reaction as well as by reactive Spark Plasma Sintering (SPS) under N2 at 1850°C for developing transparent ceramic for armour, window and laser host applications.

Towards, basic research, materials with extremely large tunable thermal conductivity was developed and UHV irradiation facility was established to study the evolution of microstructure with irradiation in model Oxide Dispersion Strengthened alloys at IGCAR. Also an indigenously designed Ion Beam Sputter

Deposition System was assembled to study the growth kinetics of Al and AlN thin films.

A new framework to yield the statistics of dislocation pinning at defects was developed for material science study at VECC. Radiation damage studies of reactor cladding materials have been successfully carried out in collaboration with BARC, using the proton beam of K=130 cyclotron of this center.

At RRCAT, two types of packaged fiber optic sensors based on long period fiber gratings and turn around point long period fiber gratings were developed and tested for measurement of radiation dose in the range of 0.1 kGy to 50 kGy for applications in the measurement of radiation dose in the linac based irradiation as well as for applications in radiation environment like hot cells. Ultraviolet GaN based photo detectors were developed and fabricated with a low sensitivity for visible range and a high response in the ultra violet range between 300 to 365 nm. Dy-Gd–YIG ferrite disks of 200 mm diameter with stringent magnetic characteristics and composite magnetic circuit were developed indigenously for the circulator of the RF system of Indus-2 and 650 MHz proton linac.



Indigenously developed high power Gd-Dy garnet disk

Cancer Research

The Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) located in Kharghar, Navi Mumbai comprises of the Clinical Research Centre (CRC) and Cancer Research Institute (CRI). The CRC continued to perform clinical research, clinical trials and develop indigenous technology. The CRI remained focused on basic and applied research on cancer.

During the year, the CRI received a sum of Rs. 8.30 crore from governmental agencies to support 43 out of 182 on-going projects.

The protein interaction research at CRI focused on identifying novel therapeutic strategies for cancer treatment and their role in regulating cell cycle progression and neoplastic progression. Findings indicated a tissue specific role of K8/K18 in malignant transformation/ progression of carcinomas. Putative driver genes associated with oral carcinogenesis were identified. The significance of epigenetics in gastric cancer and hepatocarcinoma is being investigated.

The CRC commissioned a new 22-bed ward. Over 2100 major procedures were conducted and about 1000 in-patients were admitted in the Leukemia/ Lymphoma ward and around 50 outpatients/day were seen in the adult hematolymphoid OPD.

INTERNATIONAL RESEARCH COLLABORATIONS

The Nuclear Data Physics Centre of India (NDPCI) pursued all aspects of nuclear data viz, measurements, analysis, compilation and evaluation involving national laboratories and universities in India. Under the MoU with the Institut Laue-Langevin (ILL), Grenoble, France, BARC has made in-kind contribution to ILL in the form of lead shields, neutron guide housings, precision alignment tables, stainless steel roof etc. In a collaborative India-UK project, stainless steel to titanium dissimilar materials bonding with strength 112 MPa was developed using vacuum brazing with Ag-28% Cu alloy.



Neutron guide housing made of Aluminium at ILL

International collaborations of VECC were continued with the participation in three major experiments STAR experiment at the Relativistic Heavy-Ion collider (RHIC) at Brookhaven National Laboratory, New York, USA; ALICE experiment at the Large Hadron Collider (LHC) at CERN, Geneva, Switzerland and CBM experiment at FAIR in GSI, Darmstadt, Germany. These experiments explored different regions of the QCD (Quantum Chromo-Dynamics) phase diagram. In the STAR experiment at RHIC, we have been involved in the beam-energy scan program with the aim of locating the QCD critical point, which is a major landmark on the QCD phase diagram. The analysis results, using the data from a combination of - "Made in India"- Photon Multiplicity Detector (PMD) and the STAR Forward Time Projection Chamber (FTPC) shows the presence of a localized anti-correlation in the production of photons and charged particles. In the ALICE experiment, the PMD has been conceived, designed, and fabricated by the Indian collaboration. VECC has been playing the lead role in design, simulation, development and fabrication of the muon detection system in the Compressed Baryonic Matter (CBM) experiment in the upcoming Facility for Antiproton and Ion Research (FAIR). A major milestone was achieved this year in the form of submission and subsequent approval of the Technical Design Report (TDR) of this system by the Expert Committee of Experiments of FAIR.

Two copper coated stainless steel high power RF couplers have been developed by RRCAT with indigenous efforts and supplied to CERN under Novel Accelerator Technology protocol. These couplers have been installed in the LINAC 4 and are undergoing high power conditioning at CERN.



The RF coupler installed in DTL 1 in LINAC 4 tunnel at CERN

TIFR reached an important milestone in its pursuit to build the Belle II silicon micro-vertex detector (SVD) i.e., mechanical mockup meeting the desired geometrical and mechanical precisions.

SINP has set-up a Beamline in Photon Factory, Japan. The Indo-German collaboration between SINP and Deutsches Elektronen-Synchrotron (DESY), Hamburg in Synchrotron research has been successfully going on. International Collaboration with CERN in ALLICE and CMS experiments and International Collaboration with SNOLab in PICASSO experiment are ongoing.

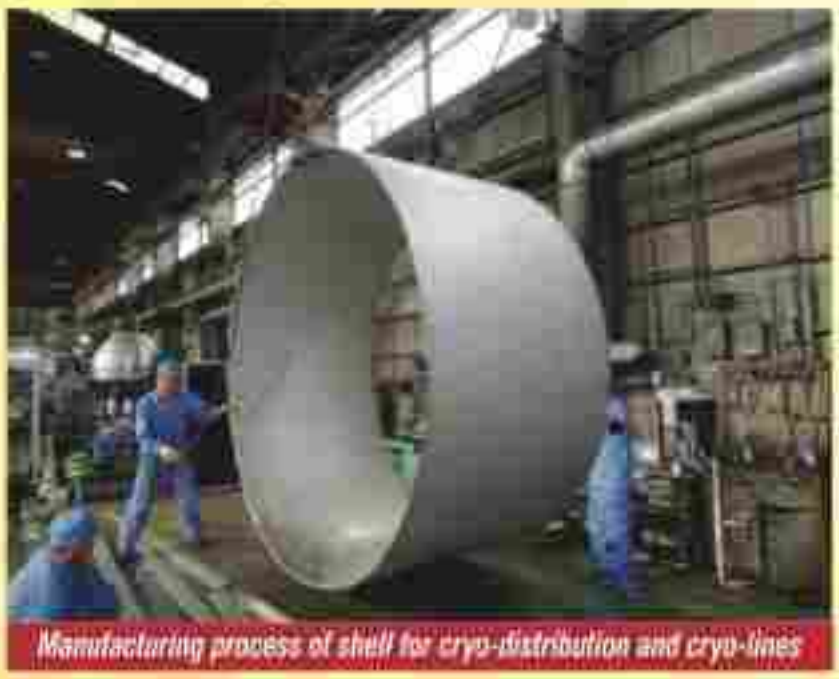
The Institute of Physics, participated in the PMD collaboration experiment at RHIC and LHC accelerator facilities in USA and CERN, Geneva respectively. The photon multiplicity detectors fabricated at the Institute are being presently installed and tested as part of the STAR experiment at RHIC accelerator. Experiments were also carried out at the Photon Factory, Japan, Elettra Synchrotron facility in Trieste, Italy, and ALPI Linear Accelerator at LNL, Italy.

At IPR for the Indo-Italian program on investigation of local structure and magnetism properties of Cobalt nano-structures, synthesis of Cobalt nano particles under externally applied magnetic fields was carried out. For the DAE-BMBF program on Low Energy Ion Beam for Nano Patterning and its Applications to Plasmonics, the project was successfully completed and the concerned report was submitted. A follow-up project proposal has also been submitted. For the Indo-UK DST program on Plasmonics based CZTS Solar Cells, a project proposal to develop plasmonics based CZTS Solar Cells and to demonstrate an improved solar cell efficiency, using Silver nano particles was submitted and sanctioned. A MoU for research collaboration between IPR and RICMASS (Rome International Centre for Materials Science and Super Stripes), Italy has been signed in March 2014. Under this MoU it has been planned to carry out an in-depth study of defects and atomic level changes in materials exposed to fusion plasma.

IMSc continued the joint projects with other international institutes which were CEFIPRA: Arithmetic circuits computing polynomials with University of Paris; Indo-Swiss PEP Joint Research Project titled "Mathematical Programming in Parameterized and ITRA- Media Lab Asia Project on Decongesting India's transportation networks using mobile devices.

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. Six major contracts for the manufacturing of ITER components have been signed till date for ITER. The workshop at the French site for the assembly of biggest cryostat which is being supplied by India was inaugurated.



Manufacturing process of shell for cryo-distribution and cryo-lines

At IPR, Nuclear design and analyses was carried out for the Lead Lithium Ceramic Breeder (LLCB) Test Blanket Module (TBM) set using the Monte Carlo radiation transport code MCNP and nuclear cross-section data Fendl-2.1. High Heat Flux Test Facility was utilized to test many potential materials for using in first wall components of fusion relevant machine. A laboratory scale Hydrogen Isotope Removal System (HIRS) for He purge gas to validate design concepts for tritium extraction is being developed.



Test setup for Hydrogen solubility studies in PbLi

Laboratory scale hydrogen isotope storage experiments in metal getter bed were conducted at BARC. The vessel was fabricated and tested to store 2 gm of hydrogen equivalent. Laboratory scale hydrogen solubility studies in liquid lead lithium eutectic were carried out. Experimental set up for Hydrogen permeation using Pd based membrane was installed and commissioned.

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.

The national facility for neutron beam research was utilised very effectively by Scientists from BARC, other DAE units, universities and national laboratories through collaborative research projects. Nuclear counting and calibration facilities of IGCAR were extended to various institutions involved in BRNS projects, researchers and industries in southern region. The Indus synchrotron radiation sources of RRCAT, which are national facilities, were used by scientists and students from various universities, national institutes and research laboratories all over the country. A number of external users from universities and other research institutions utilized beam times from 3 MV Pelletron Accelerator at IoP.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

The Homi Bhabha National Institute (HBNI) continued to strengthen its linkages with premier research and academic institutes in the country and abroad. It has MoU with the many institutes of national and international repute. HBNI has now eight Boards of Studies which are Chemical Sciences, Engineering Sciences, Health Sciences, Life Sciences, Mathematical Sciences, Physical Sciences, Strategic Studies and Undergraduate Studies. The Institute awarded 430 Ph.D, 669 M.Tech, 9 M.Phil, 118 M.Sc. (Five years integrated and as part of integrated M.Sc.-Ph.D programme), 24 M.Sc. (Engg), 159 diplomas in radiation protection, 47 diplomas in medical radioisotope technology, 40 diploma in radiation medicine and 155 post graduate medical degrees till November, 2014. During the period of report, 12 engineering post-graduate students were inducted into DAE Graduate Fellowship Scheme (DGFS) for Ph.D. A new diploma course in Fusion Technology has been started during the year.

Training

The academic programme of the 57th batch of BARC was continued. New trainees under Orientation Course for Engineering Graduates & Science Post-Graduates (OCES) and DAE Graduate Fellowship Schemes (DGFS) were selected with high standards. The Continuing Education Programme QUEST offered several advanced courses to DAE staff and to HBNI students located in Mumbai. The One year post-M.Sc. Diploma in Radiological Physics course provided the mandatory trained manpower requirement of radiation safety professionals in medical, industrial, research and agricultural applications of radiation.

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 at IGCAR.

BARC Training School AMD Campus, Hyderabad continued its activity in the fifth year with Geology and Geophysics TSO.

VECC facilitated conduct of academic programme in Physical Sciences and Engineering Sciences. Besides, VECC imparted vocational training to undergraduate B.E/ B.Tech students of IITs, NITs and different universities across India.

Human resource development activities at RRCAT were greatly enhanced by extending the available research facilities for training of university students in the areas of accelerators, lasers and their applications.

The Administrative Training Institute (ATI) of DAE continued the professional development of officials from various cadres working in Department of Atomic Energy, through a wide range of training programmes arranged specifically for them. There has been a steady growth in the number of courses being conducted and number of employees being covered. Till now 593 programmes covering over 16500 employees have been organized.

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. 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 which is sensitive and attentive to employee grievances at all levels was in operation. Performance Linked Incentive Scheme (PLIS) linked to various production targets and construction milestones proved very successful and instrumental in improving the production by boosting morale of employees and executives. In addition to this, a good award scheme for encouraging employee to work toward achievement of organizational goals in efficient and effective manner was in place in NPCIL.

The Institute of Physics (IOP) contributed in a significant way towards quality human resource development in the form of one year pre-doctoral course followed by Ph.D. program. The Institute actively promoted interactions with colleges, universities, academic institutions and other National laboratories through visitor programmes, workshops, symposia and other academic events.

The Department of Mathematics at HRI conducted the Summer Program in Mathematics (SPIM) for introducing basic mathematics in Master's level in an interesting way to the highly motivated undergraduates or the post graduates from various colleges and universities across India and other countries like Nepal and Cambodia.

TMC registered Post Graduate Medical students in various disciplines under Tata Meorial Hospital (TMH). Two new courses; one year diploma in Fusion Technology and M.Sc. in Clinical Research were initiated and students were to the Fusion technology course. ACTREC inducted research scholars for its Ph.D. program and provided short term/ summer training and conducted workshops, symposia, conferences and seminars on varied aspects of biology and cancer during the year. The centre also supported graduate students from various colleges for their master's dissertation programs.

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), Visiting Scientists Programme and The Raja Ramanna Fellowship of BRNS were continued.

During the year, new research projects were sanctioned. In addition, BRNS also entered in three new MoU for "Development, production and supply of microwave substrates for 750 W solid state amplifiers" with C-MET (Phase–II); setting up of "A 500 KeV Accelerator Mass Spectrometry facility with special emphasis on Carbon dating" at Mumbai university campus and "Development of a Photo injector based electron gun to produce electron beam of 5 MeV suitable for a Free Electron Laser (FEL)" at IUAC, Delhi.

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.

This year, six-member team secured 1 Silver medal and 3 Bronze medals at the 55th International Mathematical Olympiad held at Cape Town, South Africa. This year onwards the Board has decided for the participation of two girls candidates in the European Girls' Mathematics Olympiad (EGMO).

NBHM conducted Madhava Mathematical Competition for the undergraduate students. The Board provided scholarships and fellowships to the students, selected through nationwide competitive tests to pursue studies at masters and Ph.D. levels.

NBHM sponsored delegates for participation in prestigious ICM 2014 event held in Seoul, South Korea. The new Web-based interactive system for communication, evaluation of proposals is ready for hoisting on suitable secured server.

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 were undertaken between the Units and Aided Institutions and there was frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. 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. Homi Bhabha National Institute (HBNI), Mumbai has been granted the status of 'Aided Institution of DAE in February 2014.

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-₹ 560.91, TMC-₹ 534.50, SINP-₹ 105.28, IOP-₹ 35.08, IMSc,-₹ 53.33, HRI-₹ 36.96, IPR-₹ 609.23, AEES-₹ 54.2 & NISER –₹ 95.45 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 (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 2014-15, an amount of ₹ 4.00 crore was released to the institute by the department.

The Department also extend financial assistance to Cancer hospitals located in other parts of the country. The budget provision for the year 2014-15 for such partial financial assistance was to the tune of ₹ 19.00 crore.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

Private cloud computing service called "Megh" hosted on a cluster of 16 physical servers interconnected by a Gigabit Ethernet network has been developed by BARC for their users.

Two private clouds have been setup to host the IT services at VECC. At one end, the developed Storage-as-a-Service helps academicians, scientists and engineers to efficiently collaborate by using an e-briefcase service hosted via storage cloud. On the other end, Infrastructure-as-a-Service enables IT manager to efficiently utilize the



Megh Cloud Computing Cluster Servers

resources. The storage cloud called 'Annapurna' has been developed by using the technologies such as Gluster, and open-source software own Cloud. The system has been commissioned and is running satisfactorily for the past several months. The infrastructure cloud called 'Meghraj' has been developed with the technologies such as Gluster and open-source cloud building software, Open Nebula. The Meghraj has been deployed and tested satisfactorily in October 2014. A few Intranet services are being hosted via the cloud. Currently, the system is going through security testing and will be released to users around March 2015.

A centralised SMS-based notification system has been developed for various services of the Centre. Various IT-enabled services have been developed by Computer Division, VECC to cater to the internal need of the Centre.

VECC has achieved significant progress in the development of RFID-based Automatic Key Management System in collaboration with M/s Webel Mediatronics Limited, Kolkata.

TECHNOLOGY TRANSFER

Fourteen technologies were transferred by

BARC till December 2014. Six new technologies introduced into public domain were Robotic system for stacking objects using machine vision, Chemo Mechanical Magneto Rheological Finishing (CMMRF) Machine, Body Composition Analyser, Handheld 12-Channel Tele –ECG instrument, CsI:Tl single Crystal growth system & radiation detector fabrication and Nanocomposite DW. A technology marketing agreement was signed with M/S CSIR-Tech Pvt. Ltd. Pune.

Twenty technology transfers of Nisargruna and one technology transfer of an inexpensive growth medium for mass production of biofungicide Trichoderma spp were processed. Eight Nisargruna plants are under construction under MoU with various Municipal Corporations. A state of the art of 1 MT/day capacity plant was installed in RRCAT Indore.

The technology of a "production" variant LED based Uranium Analyser was transferred to ECIL in an agreement signed between ECIL and RRCAT in December 2014. Laser based Land Leveler technology developed by RRCAT was provided to Rural Human & Resource Development Facility RHRDF, SVERI, Pandharpur, Maharashtra.

COLLABORATIVE PROGRAMMES

RRCAT signed a MoU with IIT, Indore in July 2014 to enhance collaborative research and academic/teaching interaction in areas of mutual interest and also made available scientific infrastructure at RRCAT to the faculty and students of IIT. A MoU signed between RRCAT and Devi Ahilya Vishwa Vidyalaya (DAVV) was extended for another 5 years.

For the collaborative programmes, a MoU was signed between IPR and Central Leather Research Institute (CLRI), Chennai in September 2014 to carry out study on disposal of solid waste generated in leather industry.

SOCIETAL INITIATIVES

Four new AKRUTI Agreements were signed with Companies/Organisations and Individuals by BARC during the year. As part of DAE Outreach Centre (DAE-ORC), Two AKRUTI centres were set up in two villages in Sholapur district. Mobile exhibitions as well as stall for DAE technologies were put up. Awareness camps about Soil organic Carbon testing kit were organized in 13 villages for about 285 farmers.

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. Eight new inventions and one national phase entry were reviewed for the patentability. DAE filed eleven new patent applications which included one application under PCT (Patent Co-operation Treaty), seven Indian, two Australian and one USA application.

During the year, ten of the previously filed patents were granted to the Department. All the ten patents granted were in foreign countries. These included three each in USA & Japan, two in Europe and one each in Canada & China.

During the year, 125 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.

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.

Nuclear Power Corporation of India Ltd.

The projected net Profit After Tax (PAT) for the year 2014-15 is about ₹ 2000 crore. The net profit after tax for previous financial year 2013-14 was ₹ 2299

crore. The NPCIL bonds were 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 2013-14 was satisfying. The total income of the Company during the year 2013-14 was ₹ 814.2 Cr. The Company's profit before tax during the year 2013-14 was ₹ 16.32 Cr. Performance of the Company in terms of MoU signed with DAE was rated as "Very Good" during 2013-14.

Indian Rare Earths Ltd.

During the year 2014-15 the Sales Turnover was ₹ 379.29 crore (provisional) against ₹ 413.44 crore of previous year. Profit Before Tax in 2014-15 is ₹ 13.14 crore (provisional) compared to ₹ 71.77 crore in 2013-14.

Electronics Corporation of India Ltd.

Against the MoU target of ₹ 1800 crore each for production and net sales, the company achieved a production of ₹ 737 crore and a net sale of ₹ 767 crore upto December 2014.

INTERNATIONAL RELATIONS

India, a designated member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA) since its inception, continued to take active part in policy management and programmes of IAEA. India was represented on a number of IAEA committees, including those on safety, safeguards, nuclear radiation, nuclear engineering & application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings and offered the services of its experts under the IAEA Technical Cooperation Scheme 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. Besides, India has also made contribution to Indian Pugwash Society for its research & development activities.

India was represented in the meeting of Sherpas and Nuclear Security Summit in the Hague (Netherlands, March 2014), the Global Centre for Nuclear Energy Partnership (GCNEP) working Group Meeting with the US National Nuclear Security Administration (Washington, USA, April 2014), Indo-US Civil Nuclear Energy Working Group Meeting at Idaho National Laboratory (Washington, USA – July 2014), and Joint Collaborative Meeting (Canada, Nov 2014). India remained involved with nuclear security issues within the Nuclear Security Summit process and the Global Initiative to Combating Nuclear Terrorism.

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

An Inter-Governmental agreement with Australia for co-operation in the peaceful uses of Nuclear Energy on 5th September, 2014 and finalization of the text of the Administrative Arrangement with the United States pursuant to India-U.S. Civil Nuclear Co-operation Agreement signed on 10th October, 2008. In addition, India and Russia signed a "Strategic Vision for Strengthening Co-operation in Peaceful Uses of Atomic Energy" on 11th December, 2014. An agreement for co-operation with the Radiation & Nuclear Safety Authority of Finland was also signed on 15th of October, 2014 by Atomic Energy Regulatory Board.

The Department of Atomic Energy notified the IAEA about placing the Narora Atomic Power Station Units-1&2 under IAEA safeguards in accordance with the India Specific Safeguards Agreement signed between India and the IAEA in 2009.

The land acquisition for the Global Centre for Nuclear Energy Partnership (GCNEP) has been completed and the master plan of the institute is ready. Boundary wall construction has been completed along both the institutional as well as the residential campus. The contract for Phase-I construction has been finalized and the Environment Clearance has been received.

NPCIL continued to participate in various programmes of World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), World Nuclear Association (WNA), Institute of Nuclear Power Operation (INPO) etc. to enhance the

safety and reliability of its nuclear power plants.

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.

India participated in ConvEx-2a & ConvEx-2b exercises conducted in the year 2014 and could successfully demonstrate its capabilities of meeting convention requirements.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and hydrogen sulphide based heavy water plants periodically carried out a variety of emergency exercises. The various exercises carried out during the year 2014 included Communication Exercises, Fire Emergency Exercises, Plant Emergency Exercises, On-Site Emergency Exercises and Off-Site 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

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

VIGILANCE

The overall responsibility for vigilance in any unit of DAE rests with its Vigilance Officer/Chief Vigilance Officer (CVO). To ensure effective functioning of the vigilance machinery a senior officer in each of the Constituent Unit and Aided Institution of the Department has been designated as Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time CVOs discharges these responsibilities.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week 2014" was observed in the Department of Atomic Energy, Mumbai from 27th October 2014 to 01st November 2014. During the "Vigilance Awareness Week", various competitions such as Quiz, Slogan Competition, Poster Competition, Essay writing competition were held where officials and staff of the Department actively participated. Prizes for the winners in the competition were also distributed during the function. Vigilance Awareness Week was also observed in the Constituent Units/ Public Sector Undertakings and Aided Institutions of the Department.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resource Centre (SIRC) of DAE continued to provide library user services such as Circulation, News Clippings, Reference & Information, Reprography, etc. uninterruptedly. During the year, the centre enriched the resource collection by procuring new books, periodicals and other reading materials on topics of interest to DAE patrons. The Centre played an important role in executing and co-ordinating the printing, publication and dissemination of various public information literature such as 'Nuclear India', 'Parmanu', 'DAE Perspective', 'Atoms & Development' etc. Publication and printing of statutory documents such as 'Annual Report', 'Outcome Budget' and internal publications such as 'Cyber-Diligence', 'Accounts at a Glance', 'DAE

Diary', "CVC-Guidelines on Tenders", "DAE Essay Contest Announcement" etc. were also executed by the Centre.

The Scientific Information Resource facility of BARC provided seamless access of information to scientists and engineers with a large number of online and print journals, databases and standards useful for various R&D activities. BARC Newsletter, Scientific Information Resource Bulletin, Pulse and several internal and external reports were also brought out by the Scientific Information Resource Division. During the year, more than 800 books, 2500 scientific and technical reports and 500 bound periodicals were added to the library collection and various standards and codes were also procured. Subscription to about 980 periodicals and 11 Databases were continued. More than 3500 online journals are available on "Lakshya", the online information gateway for e-resources.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) and its constituent units promote the awareness about peaceful uses of atomic energy in the correct perspective with prime focus on benefits to the society by keeping the public abreast with current trends and developments in the areas of power production, applications of radiation technologies, healthcare, food & agriculture, industry, water, environment, advanced technologies etc.

During the year, DAE participated in and organised several events such as the 102nd Indian Science Congress at Mumbai University; 7th Vibrant Gujarat Global Trade Show at Gandhinagar; The 18th National Exhibition with the theme, "Service to the Nation for progress of India" at Kolkata; Indian Technology Congress 2014, with focal theme "Advanced Technology as change Agent to make India as Economic Superpower" organised at Bengaluru during August 21-22, 2014; Swasraya Bharat 2014 organised by Swadeshi Science Movement at Kasargod, Kerala; The 34th India International Trade Fair 2014 organised by the ITPO, at the Pragati Maidan, New Delhi; The 6th edition of AGROVISION with theme as "Building Sustainable Livelihoods & Increasing Farmers 'Income" held at Nagpur; The 39th International Kolkata Book Fair at



Visitors being briefed at the DAE Pavilion during IITF 2014



Students at the DAE pavilion during the Science Expo 2015, Mumbai

Kolkata and Science Expo 2015-an Interface of Science and Society held at Nehru Science Centre, Mumbai etc.

The 26th All India Essay Contest on 'Nuclear Science and Technology' was held in October 2014. About 450 essays were received out of which the authors of twenty nine were selected for making an oral presentation at Mumbai.

DAE organised the 6th International Exhibition and Conference, 'India Nuclear Energy 2014' at the Nehru Centre, Mumbai during November 6-8, 2014.

For the first time in its history, the Department displayed a tableau in the prestigious 66th Republic Day Parade Ceremony at Rajpath, New Delhi. The tableau, based on the theme "Atoms in the Service of the Nation", presented nuclear power as a clean and environment friendly energy option for peace, power and prosperity by showcasing the achievements and services of the Department in the areas of healthcare management

and food & agriculture.

Under the banner "uranium leads the way", the Department participated in the popular Mumbai Marathon 2015 with over a hundred participants from its various units including the school children from Atomic Energy Education Society, Jaduguda. The event offered the Department a unique opportunity to reach out to people on the street and spread the message of public service espoused by the



DAE Contingent in Mumbai Marathon 2015

Department.

The on-going campaign on broadcast media was augmented with new advertisement films on nuclear power; Bengali language has been added to the plan to comprehensively cover major activity areas of the Department including the North Eastern states of the country. The newly constituted Public Outreach Management Cell of DAE spearheaded and financially supported the outreach activities under the aegis of Diamond Jubilee Year celebration across the constituent Units encouraging some units to take their first steps in the all-important area of public outreach. Conventional methods of public awareness such as lectures and seminar in schools and colleges, public awareness events, participation in science fairs and exhibitions etc. are also continuing.



NPCIL's participation in the India International Trade Fair (IITF) - 2014 Exhibition under Ministry of Power pavilion at Pragati Maidan, New Delhi

NPCIL's public outreach included 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 such as media personnel, policy and decision makers, people's representatives, state officials, students and teachers, medical professionals and the public at large. NPCIL initiated the process of setting up of a number of nuclear galleries at the science centers across the country to allay the apprehensions of public on nuclear power.

Use of street plays, TV commercials, advertisements, radio jingles, single-sheet publications, innovative comic books and animated films in vernacular languages, enhanced interaction with press and media, e-public awareness campaigns, exhibitions to name a few that were adopted to scale up outreach activities. NPCIL entered into partnership with several specialized agencies like National Geographic TV channel, National Council of Science Museums, Tamil Nadu Science and Technology Center and Department of Science and Technology etc.

NPCIL reached out to an average of around one lakh people per month as a result of the above multi-pronged initiatives.

Public awareness programme were continued by AMD in various cities as well as in remote field areas and a total of 30 events were organised for students, teachers and general public. RRCAT conducted several events to increase public awareness of the scientific activities of DAE tomotivate young students to take up a career in science research. GCNEP has taken major initiatives towards enhancing public awareness and acceptance of nuclear energy programs with particular focus on students and faculty. In this direction, GCNEP organized a series of three Public Awareness & Outreach Programs in the Year 2013-14, entitled DAE Technologies for Rural India (DTRI-2013).

SOCIAL WELFARE

Corporate Social Responsibility

Corporate Social Responsibility and Sustainability activities were performed at NPCIL on the thrust areas of education, health , infrastructure development, skill development and environmental sustainability within the gamut of the Notification of the Ministry of Corporate Affairs and the activities were decided taking into account the actual needs of the stakeholder

During the financial year, total 157 projects were been taken up. ₹ 42 Crores of fund was sanctioned for all these projects. Out of additional CSR fund of ₹ 125 Crores, the CSR projects about ₹ 50 Crores have been planned and being implemented. In addition to the ongoing CSR projects, implementation of three projects namely 'ASAN' for supporting Specially Abled Persons by providing 'Assistive Devices', School Sanitation project as part of 'Swachh Bharat Abhiyan' and Drinking water project by providing BARC developed water filters to the families were also taken up.

The project 'ASAN' is for persons living at villages within 16 KM radius of nuclear power stations and projects at fourteen locations. This is in



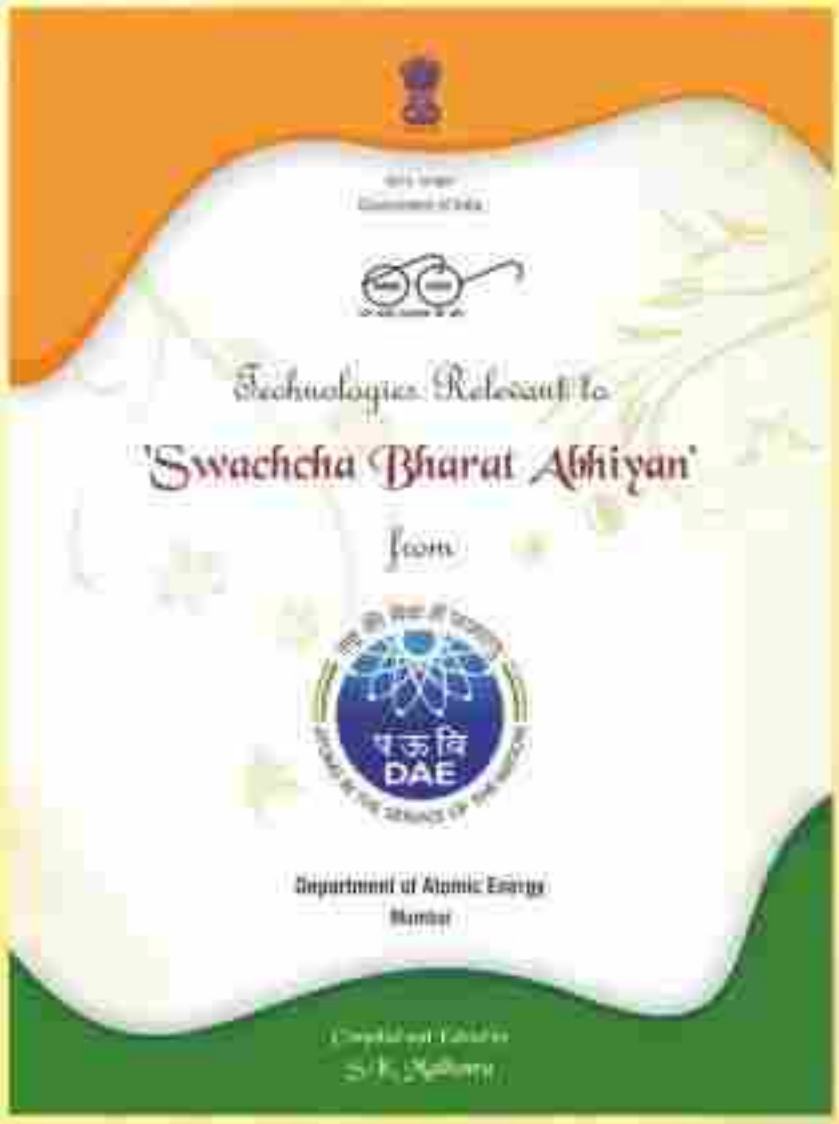
Skill Development Programme on Tailoring

participation with Artificial Limb Manufacturing Corporation of India. For this project, assessment camps were completed and Distribution Camps are expected to be completed by the end of this financial year.

Under School Sanitation project, construction work was in progress for 92 toilet facilities and 11 urinal facilities in different schools. For the purpose of providing drinking water, BARC developed water filters are planned to be distributed to families living at villages within 5 km radius of NPCIL Stations and Projects. Artificial reef structures were deployed in the sea at a distance of about 4 to 5 nautical miles and at a depth of about 50 to 60 meters at MAPS, Kalpakkam.

Swachcha Bharat Mission

The Department of Atomic Energy and its constituent units organized collective cleaning programme on 2nd October, 2015 on the eve of 150th Birth Anniversary of Father of the Nation, Mahatma Gandhi under the "Swachcha Bharat Mission" along with Swachchata Shapath called by the Prime Minister's Office.



A series of seminars on 'DAE technologies relevant to Swachcha Bharat Abhiyan' have been started. First such seminar in the series was held at Gujrat Technological University, Ahmedabad. A publication with details of such technologies has also been brought out.

RIGHT TO INFORMATION ACT (RTI) COMPLIANCE

The Right to Information Act of Government of India has been implemented at DAE and all its constituent units.

DAE received 907 RTI applications out of which 881 were answered and out of 63 appeals received 61 appeals were disposed.

BARC RTI Cell received 349 RTI requests and proactive disclosure was done to the extent possible. The provisions contained in RTI Act 2005 were fully complied with at IGCAR. Suo Motu disclosure under Section 4 of RTI Act 2005 and updated information were uploaded in the website. During the year, 69 applications were received, 3 applications were transferred to other PIOs. Information was provided to all the remaining applicants.

An elaborate mechanism exists at NPCIL with 7 Central Public Information Officers and 7 Assistant Public Information Officers, one at each site. One Central Public Information Officer, one Assistant Central Public Information Officer and one Appellate Authority at Headquarters. RTI computerised management system has been developed in-house and implemented for effective disposal of RTI applications and appeals in timely manner in NPCIL.

The mandatory information required under the Act [section 4(1) (b)] has been posted on NPCIL website and the information was updated as required. Presentations & lectures were organised in NPCIL for creating awareness about the importance and ways to implement the Act. During the financial year, 950 RTI applications and 135 appeals were received under the RTI Act, 2005 and were disposed.

RTI related issues were dealt efficiently at AMD. A total of 178 RTI applications were received, out of which 172 replied, 5 transferred, 1 rejected, 28 first and 7 second appeals are received and attended 2 CIC hearing on second appeal. IREL received 146 RTI queries during the year and 152 RTI queries were replied. The Tata Memorial Centre received 100 RTI queries and 13 appeals which were replied within the stipulated time period. SINP received 45 applications of which 44 were replied and out of the 3 appeals 2 were replied. NBHM received 4 RTI queries and they were all answered during the report period.

AWARDS & PRIZES

NPCIL and its various sites won several awards in area of stations safety and performance, Public Outreach Activities, Corporate Social Responsibility and Official Language.

NPCIL headquarters was felicitated with special award for "Excellence for Implementation of the Official Language" for the year 2013-14 on 31st October, 2014 in 23rd Ashirwad Rajbhasha Puraskar Samaroh by Ashirwad Sansthan, an NGO committed for propagation of the Official Language in Mumbai since 1967. Urjaswi, the house-magazine of NPCIL headquarters was awarded Second Prize for the year 2013-14 by PSU TOLIC. NPCIL headquarters was honoured with Rajbhasha Shield of DAE for the year 2013 for its excellence in implementation of Official Language Policy of Govt. of India.

AMD was conferred with various awards such as Homi Bhabha Science and Technology Award – 2013, Outstanding Service Award-2013, Outstanding Achievement Award - 2013, DAE Group Achievement Award - 2013, Journal Geological Society of India (JGSI) Radhakrishna Prize – 2013 and Dr. G.R.Udas-Dr.K.K.Dwivedi Medal - 2014 to their officials.

BARC received an IAEA award for outstanding contributions in mutation breeding for crop improvement.

Various Heavy Water Plants of HWB won a variety of awards on safety, environment management and indigenous development.

Chairman & Managing Director, ECIL was

selected as the "Electronics Man of the Year" by the Electronics Industries Association (ELCINA). ECIL received the Industrial Excellence Award for the year for the year 2013 from the Indian Nuclear Society. The company's Quality Circle LAKSHYA won the Gold Award from the Quality Circle Forum of India.

During the year, UCIL received many accolades for its outstanding activities in different domains which included the "Best in CSR & Sustainability Award" among 'other PSUs' by India Today Group; "Most Eco-Friendly Award" among 'other PSUs' by India Today Group; "Dr. J. Coggin Brown Award-2014" to C&MD UCIL by Mining, Geological and Metallurgical Institute of India (MGMI); "Distinguished Alumnus Award -2014" to C&MD UCIL by IIT Kharagpur; "Greentech HR Gold Award for outstanding achievement in Technology excellence in HR"; "Engineering Excellence Award 2014" by Engineering Watch magazine for remote monitoring of noxious gases and automated control of ventilation fan at UCIL Turamdih underground mines; "Aqua Foundation's Excellence Award" for 'Outstanding Contribution towards cause of sustainability, Public Sector' and "Skoch Order of Merit" for 'Corporate Social Responsibility for qualifying in India's Best Projects – 2014'.

At HRI, Shri S. D. Adhikari was awarded the M K Singhal Memorial Award by the Indian Science Congress Association. B. Ramakrishnan was elected as a fellow of National Academy of Sciences, India (Allahabad). Ashoke Sen received the Dirac medal of the International Centre for Theoretical Physics (ICTP, Trieste, Italy) and M. P. Birla Golden jubilee award. R. Gopakumar was the recipient of the TWAS physics prize (TWAS, Trieste) and G.D. Birla award. Aditi Sen De received the Butti Foundation Award of the Indian Physics Association. Raj Gandhi was awarded the Intensify Frontier Fellowship of Fermilab (USA). Sudhakar Panda was elected as a fellow of the Indian National Science Academy (New Delhi) while R. Gopakumar and A.K. Pati were elected as fellows of National Academy of Sciences, India (Allahabad).

CHAPTER-1

NUCLEAR POWER PROGRAMME STAGE-I



Kudankulam Nuclear Power Project (KKNPP)-1&2: Plant view

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

Nuclear Power Corporation of India Ltd. (NPCIL), a public sector undertaking of DAE and dividend paying company with AAA credit rating by CRISIL and CARE is responsible for design, construction, commissioning and operation of nuclear power reactor. 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. Of these reactors, the Kudankulam Nuclear Power Project-1 (KKNPP-1) of 1000 MWe commenced commercial operation from December 31, 2014. The second unit KKNPP-2 is also in advanced stage of commissioning. First pair of indigenously designed 700 MWe Pressurised Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat followed by second pair at Rawatbhata in Rajasthan are under construction. NPCIL, in all its endeavors, is committed towards upgradation and 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 2014 NPCIL recorded highest ever generation of 37146 MUs (including 2984 MUs infirm power from KKNPP-1) which was 10% higher than the last year's generation of 33673 MUs (including 364 MUs infirm power from KKNPP-1). During the financial year 2014-15 NPCIL recorded generation of 27284 MUs till December 31, 2014 (including 2243 MUs infirm power generation from KKNPP-1) and it is expected to reach about 37000 MUs by end of Financial Year 2014-15. In the previous financial year 2013-14, the total electricity generation was 35333 MUs including 1106 MUs infirm power from KKNPP-1.

During the year RAPS-5 recorded continuous run of 765 days which is best in Asia and second best in the world. In addition KGS-1, KGS-2, KAPS-2 & MAPS-2 also achieved continuous run of more than a year. So far, this feat has been achieved 17 times by various reactors operated by NPCIL.

The overall plant load factor (PLF) and Availability Factor (AF) for all the reactors in operation

Capacity Factors of Operating Reactors (FY 2014-15 till Dec. 2014)



Continuous Run (for more than one year) of NPCIL's Reactors





Glimpse of occasion of RAPS-5 continuous run of 765 days. At the center Dr. R.K. Sinha, Secretary DAE and Shri K. K. Pandit, CMD, NPCIL

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were 81% and 89% respectively till December 31, 2014 in the financial year 2014-15.

Twelve reactors with installed capacity of 3280 MWe are under IAEA safeguards and operating on imported fuel. Out of these, KKNPP-1, 1000 MWe LWR commenced commercial operation from December 31, 2014. As per separation plan, NAPS-1&2, has also been notified under IAEA safeguard from December 2014. Eight reactors with installed capacity 2400 MWe are under AERB safeguards and operating on domestic fuel. PHWRs on domestic fuel continued to operate at power level matching fuel supply.

Projects under Commissioning

Kudankulam Nuclear Power Project (KKNPP) Unit-1&2 (2x1000 MWe)

Kudankulam Nuclear Power Project, located in Tirunelveli District of Tamilnadu, is being implemented with Technical Co-operation from Russian Federation within the framework of the Inter-Governmental Agreement signed between USSR and India. The power generated from the project (2x1000 MWe) is being fed to Tamilnadu and other beneficiary states in the southern grid.

The Unit-1 of KKNPP has been declared in commercial operation from 00:00 hrs of December 31, 2014. It has generated 3,348 MUs infirm power and 24 MUs commercial power up to December 31, 2014 since its first synchronization to the grid in October 2013.

In Unit-2, all the construction and equipment erection were almost completed and commissioning of the systems was in advanced stage. Important commissioning milestone "Hydro test and Circular Flushing of Primary Circuit" was achieved in July 2014. Subsequent to hydro test, first inspection of primary circuit equipment and pipelines was completed. Spray test of Sprinkler System, Control & Protection System Absorber Rods (CPSAR) drives test, EMergency Load TRansfer Test (EMTR) of reliable Diesel Generators etc. were completed. All the 6 kV and 380 V power supply buses are charged and are in service. Main Control Room (MCR) is operational. Commissioning of turbo generator and its auxiliary systems are in progress. HV test of generator is completed. Commissioning of other systems like fire protection systems, ventilation systems, sea water systems, reactor auxiliary systems, DG systems etc. are in advanced stage. The application for clearance of Hot Run is currently under review by AERB. The overall physical progress of the Unit-2 up to December 31, 2014 was 97.65%. The Unit is expected to be completed in 2015-16.

Projects under Construction

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

Kakrapar Atomic Power Project 3&4 is India first indigenously designed Pressurized Heavy Water Reactors of 700 MWe series. Civil work for Nuclear Building, Control Building (CB), other auxiliary and common buildings have almost been completed. The finishing activities are also in different stages of completion for all Unit-3 and common buildings. The works related to Inner Containment (IC) dome of Reactor Building-3 have been started. Piping, mechanical, electrical, ventilation and instrumentation works are progressing on multiple fronts in Unit-3 and common buildings.

After exhaustive appraisal of construction activities by the regulators "Major Equipment Erection clearance" was given by AERB on 26th May 2014 subsequent to which project critical path activity related to the reactor core i.e. End shield, Calandria erection and welding works were completed successfully and preparation of Calandria tube installation for Unit-3 was in progress.



Kakrapar Atomic Power Project (KAPP)-3&4: Main plant view

In Reactor building-4, all major floors including slab at El 115 M were completed and work fronts have been released for piping, mechanical, electrical and instrumentation activities. FM Vaults & Calandria Vault have been released for Reactor erection activities.

Construction of Turbine Generator Deck for both the units have been completed. By March, 2015 operating floor of Turbine Building is planned to be released for Turbine Generator installation work.

Several equipment/components such as Headers, Primary Coolant Pumps (PCP), PCP motors, Moisture Separator Heater, Emergency Core Cooling System, Pump motors, centrifugal pumps, Sealing and Shielding plugs, End-fittings, Liner tubes, Journal rings, etc. have been delivered to site.

Piping works in Common Services System and Primary Piping Package are in progress on all fronts and nearly 70% pipe fabrication & 55% Pipe erection for common services are completed. Simultaneously, equipment erection has also been taken up.

Both main buses in 220 kV switchyard have been successfully charged. In 400 kV switch yard tower & structure erection works are completed and equipment erection work is in progress. In main plant electrical works, major items like Diesel Generator sets, start-up transformer, 6.6 kV switchgear, 415 V switchgear, 220 V DC system have been installed and are under commissioning. Further, cable tray installation, conduit installation and lighting works are nearing completion on priority routes. Manufacturing and progressive delivery of various equipment/components are in progress.

The KAPP-3&4 achieved an overall physical progress of about 64% as on December, 2014 and the project is expected to be completed in 2017-18. However, delay in supply of some major /critical equipment like Steam Generators, Reactor Headers, End-shields, Primary piping balance equipment components, Pressuriser, Passive Decay Heat Removal System (PDHRS) tanks etc. is impacting the project schedule and further delay may have further impact on overall project schedule.

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

At RAPP, the civil works are progressing on multiple fronts. In Reactor Building-7, Inner Containment (IC) wall has been constructed up to 126.7m elevation and 109M Elevation floor slab has also been constructed. In Reactor Auxiliary Building-7 (RAB-7) which is an integral part of Nuclear Building, construction of peripheral walls and slabs at 95M & 100M Elevations is in progressive stage of completion. Ball filling has been completed in both End Shields of unit-7 and are ready for erection. Major equipment erection clearance is under reviewing by AERB.



Rajasthan Atomic Power Project (RAPP)-7&8: Main plant view

In Unit-8, concreting of Calandria Vault up to 5th lift (out of 6) and IC Wall upto101.7M Elevation has been completed. In control building, construction of Unit-7 side 100M Elevation slab has been completed and work for other slabs at 106M& 111M Elevations is progressing. Construction of Waste Management Plant, Fire Water Pump House, Plant Water Pump House and DM Water Plant also progressed in parallel.

In Turbine building-7, construction of columns of TG deck on which Turbine & Generator are erected, has been completed up to 106M Elevation. Construction of other structures of Turbine building-7 like Electrical Bay, Pipe & Cable Bridge and Access Bridge was in progress. Construction of Turbine building-8 TG deck columns& Electrical Bay was also in progress.

Erection of equipment related to Common Service System like Chillers, Compressors & Pumps has been completed in Control Building basement

and erection of associated piping has started in Control Building & RAB-7 basements. DG Fuel Oil Storage Tanks were erected in the Diesel Oil Storage Area of Unit-7.

All construction works of 220 kV switchyard was completed and the switchyard is energized. Civil work and erection of equipment structures in 400 kV switchyard also progressed well.

Major equipment's like Calandria, End Shields, Moderator Pumps, Primary Coolant Pumps, Shutdown Cooling Pumps, Startup Transformer (SUT), Diesel Generators, Chillers, Calandria Tubes, Coolant Tubes etc. have been received at site.

The RAPP-7&8 achieved an overall physical progress of about 47% as on December, 2014 and the project is expected to be completed in 2018-19. However, delay in supply of some major/critical equipment like Steam Generators, Reactor Headers, End-shields, Primary piping balance equipment components, Pressuriser, Passive Decay Heat Removal System (PDHRS) tanks etc. is impacting the project schedule and further delay may have further impact on overall project schedule.

New Projects

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

The 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 the 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.

Government Administrative approval and financial sanction of the project exists. General Frame Work Agreement (GFA) for setting up of KKNPP Units-3&4 has been signed with M/s. Atomstroyexport (ASE) and made effective. First supply contract for implementation of the project i.e. "Supply of Long Manufacturing Cycle equipment & First Priority Equipment" has been signed in December 2014.

First priority design activities are in advance stage (86%) for which a contract is already signed with M/s. Atomstroyexport (ASE). The first priority works include design of hydro-technical structures, changes of Units-3&4 with respect to Units-1&2, layout finalization, interface documents, excavation drawings and raft foundation drawings for main plant etc. which are essential to take up the First Pour of Concrete (FPC).

Application for excavation consent has been submitted to AERB and it is under review. Clearance for Consent to Establish from TNPCB has been obtained.

Tendering is in progress for main plant pit excavation, consolidation grouting and confirmatory soil investigation; design, construction and maintenance of temporary dyke and construction of multistoried residential quarters at Anu-vijay Township.

Construction of project office complex, approach road, sewerage treatment plant, compound wall along the sea shore and at the entrance of KKNPP site, fire and industrial safety complex with first aid facility, electrical infrastructural works are under progress.

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

Government Administrative approval and financial sanction of the project exist. Environmental clearance from Ministry of Environment and Forest (MoEF) has been obtained for project plant site. Clearance from the wildlife angle for the township land is awaited. Haryana State Pollution Control Board has granted consent in October, 2014 to establish GHAVP. Report for siting clearance has been prepared and submitted to AERB and it is under review. Issue of eviction of 11 families (landowners of 28.5 acres of land) who have not accepted compensation and moved the court against the land acquisition is on hold for siting consent for the project from AERB. Application for excavation consent has been submitted to AERB. Review of technical assignment Part-I is opened and technical evaluation is in progress for long delivery equipment like End-Shields, Calandria, Steam Generators and Reactor Headers. However, issues raised by vendors related

to Civil Liability for Nuclear Damage (CLND) Act clauses need to be resolved.

Technical sanction for main plant civil works has been prepared and it is under approval. Tender document for main plant civil works is under preparation. Property fencing has been completed. Topographical survey has been completed. Geotechnical investigations are in advanced stage of completion. Work order for Social Impact Assessment (SIA) in villages within 5 km radius around the plant site is placed on Tata Institute of Social Sciences, Mumbai. Field survey has been completed and preliminary report is finalized.

Scheduled first pour of concrete as per financial sanction is in June 2015. However, there could be some delay in commencement of construction of the project due to issues related to CLND, delay in eviction of 11 families (landowners of 28.5 acres of land) and delay in clearance from the wildlife angle for the township land etc.

Jaitapur Nuclear Power Project (JNPP) Units-1&2 (2x1650 MWe LWRs)

The reactors proposed to be set up are Evolutionary Pressurized water Reactor (EPRs) in technical co-operation with France in phases of 2x1650 MWe. Techno commercial negotiation to evolve an appropriate business model for implementation of the project is currently under progress. Review of Technical assignment Part-I by working group is completed and observation has been forwarded to M/s AREVA. Review of Technical assignment Part-II is in progress. An application for siting consent is submitted to AERB and it is under review.

Construction of site office cum core storage, Concrete Testing Laboratory at JNPP plant site, Liaison office complex at Ratnagiri, Boundary wall of plant site towards land side, Boundary fencing toward sea side and Meteorological Laboratory building at JNPP plant site is completed. Asphalting of approach road is completed. Work is completed for on shore geo-technical investigations. Plantation of 1000 trees is completed.

New Sites

Land acquisition, Environmental studies, Public outreach activities, Site studies to the extent possible etc. are going on at new sites namely Chutka and Bhimpur in Madhya Pradesh, Mahi Banswara in Rajasthan, Mithi Virdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga 5&6 in Karnatka and Haripur in West Bengal.

Section-9 notification has been issued by State Govt. authorities for Chutka site in Madhya Pradesh and Mahi Banswara site in Rajasthan. Public hearing was organized at Chutka on February 17, 2014. Section-11 award is in advanced stage of issue for Chutka. NPCIL has to make a fresh application for acquisition of project land at Mithi Virdi in Gujarat and Kovvada in Andhra Pradesh as per the new RFCTLARR Act, 2013. Pre-project activities like Public outreach activities are going on at other new sites at Bhimpur in Madhya Pradesh, Kaiga 5&6 in Karnataka, Mithi Virdi in Gujarat and Haripur in West Bengal. For Mithi Virdi site, Preliminary Contract (Early Works Agreement) for Technical Feasibility Study for AP 1000 reactors was signed on September 27, 2013 and the work is progressing as per defined milestones.

Quality Assurance

Quality Assurance / Surveillance activities were carried out expeditiously for projects and stations by NPCIL. Pre-service inspection of KKNPP Unit-2 has been taken up. Corporate QA audits of KAPP-3&4 and RAPP-7&8 projects 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. Directorate of Engineering, Directorate of Quality Assurance, Directorate of Procurement, Directorate of Reactor Safety & Analysis, Directorate of Health, Safety & Environment and Directorate of HR (Knowledge Management functions) are ISO: 9001 certified. Surveillance Audits of these directorates by the certifying body have been successfully completed.

CHAPTER-1

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.

During the year, HWB emerged as the largest global producer and a trusted supplier of Heavy Water. Realizing the large potential for non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology areas, HWB also nurturred R&D activities in this area.

Performance of the Board during the year was very good with respect to heavy water production, specific energy consumption and safety & environment performance. Despite shutdown of HWP, Kota in June 2014 due to partial breakdown of cooling tower structure and non-availability of feed gas in required quantity and quality for the NH3-H2 based plants, HWB surpassed the targeted production during the period.

The Heavy Water Board achieved more than 104% of targeted production for the financial year 2014-15 and the specific energy consumption was more than 28 GJ/Kg.



Specific Energy Consumption(GJ/KG) of Heavy Water Plants during 2014-15

Heavy water from research reactors has been upgraded and dispatched to the user. System has been installed for testing, performance evaluation and integration of ion exchange cartridges for product conductivity improvement.



Upgradation plant



Structured packing module

About 70 structured packing modules for 1.05m dia upgrading column sections of RAPS-7&8 have been fabricated.

Following are the highlights of performance of the various Heavy Water Plants:

Heavy Water Plant, Manuguru

The performance of HWP, Manuguru during the year 2014-15 was excellent achieving 102.6% of

target production and on stream factor close to 1.0. Throughout the period, system gas purity was consistently maintained at around 99.3 % and average system gas pressure at 19.3 kg/cm^2.

The smooth operation of Auxiliary Steam Turbo Generator (TG-4) and installation & commissioning of Variable Frequency Drives (VFDs) reduced the power consumption, enabling export of surplus power @ 10 MW totaling 59.224 MU as per the agreement with PTC. This resulted in substantial revenue receipts.

For utilisation of waste heat/low grade heat to generate refrigeration, Hot Water Vapor Absorption Refrigeration machines are being procured and trial run of its Mist Cooling System (MCS) made progress.

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

As an initiative towards utilization of renewable energy resources and also to meet mandatory requirement of Renewable Power Purchase Obligation (RPPO), a 12 MW Solar Photo Voltaic Power Plant is being set up at HWP, Manuguru. Site Clearance was completed and the civil works and equipment deliveries were under progress.

Boron Enrichment Plant for production of Enriched Boric Acid and Elemental Boron Plant to convert KBF4 into elemental boron were in operation on sustained basis. A facility for converting elemental Boron to Boron Carbide pellets was commissioned successfully with trial production of natural and enriched Boron Carbide pellets of desired quality.

Heavy Water Plant, Kota

Performance of the plant was affected in June 2014 when full plant shut down was taken due to partial breakdown of cooling tower. After due assessment it was decided to go for partial replacement of cooling tower by adopting Pultruded FRP, counter current flow type system. After successful commissioning of cooling tower, plant was re-started in November 2014 and it is operating normally since then.

Heavy Water Plant, Hazira

HWP, Hazira achieved the targeted production during the period of report, despite low load operation of the plant due to restricted feed synthesis gas supply from only one ammonia plant of M/s KRIBHO. This was achieved mainly due to increase in deuterium concentration of feed gas by provision made to selectively enrich synthesis gas from one of the ammonia plants in Deuterium by partially diverting rich condensate from other ammonia plant.

Heavy Water Plant, Thal

During the year, the performance of the plant with regard to production and specific energy consumption was satisfactory in spite of intermittent CO2 ingress in feed gas from connected Ammonia Plant of M/s. RCF. The adverse effect was mainly controlled by effective monitoring, load reduction, isolation from respective Ammonia Plant, frequent changeover of purifiers and filters, periodic bleeding of impurities, and water washing of exchange towers.

As a step towards energy conservation, Variable Frequency Drive (VFD) was installed for ammonia reflux pump. An exclusive line to help quick regeneration of purifier and satisfactory performance of additional air pre-heater installed in Cracker-B to recover waste heat from flue gas thereby reducing natural gas consumption were the highlights.

Heavy Water Plant, Baroda

The Tributyl Phosphate Plant (TBP) and the Potassium Metal Plant achieved the targeted production during the period. To improve the performance of ETP for the TBP plant, a system was developed for the recovery of costly Butanol from the effluent. The existing column was modified for processing effluent with indirect heating in Multiple Effect Evaporator (MEE). The recovered Butanol was re-cycled after purification. POCL3 drum unloading system was improved by incorporating fume extractor and thus reducing the personal exposure during connecting / disconnecting the unloading pipe.

For production of Sodium metal, a new 2000Amp cell have been fabricated & installed for

further trials. The operation of Eutectic Melter is being established for preparation of fused eutectic and inventory build required for the operation of 2000Amp cell.

Actions were taken to set up an industrial facility for production of sodium metal with 600 MT/annum capacity at HWP Baroda. Applications have been submitted to AERB for siting clearance as well as to GPCB for consent to establish.

Heavy Water Plant, Tuticorin

In the Versatile Solvent Synthesis Pilot Plant (VSSP) at HWP, Tuticorin, synthesis campaigns of D2EHPA–II and TiAP were taken up and necessary engineering data were collected, analysed and accordingly basic engineering was done for industrial level production of these products.

In the solvent extraction test facility, campaigns were taken up for extraction study of rare materials from Phosphoric acid along with various solvent mixtures. Also, conversion of Sodium Uranyl Tricarbonate (SUT) into Sodium Di Uranate (SDU) yellow cake was achieved.

A laboratory method was identified successfully to reprocess the waste intermediate (2-ethylhexyl chloride) produced during D2EHPA production.

HWB is setting up a Solvent Production Plant (SPP) at HWP, Tuticorin for production of special solvents required by various units of DAE for sustaining nuclear fuel cycle of Nuclear Power Plants (NPP). The basic engineering documents for this SPP facility is under preparation. Application for environmental clearance from MoEF and establishment clearance from State Pollution Control Board has been initiated.

Heavy Water Plant, Talcher

At HWP, Talcher, the production facilities for D2EHPA and TBP were operated continuously to meet the target production. In TBP facility, reduction of effluent generation was achieved by a new step of reusing reject water from Butanol Distillation Unit for preparation of alkali solution. Previously, this reject water, which contains slight amount of butanol, was sent for treatment in effluent treatment plant.

Integrated Effluent Treatment Plant (IETP) was operated for treatment of effluents generated from R&D pilot plant being utilized for Synthesis of TOPO, TBP and VSPP facility. Solid cake generated from this treatment plant was disposed of through external agency.

A special solvent, Tri-Octyl Phjosphine Oxide (TOPO) was synthesized in batch mode and part of the product was dispatched to NFC, Hyderabad.

Boron Enrichment Facility at HWP, Talcher was operated continuously to achieve the production targeted for the year. Chemical conversion of enriched BF3-Ether complex to KBF4 was carried out in the KBF4 conversion unit and the product was sent to HWP, Manuguru for producing elemental Boron.

The Technology Demonstration Plant (TDP) at Mumbai for SX technology demonstration achieved intended deliverables. TDP is operational and process development and energy optimization are in progress. The facility is providing vital process and technological inputs which will go a long way in achieving efficient configuration of industrial scale facilities.

Mineral Exploration

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

During the Annual Programme of work 2013-14, an integrated multi-disciplinary approach has been adopted for uranium exploration with substantial inputs of radiometric, geological, ground and heliborne geophysical, geochemical surveys and drilling, which resulted in augmentation of reserve by 16,537 tonnes of Uranium Oxide U3O8

making the XII total to 39,148 tonnes and the country's total Uranium reserve to 2, 14,158 tonnes of Uranium Oxide.

Uranium investigations were continued at AMD in the thrust areas for unconformity related, carbonate related, metamorphite, QPC, metasomatite types in Proterozoic basins; sandstone and calcrete types of uranium mineralisation in Phanerozoic basins.

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

The laboratories at AMD Headquarter and in Regional Headquarters are equipped with state-of-the-art instruments and every effort was made to use their full capacity. All laboratories of AMD contributed wholeheartedly by providing speedy analytical support.



Clean laboratory of Chemistry Group, Hyderabad



Multi para logger designed, developed and fabricated by Instrumentation Group, Hyderabad

Some of the significant achievements are summarized below:

Uranium Investigations

Ground radiometric surveys

Reconnaissance (5,779 sq km) and detailed (281.55 sq km) surveys helped in locating following promising new uranium anomalies/extension of known occurrences in the following geological environs:

Vempalle Formation, Kadapa district, Andhra Pradesh: Impure dolostone near Nandimandalam.

Narendranagar Syncline, Tehri-Garhwal district, Uttarakhand: Phosphatic black shale along Narendranagar-Kaligaon-Shivpuri tract.



A view of Nandimandalam hill, Kadapa district, Andhra Pradesh



Kroi-Tal Contact along the southern limb of Garhwal synclinm at Narendranagar, Tehri-Garhwal district, Uttarakhand

Delhi Supergroup, Sikar district, Rajasthan: Cal silicate rock at Hasanpura.

Chilpi Group, Kawardha district, Chhattisgarh: Dark grey igneous calcareous rock at Pipradhar.

Gondwana Formation, Sundergarh district, Odisha: Barakar sandstone at Telandih.

Geochemical Surveys

Geochemical surveys carried out over 2,720 sq. km. have indicated upto 322 ppb Uranium in 840 water samples collected along Khemsar-Tosham-Hansi tract, Churu and Jhunjhunu districts, Rajasthan. Two N-S and NW-SE trending hydro-geochemical anomalies (U >90 ppb) have been delineated along the intersection of Kantli and Saraswati river paleo-channels. Magnesian calcretes of Inderpura and Melusar have been analysed upto 24 ppm and 20 ppm Uranium, respectively.

Ground Geophysical surveys

Ground geophysical surveys of about 288 sq. km. were carried out. Conducting zones associated with the fault/fractures and faulted contact of basic volcanic rocks with meta-sediments have been deciphered in Matri-Raigarh area, Balod district, Chhattisgarh. N-S trending parallel conductors over a strike-length of 2.0-2.5 km have been delineated in Rambas-Dhancholi-Gorir sector, Mahendragarh district, Haryana and Jhunjhunu district, Rajasthan. High chargeability zones were identified in Guman Singh Ki Dhani and Karoi, Sikar district, Rajasthan.

Airborne survey and Remote Sensing

Heliborne geophysical survey was carried out over 11,355.50 line km in parts of Chhattisgarh basin. Processing and interpretation of data is in progress. A circular conductor surrounded by magnetic body at a depth of 220-370m at Chirudih-Paniada in North Singhbhum Shear Zone has been delineated by integrated studies. Ground validation of heliborne geophysical target zones has also been carried out in Karoli-Nerach-Ghasiar and Madal-Nora-Nayakhera-Kaya sectors in parts of Aravalli Fold Belt.

Exploration by Drilling

A total of 1,76,654.85m (Departmental drilling: 82,654.95m and Contract drilling: 93,999.90m) drilling was carried out to establish (a) additional uranium reserves in the known deposits/occurrences and (b) sub-surface continuity of mineralisation in the new promising areas.

The drilling has established significant co-relatable uranium mineralised intercepts / bands as listed below:

Tummalapalle, Kadapa district, Andhra Pradesh: In hangwall and footwall at Tummalapalle Block-I, Tummalapalle Block-II, Tummalapalle Block-II Deeper (500-800m), Kanampalle, Rachakuntapalle, Motunutalapalle and Gidankivaripalle blocks in Vempalle dolostone.

Chenchu colony and Dwarkapuri, Guntur district, Andhra Pradesh: Along unconformity between Banganapalle quartzite and basement granite and within the Banganapalle quartzite.

Rohil and its surrounding, Sikar district, Rajasthan: In albitite zones at Rohil Central and North blocks, Gumansingh Ki dhani, Narsingpuri and Jahaz areas.



A view of Wahkut exploration block from Kulung, West Khasi hills, Meghalaya



AMD drilling unit crew under operation in Koppunuru sector, Guntur district, Andhra Pradesh

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

Kanchankayi, Yadgir district, Karnataka: associated to limestone, in a similar geological setup as that of Gogi uranium deposit.

Devri, Surguja district, Chhattisgarh: Associated with brecciated granite, grey granitic and granite-gneisses 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 above, the following potential/significant blocks are also identified through sub-surface exploration included Gorir-Ilakher, Jhunjhunu district and Karoi, Maota, Narsingpuri, Sikar district, Rajasthan; Rambas, Golwa-Gangutane, Mahendragarh district, Haryana; Loarkha, Dehradun and Tehri-Garhwal districts, Uttarakhand; Pakkanadu & Rasimalai, Vellore district, Tamil Nadu; Beldih- Bhawanipur, Purulia district, West Bengal; Sie Rimi-Dupu-Maro-Barirzo, West Siang district, Arunanchal Pradesh and Dwarkapuri, Guntur district, Andhra Pradesh.

Exploratory Mining

Uranium Resources

AMD has established an additional reserve of 16,537t uranium oxide (U_3O_8) as detailed below:

- 11,136t U_3O_8 established in Tummalapalle and its extensions, Kadapa district, Andhra Pradesh.
- 321t U_3O_8 in Wahkut and 110t U_3O_8 in Umthongkut, West Khasi Hills district, Meghalaya.
- 2,150t U_3O_8 at Banadungri-Singridungri, 932t U_3O_8 at Narwapahar deeper, 1,338t U_3O_8 at Jaduguda and 550t U_3O_8 at Bhatin, East Singhbhum district, Jharkhand.

The country's uranium reserve have been updated to 2,14,158t of U_3O_8 as on 31.10.2014.

Rare metal and rare earths investigations

Reconnaissance (1,302 sq km) and detailed (3.55 sq km) surveys were carried out for location and evaluation of columbite-tantalite and beryl in pegmatites of Karnataka, Odisha, and Chhattisgarh. Additional reserves of 3,867 kg of columbite-tantalite



Xenotime Crystals at Siri River, Jeypur district, Chhattisgarh



Columbite -Tantalite Crystal within pegmatite, Marlagalla area, Mandya district, Karnataka

are estimated in pegmatites at Allapatna-Marlagalla, Mandya district, Karnataka; Domapara, Bastar district, Chhattisgarh and Jangapara, Jharsuguda district, Odisha.

The production of columbite-tantalite (4,250kg), beryl (2,650 kg) as by-product and xenotime concentrate (7,500 kg) was achieved in the field units of Pandikimal and Jangapara unit, Jharsuguda district, Odisha; Bodenar, Bastar district, Chhattisgarh; Marlagalla, Mandya district, Karnataka and Siri River, Jashpur district, Chhattisgarh.

Beach Sand and Offshore Investigations

Surveys (Reconnaissance- 302.62 sq km and detailed- 14.45 sq km) and exploration (drilling, sampling and evaluation) were continued along the coastal tracts of Andhra Pradesh, West Bengal, Odisha, Karnataka and Tamil Nadu to establish additional beach sand heavy mineral resources.

Exploration/Evaluation

Total 1,993 boreholes with a cumulative depth of 12,729m are drilled in a grid pattern and 9,380 individual and 59 bulk samples have been generated. Composite samples are processed for resource evaluation and bulk samples for separation of monazite and zircon.

Potential heavy mineral zones were delineated at Bajrakot-Brahmapur (0.67-56.27%) and Patisonapuram-Agastinuagan (3.09-57.31%), Ganjam district, Odisha; Kesanapalli-Karavaka (5-10%), East Godavari district, Andhra Pradesh and Vaipar-Gunder Rivers (5-15%), Ramanathapuram district, Tamil Nadu.



Heavy Mineral Concentration (HMC) in beach and frontal dune along Bajrakot-Brahmapur tract, 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 resources has crossed the 1,000 million tonnes (mt) mark and the total resources have been updated to 1,064.79 mt.

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 Earth Limited (IREL) is a Mini Ratna (Category-I) Company and it is engaged in mining and production of beach sand minerals and rare earth compounds. The minerals produced by IREL find use in the Nuclear Power Programme and wide ranging industrial applications. The minerals separated by IREL from the beach sand at its three units located at Chavara, Kerala; Manavalakurichi, Tamilnadu and Chatrapur, Odisha are ilmenite, rutile, leucoxene, zircon, monazite, sillimanite and garnet. IREL also produces uranium, thorium and rare earth compounds.

The overall performance of UCIL during the year 2013-14 was satisfying. First phase of surface exploration for extension of ore lenses in deeper levels of Jaduguda Mine beyond Tirukocha fault was completed by AMD. Twelve boreholes were drilled and assay results of eight boreholes gave positive indication of additional low grade lenses. Second phase of exploratory drilling will start soon.

A project for modernization of Bhatin Mine has been taken up for capacity augmentation. The details have been submitted to Standing Project Appraisal Committee (SPAC) and proposed to be included in additional schemes of the XIIth Plan.

Work on seven new projects were initiated towards strengthening the existing operations in Jharkhand and ongoing project at Tummalapalle. Details of all these projects grouped under "Debottlenecking Operations: Singhbhum and Tummalapalle" have been submitted to Standing Project Appraisal Committee (SPAC) and proposed to be included in additional schemes of the XIIth Plan.

Tummalapalle uranium project is readying for commissioning in 2015-16. The mine has achieved the desired ore production capacity and adequate ore has been stockpiled. Efforts at finding safe procedure for mining of Hang-Wall (HW) lode are in progress.

UCIL continued its spirited neighborhood development programme around its operating units in Singhbhum and Tummalapalle. In addition, drinking water supply and mobile medical camp around Gogi uranium project, infrastructure development around KP M project in Meghalaya etc. continued to generate goodwill towards uranium mining.

UCIL has proposed for restarting of exploratory mining at Gogi uranium Project. The same is under consideration of AMD. Proposal to start exploratory mining at Rohil in Rajasthan is also under consideration of AMD.

The mineral processing plant of IREL filed the following three international patents during the year:

- Development of a modified High Tension Roll Separator (HTRS) for electrostatic separation of minerals based on their electrical resistivity. An innovation incorporating a modification for achieving effective corona charging of mineral particles in a HTRS was developed and successfully implemented on plant scale. It provides a means for increasing the charge distribution on mineral particles, which results in higher recovery of conducting mineral, significant energy saving due to reduction in feed temperature and also enables separation of non-conducting minerals.
- Development of an improved Electrostatic Plate Separators (ESPS) for mineral separation based on difference in electrical resistivity & size of minerals. This invention incorporates a combination of corona charging and conductive induction charging in an ESPS by which the lifting of non-conducting particles is reduced by an order of magnitude, thus resulting in a cleaner conducting fraction. Higher recovery of fine conducting minerals and also effective separation of fine non-conducting minerals is achieved.
- Development of a method & equipment for separating non-conducting non-magnetic minerals. This invention involves the application of Fleming's Left Hand Rule for achieving separation of minerals based on differences in their electrical permittivity (i.e. dielectric constant) and specific gravity. This is the first time ever an equipment based on the above principle has been designed and tried successfully for beneficiation of minerals having similar electrical resistivity and magnetic susceptibility.

The above works have resulted in following significant achievements and benefits:

Premium grade Garnet production at OSCOM

A garnet plant for producing premium grade coarse garnet was successfully erected and commissioned in Orissa Sand Complex (OSCOM). The plant utilizes the modified HTRS to eliminate conducting as well as non-conducting impurities thereby producing 75 MT/day garnet of premium grade valued at ₹ 20 crores annually.

Process optimisation in Mineral Separation Plant (MSP) in OSCOM

Tapping of garnet concentrate middling stream of coronastat in primary circuit in MSP has resulted in enhancing the feed rate to the plant thereby increasing the production of all minerals in MSP by about 20%. Resultantly, highest ever monthly production (25530 MT total minerals) at OSCOM was achieved in Dec 2014. This additional production is valued at ₹ 36 crores annually.

25% reduction in specific consumption of power & furnace oil

On account of increased production of total minerals at OSCOM, the specific consumption of power & furnace oil has reduced by about 25%. This amounts to a saving of ₹ 11.5 crores annually.

Monazite up-gradation plant at Manavalakurichi and Chavara

Project for up-gradation of monazite at Manavalakurichi and Chavara using modified electrostatic separators and high tension roll separators was successfully completed. Resulting in the reduction of project cost by Rs 5.30 crores at Chavara and Rs 1.09 crores at Manavalakurichi due to elimination of procurement of RED and RERMS.

Online production of Leucoxene at IREL, Chavara

Separation of leucoxene from monazite is very challenging as their electrical and magnetic properties are similar. Repeated recycling has to be resorted to reduce monazite to acceptable levels of less than 0.25%. This problem was overcome by developing a flowsheet incorporating in-house modified and patented Electrostatic Plate Separator (ESPS) to produce leucoxene product containing TiO_2 more than 75% and monazite less than 0.25%. This flowsheet has been implemented on plant scale at IREL, Chavara during January 2015.

Xenotime production flowsheet

A flowsheet was successfully developed to separate xenotime from radioactive monazite thereby overcoming the most challenging problem of xenotime processing for recovery of strategic and precious heavy rare earths. The new process eliminates the need for processing xenotime and monazite synchronously.

The performance of the chemical plants at IREL during the year made following significant achievements:

Production of nuclear grade uranium at RED, Alwaye from uranium bearing metallic radioactive waste from BARC

Processing of uranium bearing metallic radioactive waste namely uranium slag disc obtained from BARC was successfully completed by adopting in-house developed process involving selective acid leaching in presence of H_2O_2 and solvent extraction operation. Subsequently, processing of copper clad uranium metallic tubes received from BARC has been undertaken successfully. Apart from ensuring continuous supply of nuclear grade uranium to BARC for operation of its nuclear reactor, IREL helped BARC in eliminating the requirement of long term storage of these radioactive wastes.

High Purity Rare Earth (HPRE) plant, RED

Design, erection and commissioning of HPRE plant at RED, Alwaye was successfully completed to produce high purity separated rare earths. Further, process optimisation for increase of solvent concentration to 1.5 M (from 1 M) to ensure higher loading of solvent and Rare earth refluxing to ensure reduction in number of stages and achieving better product quality has been carried out.

Rare Earth Metal making process

Process for Neodymium (Nd) metal production using induction furnace and Samarium (Sm) metal production using reduction diffusion furnace undertaken in BARC with high purity Nd fluoride and Sm oxide powders were produced at RED, Alwaye. Initial trials were successful. Process optimisation and scale-up are underway.

Value addition of Monazite - MoPP at OSCOM

Monazite Processing Plant (MoPP) erection and commissioning was completed. Mixed $ReCl_3$ of acceptable quality was produced. AERB safety recommendations have been implemented and regular production scale trials were successfully undertaken.

Value addition of ilmenite & zircon - high purity TiO_2, ZrO_2 and HfO_2

Based on in-house developed solvent extraction process using long chain primary amines a pilot plant was set up at OSCOM to produce high purity TiO_2 and ZrO_2. Further, flowsheet has been developed for production of nuclear grade ZrO_2 and HfO_2. Based on this experience, technology demonstration plant is being set-up.

Single-stage micro-channel based solvent extraction at total flow rate of 3 LPH was demonstrated using 6 parallel microbore tubes connected to an indigenously fabricated Monoblock Distributor with Integrated Microfluidic Junctions (MDIMJ) at BARC. Experiments conducted with uranium raffinate as the aqueous phase and 30% TBP in dodecane as solvent gave stage efficiency of 92% in contact time of about 5 sec. This study will be useful in designing a portable plant for multi-stage microscale extraction at total through put of the order of 10 LPH.



MDIMJ (left) and settler used with MDIMJ (right)

A phosphate precipitation based method to recover uranium from Tumalapalle ore carbonate leach liquor has been developed and tested with more than 99.95% recovery of uranium. The process was found to be effective and adoptable even for low concentration (less than 100ppm) of uranium in the solution.

Upgradation of Metal Reduction Technology & Effluent Handling (UMRT&EH) facility was commissioned for production of nuclear grade Aammonium Diuranate (ADU) from scrap generated during fuel fabrication for research reactors.

A simple and rapid method was developed for the simultaneous separation of U and Zr from U-Zr alloy using Di-(2-ethyl hexyl) phosphoric acid (HDEHP)-impregnated XAD resin to determine the trace and ultra-trace metallic constituents in the alloy by ICP-MS.

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 and titanium half alloy products for critical and strategic application in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

PHWR Fuel

NFC manufactured a record no. of PHWR fuel bundles and met the requirement of fuel bundles for all the PHWRs in time. All the indigenous raw material in the form of MDU/HTUP/SDU received from M/s UCIL was converted into 19 element and 37 element fuel bundles for meeting the requirement of the reactors that are out of IAEA safeguards.

NFC achieved highest ever production of around 865 MT of PHWR fuel bundles till December, 2014 and marched towards 1200 MT for the financial year 2014-15 which is expected to be highest ever production since the inception of NFC.

Modification and special works in fuel plants

Design, Fabrication and commissioning of Dissolution reactors

For the first time in the world, the low temperature oxidative dissolution of Imported Uranium Ore Concentrate (UOC) which is mainly U_3O_8 and UO_2 was carried out in newly designed dissolution reactor vessels which can hold pressure up to 4.5 Kg/cm^2. These new reactors helped in



New dissolution reactors

increasing the throughput up to 2.5 MT per day from present capacity of 1.5 MT per day. These reactors have design of body fitted flange type model.

Development of process flow sheet for Sodium Uranate (SU)

Sodium Uranate produced from alkali leaching contains carbonates and acid insolubles, which mainly resulted in crud formation with TBP due to stable complexes of Uranium. Uranium Oxide Plant has developed an innovative, simple and cost effective technique for processing of Sodium Uranate by introducing a novel reagent addition in dissolution process which inhibits formation of all strong stable complexes and thereby preventing the detrimental effect on the solvent during extraction. This technique was adopted at plant scale by NUOFP-O and successfully produced sinterable grade UO_2 powder through this route. This is a significant step as future mining operations of UCIL are going to produce raw material by this route.

Capacity Enhancement of Ammonium Uranate Batch Precipitation

After carrying out series of plant scale experiments, batch precipitation time was decreased to 2.5 hours from 8 hours which increased the production capacity by nearly four folds. This development has resulted in removal of few tanks and created additional space for future capacity augmentation purpose.

Development of process flow sheet for volume reduction of accumulated UNRC

Trials were conducted at pilot scale level to develop a process flow sheet for 'U' recovery and volume reduction of accumulated Uranyl Nitrate Raffinate cake (UNRC) in NFC. The cake was leached with 2N nitric acid to recover uranium followed by water wash and then calcination at 600°C. This modification has resulted in volume reduction by ten folds along with uranium recovery. This chemical change of the solid effluent paved the way for further recovery of uranium.

Integrated Spacer & Bearing pad welding machines

These machines are used for welding of appendages on the fuel tubes for manufacturing of PHWR fuel bundles. This machine is suitable for welding of any appendage (Spacer pad, Bearing pad) configuration for manufacturing of either 19 element or 37 element type PHWR fuel bundles. Two machines suitable to 19 element & 37 element (One each) were assembled and supplied to fuel assembly plants to meet the increased production targets. Modifications in the existing manual spacer pad welding unit to make it in par with the ISBUs with respect to Argon Shrouds and Clamps were carried out to increase the productivity.

Fully Automated 'MDU' powder samples collection unit

A fully automated 'MDU' powder sample collection unit based on Flexible Screw Conveying (F.S.C) concept was developed in-house. An experimental set-up based on F.S.C. technology with a screw inclination of 90° to the ground was fabricated and it was tested with various types of radioactive powders to be handled. All the results were fruitful and experimental set-up performance was satisfactory.

This automated unit is expected to collect 'MDU' powder samples from 'MDU' drums at a depth of about 600 mm from the top rim of the drum. Three Flexible Screw Conveyor units which are located at 120° spacing across the cross section of the drum will collect powder samples directly into an S.S. container, specially fabricated for the purpose. The main benefits are that it is a fully automated system with very less cycle time as compared to either manual operations or UCIL's conventional screw conveyor based operations. Operators exposure to the radioactive powders is very less and environmental impact is also very less as compared to the manual operations.

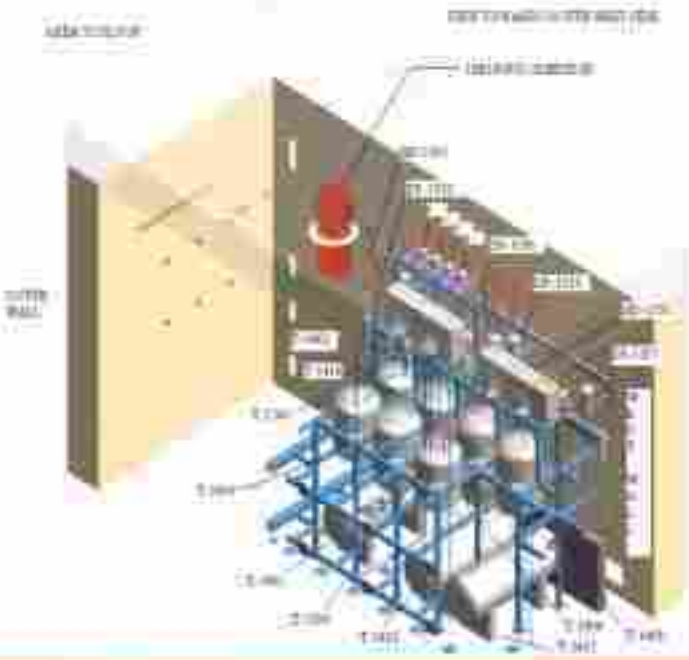
Metallic Fuels

Parametric studies based on 2D two-phase Computational Fluid Dynamics (CFD) simulations were carried out to understand the effect of different operating parameters and geometric parameters on the dispersed phase holdup in pulsed sieve plate columns. Pulsing velocity and percent free area of the plates were found to have significant influence on

dispersed phase holdup. Indigenously synthesized solvent Mixed Alky Phosphine Oxide (MAPO) was used in continuous countercurrent mode to separate Zr and Hf from Zirconium Oxide Plant raffinate in box type mixer settler. Complete Hf from the feed was recovered as 4.3 gpl Hf in scrub product.

Production of Uranium metal ingot was continued to meet the requirement of research reactors. A process was developed for recovery of uranium values from legacy wastes and the recovered uranium was utilized for metal ingot production.

A novel approach for the separation of molybdenum in uranium matrix was standardised by extracting Mo using pyrohydrolysis technique. An analytical method was developed for the chemical characterization of dysprosium-titanate ($Dy_2Ti_2Mo_2O_7$), a control rod material for LWR.



3-D model of the facility-Legacy Waste



Mast-Setters in the hot cell-Legacy Waste

Structural Materials & Components

Zirconium activities

A solvent extraction process has been developed for the total recovery of free nitric acid from Zirconium nitrate pure solution towards further reduction in specific consumption of nitric acid and ammonia. This process enabled reduction in free acidity of Zirconium nitrate pure solution from 3 N to less than 0.1 N.

An indigenous purification technology was developed and the required quantity of highly pure Zirconium di-nitrate oxide was produced with impurity levels well below the requirements sought by M/s Areva of France.

Towards production of Hafnium sponge required for applications in space technology as per the tripartite MoU among NFC, Hyderabad, VSSC, Thiruvananthapuram & C-MET, Hyderabad, the plant supplied about 75 KL of Scrub Raffinate (feed material for Hafnium production) to C-MET, Hyderabad. Another 40KL scrub Raffinate will be supplied soon.

Design of the 1.5 MT batch Magnesio thermic reduction and pyro vacuum distillation units were completed to increase the batch size from 750 kgs to 1500 kgs for higher productivity.

Zr-Nb rejects from fabrication plants for production of Zr-Nb grade sponge were recycled to recover Zr-values.

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 are carried out.

CHAPTER-1

Following important works were carried out at Extrusion and Piercing Plant (EPP):

Extrusion process development for low nitrogen Super Ni-42 thin wall clad tube for LWR:

There is a considerable effort in the direction of developing extremely thin wall clad tube for strategic light water reactors (LWR) from Ni- Cr super alloy. This alloy tube has longer residence time and higher fuel burnup as compared to Zr-1Nb due to its resistance to radiation embrittlement. Super alloy being most difficult to extrude material, requires very narrow range of temperature and strain rate. To achieve sound hot extruded tube initially deformation conditions were identified by hot compression testing. Optimized conditions obtained from hot deformation studies were converted successfully into extrusion parameters with respect to preheating temperature, soaking time and strain rate. Extrusion trials were successfully taken to produce 67mm OD X 13 mm WT, 41mm OD X 6 mm WT blanks and 22mm rod both from 3780T horizontal extrusion press and 630T vertical extrusion press. To obtain the suitable microstructure for hot working heat treatment trials were conducted.

Having successfully established the hot working condition for low nitrogen super NI-42, efforts are underway to establish the processing conditions for high nitrogen grades of super Ni tubes. Efforts are also underway to establish the cold working and heat treatment parameters to produce final thin wall clad tube, sheet and rod components of Super Ni-42.



As Extruded SuperNi-42 67mm x 13 mm Wt with excellent OD and ID surface Finish

Design and fabrication of Resistance heating furnace for heat treatment of Super Ni 42 blanks and tubes

Super Ni 42 material is required for BARC for strategic application. The material is being processed for the first time and characterisation of the same is in progress. It was required to carry out heat treatment of the 6.3 mm OD x 0.25 mm WT x 1.5 mtr long & 7.2 mm OD x 0.5 mm WT x 1.5 mtr long Super Ni 42 tubes. The heat treatment of the material was proposed to be carried out in temperature range of 1130° C to 1150° C. As the process was being developed, it was required to keep the temperature variation to as minimum level as possible. The soaking time of the material was very less and same was required to be quenched in water as quickly as possible. The furnace operating at above 1150° C & having such a quenching mechanism was designed and fabricated in-house.

Double clad tube for high burn up fuel of AHWR-LEU reactor

Zircaloy based double clad consisting of bulk outside tube of Zr-2 with dilute Zr-Sn (0.4 wt%) as inner liner have been proposed for high burn up AHWR-LEU upto 64 GWd/t. In this effort a co-extrusion technique has been adopted to produce the clad tube which was further cold worked to achieve final dimension of 10mm ID X 0.6mm WT. Presently, double clad tube with the final liner thickness ranging between 50 to 200 microns have been produced as against the target of 75 micron. Efforts are underway to improve the uniformity of liner thickness and better metallurgical bonding. The tube met all the requisite mechanical properties.

Production of Titanium full alloys for LCA application

TI-6AI-4V alloy having high specific strength is the suitable candidate material as a power transmission shaft in LCA. The alloy tube of 54 mm OD X 9.5 mm WT has been successfully produced by hot extrusion. Extrusion was carried out by suitably optimizing the extrusion temperature, ram speed and lubrication condition to achieve better surface finish. The finished tubular product can withstand more than 1500 million cycles of reversal load upto 300 MPa



As Extruded Ti-6Al-4V (Ti Full alloy) Tube 54mm OD X 9.5mm WT

and dynamic torque up to 105 Nm. Hot working of Titanium full alloy is difficult due to its very high strength at high temperature and also this alloy is very sensitive to strain rates. EPP conducted hot deformation studies for this alloy using thermo mechanical simulator. Based on these data extrusion was conducted at different temperature and strain rates and parameters were optimised to get thin wall tube by hot extrusion.

Replacement of 3780 T Extrusion Press Rams along with its guide bushes – (a) Piercer Main Ram, 500 mm x 5000 mm L, 5.5 MT, Qty 1 set and (b) Piercer Return Stroke Rams, 180 mm x 4000 mm L, 1.5 MT, Qty 1 set

Rams of 3780 MT Horizontal Extrusion Press were supplied along with the press and have given satisfactory life of approximately 44 years. During these years, Rams have developed severe scoring marks and degradation of surface, resulting into the frequent failure of set of 'V' seals. Severe wear and tear of all the respective Phosphor Bronze bushes were also observed. This necessitated the urgent replacement of both Rams and Bushes. The work involved included the maintaining of the critical close tolerances between Rams and bushes over the entire length of the Rams; especially in the case of handling of 4 mtr long Piercer Main Ram. Post replacement major task of alignment of Press while handling 21 MT (total weight of Rams along with platen) of material was also carried out successfully. The work has led to reduction in the failure of 'V' Seals.



Extrusion Press with new Rams



Old Piercer Main Ram and Return Rams along with guide bushes

Replacement of entire Power system & control system of 3780 MT Extrusion press

Existing hard wired logic control for 3780T Extrusion press consisting of limit switches contactors and switch gears which is about 4 decades old was replaced by PLC system with new cable trays and proper tagging.

Core Structurals

For each of the forthcoming 4x700 MWe, 425 calandria tubes and 425 pressure tubes were ordered by NPCIL. The requirement of calandria tubes for both KAPP 3 & 4 and RAPP 7 & 8 were successfully manufactured and supplied thus



The first consignment of reactivity mechanisms sent to KAPP-3

completing the total requirement for all the four reactors.

After successfull manufacturing trials in previous years for fabrication of Zr-2.5Nb pressure tubes based on double radial forging, extrusion and single pass pilgering route, production of large number of pressure tubes was undertaken. Pressure tubes required for RAPP 7 were successfully completed.

Reactivity Mechanisms

Several reactivity control mechanisms were taken up for manufacturing for the forthcoming 4x700 MWe reactors. After successful completion of more than 100 numbers of Adjuster Rod Guide Tube (ARGT), Shut off Rod Guide Tube (SRGT) and Control Rod Guide Tubes (CRGT), presently Liquid Zone Control (LZC) ,Vertical Flux Unit (VFU), Horizontal Flux Unit (HFU) and Liquid Poison Injection (LPI) units are being taken up. The first consignment of reactivity mechanisms were sent to KAPP-3.

Fuel Tubes & Components

Fifteen lakh fuel tubes and components required for 220 MWe & 540 MWe PHWRs were manufactured and supplied for the manufacturing of 1200 MT of fuel bundles. Efforts were put to improve the recoveries and increase productivity in various operations.

A new 9 meter long horizontal vacuum annealing furnace and 10-20 Pilger mill were developed and procured indigenously for catering to the higher production of PHWR fuel assemblies.

Special Materials

Zirconium-Niobium-Boron alloy was developed for Reactor Project Division, BARC. Three different compositions of the alloy were prepared through EB melting route. The alloy will be used for development of Borated Zirconium rods and strips. Zr, alloy powder, Niobium plates, Tantalum disc were supplied to RRCAT. Various high purity materials such as Niobium oxide, Tantalum oxide, Tellurium, Antimony Oxide, Selenium, etc. on market demand were supplied by NFC.

Commercial activities

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, etc. for strategic applications in the 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 required for Nuclear Power Plants. SSTP supplied Incoloy-800 U-bend Steam Generator tubes for 700MWe PHWRs and also manufactured and supplied modified 9Cr-1Mo Steam Generator Tube for Fast Breeder Reactor (FBR).

During the report period, SSTP manufactured and supplied critical products which included 2 sets of Incoloy 800 U-bend Steam Generator (SG) tubes for upcoming 700 MWe PHWRs, 6000 nos. of SS-D9 grade Fuel clad tubes for Prototype Fast Breeder Reactor (PFBR), Titanium Half Alloy tubes for Space applications, etc.

Developmental Activities

In addition to the above regular production activities, a number of developmental activities were also undertaken at SSTP which are of strategic nature for advanced Nuclear, Defence and Space programme of the country. These included the following:

Alloy-690TT Steam generator tubes for PWRs

Alloy-690TT is a Nickel based Super alloy having excellent Stress Corrosion Cracking (SCC) resistance being used worldwide for Steam Generator (SG) tube application for Pressurized Water Reactors (PWRs). These tubes require special long cycle Thermal Treatment (TT) under vacuum at final stage to obtain desirable microstructure for improved corrosion resistance. As a part of development programme, the plant established the manufacturing process route, specifically the required heat treatment parameters and successfully achieved the intended metallurgical structure and resultant corrosion properties.

Al-6%Mg Tube for Defence Strategic (BrahMos) Application

Aluminium-6% Magnesium (Al-6%Mg) Tubes are critical components of BrahMos missiles. The alloy, sensitive to the manufacturing process was developed successfully for the first time in India at NFC as an import substitute. During the developmental effort, the plant established the manufacturing process such as Cold working schedule, Heat treatment parameters, etc. to meet the desired Mechanical, Chemical, Metallurgical properties and Non Destructive Testing requirements by ultrasonic testing against stringent reference defect standards. Various sizes of tubes required by BrahMos were successfully produced meeting the specifications by adopting the process developed.



Bull Gear and Pinion Shaft assembly on the mill

Indigenisation of Drive System assemblies for Imported Pilger Mills

NFC plays a pivotal role in the manufacturing of tubes of Stainless steel and other high alloy steel. These are extensively used in power generation - both Thermal and Nuclear, Fertilizer and Chemical industries, Defence and Aerospace applications.

NFC utilizes numerous indigenised and imported Pilger Mills. Since majority of these mills are under operation for more than three decades, numerous issues were encountered in the drive systems. The drive systems of these mills can be termed as hearts of the mills. In order to reduce dependency on foreign suppliers for spares, initiatives for indigenization of these sub-assemblies were taken and these drive systems were successfully indigenised and were put into use.

The indigenization provided self-reliance for such systems, instilled confidence for undertaking such critical jobs in future and has saved huge Foreign Exchange.

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 at present to meet the fuel requirement of four 700 MWe PHWRs viz RAPP 7 & 8 and Kakrapara 3 & 4. The Project status is as follows:

Financial sanction was obtained for setting up the project with an outlay of 2401 crores; Siting consent for the project by AERB has been received; Clearance from Rajasthan State Pollution Control Board (RSPCB) has been received; Approval from DAE for award of Site Grading Work has been obtained and Letter of Award for work is issued; Preparation of DBRs by consultant M/s EIL is nearing completion for submission to AERB for obtaining construction consent; Tenders are in various stages of processing for construction power supply and some of the long delivery items; The Standing Committee of NBWL recommended the proposal for establishment of NFC and township near Kota subject to certain conditions.

Fabrication of equipment/ execution of work, processing for placement of PO/WO, tendering, finalising of specifications were in progress for various sanctioned projects. Approval of proposal for expenditure sanction for the 6 projects (3 proposed originally and 3 during MTA) was forwarded to DAE.

NFC-5 & 6

Site selection activities for these two green field projects are in progress. In this connection, site offered by AP Government was visited by Site Selection team. Letters were written to Chief Secretaries of Orissa, Karnataka, Gujarat, Rajasthan & Madhya Pradesh for identification of suitable land. AP government offered site in Orvakal mandal, Kurnool and a preliminary visit was made by

NFC during Sep., 2014 and further a revised land & utility requirements were forwarded to DAE regarding communication to these states (except AP) for evaluation by Site selection Committee. Response from these states is awaited.

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) with a capital outlay of 304.12 Crore. Zirconium Complex was commissioned in November 2009 and regular production activities for both zirconium oxide and zirconium sponge is continued since then.

Both Zirconium Oxide Production Facility (OPF) and Zirconium Sponge Production Facility (SPF) operated regularly. Around 172 MT of nuclear pure zirconium oxide and 187 MT of zirconium sponge were produced till December 2014. All the utility systems and service facilities were operational. Zirconium Complex is expected to achieve its full production capacity of 250 MT of Zirconium Sponge during the year 2014-15.

Construction of quarters and other amenities planned to accommodate staff of Zirconium Complex and CISF personnel were completed. Township was inaugurated on 25th April 2014 and is occupied by ZC staff and CISF personnel.

Desalination Plant at Zirconium Complex

Desalination Plant with two streams each of capacity 30 m3 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. were completed. Civil construction works for plant buildings were in advanced stage of completion. Structural fabrication and erection works were in progress. Major critical equipments have already been received and erection activities have been commenced.

Works related to pump house, laying of sea water intake pipeline, intake structure and discharge pipeline have commenced recently after receipt of CRZ clearance from Ministry of Environment, Forests & Climate Change (MoEF). Physical progress of about 67.88% has been achieved.

Magnesium Recycling Technology Development & Demonstration Facility

During the production of zirconium sponge by the well-known Kroll Process of magnesio-thermic reduction of zirconium tetrachloride, anhydrous magnesium chloride is generated as a by-product. This magnesium chloride can be converted to magnesium metal and chlorine by fused-salt electrolysis for captive recycle, thereby contributing to the reduction in the cost of production of zirconium. By-product chlorine from the Cells can be recycled after purification.

The multi-polar cell technology has been extensively studied and experimented at Defense Metallurgical Research Laboratory (DMRL) during 1983 - 2003 in different campaigns along with the titanium technology development programme and the intricacies of the process technology have been fairly understood. However, the technology needs to be further evaluated in respect of some parameters such as cell life, quality and purity of the metal produced, consistency of process operation, quality of by-product chlorine and mechanised collection of magnesium from the cell, which can be achieved only through sustained operation of the cell over longer duration.

In order to perfect the technology and make it suitable for commercial adaptation, it is proposed to set-up a Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF) at Zirconium Complex, Pazhayakayal, Tuticorin. Sanction is obtained with a capital cost of 32.4 Crore. The project is being implemented jointly by NFC, HWB and DMRL as a collaborative effort pooling resources and technological strengths of all the organizations under a Memorandum of Understanding (MoU).

Basic engineering was completed and the detailed engineering is in progress. Tender specifications for civil construction works have been finalised and the tenders have been floated. Technical specifications of various equipment /

materials such as melting furnaces, electrolytic cells, vacuum ladle, dehumidification system, chlorine handling system, cooling towers, refractory, graphite and electrical equipment are made ready.

Meltshop

A process has been developed for salvaging zirconium fines by mixing with zirconium sponge before compact fabrication.

Development of higher capacity copper hearth to increase batch size in existing plasma melting furnace from 160 kg to 300 kg of Zircaloy scrap.

As a technology up-gradation towards process recovery & safety, a new process of producing quadruple melt 550 mm dia Zr-2.5%Nb ingots dispensing with skin machining at all the three intermediate ingot stages and final ingot stage has been developed and introduced in production scale. The process development increases the process recovery by 15%. Also generation of fire-hazardous skin turnings is drastically curtailed through this development.

Niobium Thermit Production Facility

Activities were in progress for establishing Niobium Thermit Production Facility (NTPF) to meet the Niobium requirement of VSSC (Dept. of Space) indigenously.

BACK END FUEL CYCLE

Fuel Reprocessing

Nuclear Recycle Board (NRB) is operating back-end fuel cycle plants at Tarapur and Kalpakkam. Most of the operating plants are working near to their name plate capacity and few are even operating beyond their design capacity. Power Reactor Fuel Reprocessing-2 (PREFRE-2) at Tarapur has set new records of operating performance in back-end fuel cycle program. The plant achieved 122% of its name plate capacity in the year 2014.

Kalpakkam Reprocessing Plant (KARP) is giving excellent performance after its refurbishment. The plant has achieved a target near to its name plate capacity in the year 2014. During the year, Nuclear fuel Material for first fuel loading of PFBR was supplied to Fuel Fabrication Facility.



PREFRE-2, Tarapur



PREFRE-2 Control Room

The civil work of Uranium Oxide Facility (UOF), Kalpakkam is nearly 80% over, and other systems are under various stages of design and procurement. This project will cater to KARP and PREFRE-3A. This is a 150 Te of heavy material reprocessing name plate capacity plant coming up at



KARP, Kalpakkam



Automated Charging Facility (ACF) and Charging Cask PREFRE 3A - During inactive Commissioning

existing site of Kalpakkam. The physical completion of the Power Reactor Fuel Reprocessing - 3A (PREFRE-3A), Kalpakkam project is nearly over and commissioning of various systems is under progress.

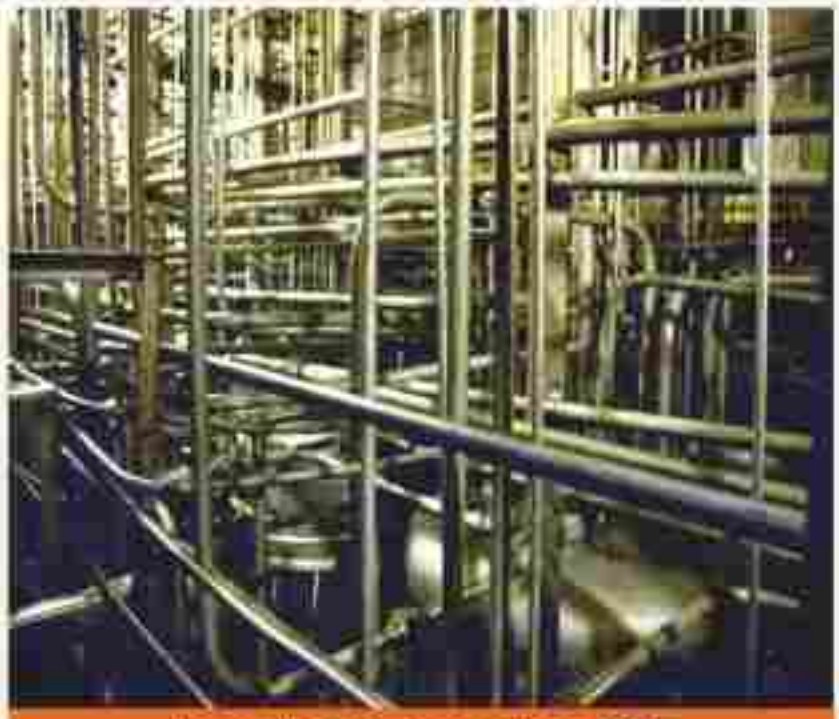
Design activities for various systems for Integrated Nuclear Recycle Plant (INRP), Tarapur continued. Tender for construction of Front end Blocks has been floated after obtaining regulatory clearances. Design of Front end Blocks, Piping and Tanks has been completed.

Concreting of fuel pool of Additional Spent Fuel Storage Facility (ASFSF) has been completed. Construction and procurement activities for other items are under progress.

In order to achieve near total conversion of uranyl nitrate to uranous nitrate with fast kinetics, a heterogeneous catalysis route using H2 as reducing agent was developed. Reduction process was established using uranyl nitrate solution generated from Plutonium Plant in presence of 2wt% Pt loaded on silica. 100 kg of uranous nitrate produced by catalytic hydrogenation was deployed for the first time in the partitioning step at Plutonium Plant, Trombay.

Based on the studies at various stages, a flow sheet was developed for near total conversion to uranous in a batch mode. A demonstration facility for making 100 litre of uranous / batch was installed at BARC and four runs were taken with PP uranyl nitrate solution with a catalyst to U ratio of 1:300 to 1:350.

Reprocessing of Th based fuels is a pre-requisite for the 3rd stage Indian Nuclear Program. An advance action was taken in the form of utilization of Th for initial flux flattening in PHWRs. On discharge from reactor, the irradiated ThO_2 contains 2% ^{233}U. Power Reactor Thorium Reprocessing Facility (PRTRF), the first industrial-scale plant in the world was built in Trombay to reprocess Th-based fuels.



Complex In-Cell Equipment & Piping-PRTRF



Active Demonstration Facility for producing Uranous by Catalytic Route

Based on analytical data of irradiated thoria pellets, a solvent extraction based process flow-sheet was developed at laboratory scale using simulated feed solution. The first step in the process involves use of chop leach method for decladding of zircalloy clad. This is followed by dissolving the fuel in Nitric acid containing 0.03 M HF and 0.10 M aluminum nitrate. Single cycle solvent extraction process is adopted for preferential extraction of ^{233}U employing Cal-mix mixer settlers. 5% TBP in n-dodecane is used as an extractant in the facility.

A shielded reconversion laboratory with articulated master slave manipulators was set up to



Powder obtained from denitration

purify and solidify ^{233}U. Chemical conversion of U(VI) to U(IV) is carried out by oxalate precipitation prior to its calcination. Four irradiated thoria bundles were chopped for further reprocessing.

Thermal denitration technique will be deployed in two upcoming reprocessing plants to obliterate the problem of liquid nitrate disposal arising from the precipitation of ammonium diuranate cake. The plants will be based on the modular scale-up of the pilot plant study to treat 1000 m^3/year and 6000 m^3/year of 75 g/l ammonium nitrate waste.

Parametric studies for direct-denitration of uranyl nitrate in 80 NB size SS 304L fluidized bed reactor with internal cartridge filter in the free board was continued. Campaigns extending upto 30 hrs with feed solution of 160 g/l U in the temperature region 325 to 380°C favoured higher temperatures for smooth operation and agglomerate free oxide powder. The O/U ratio was in the order of 2.66 for orange powder in the bed with nitrate content in the order of 700-800 ppm.

The thermodynamic properties, chemical potential diagram and Gibbs phase diagram of Gd-P-O system have been computed to predict its long term stability to immobilize radio-nuclides.

For input accountability of Pu, nineteen dissolver solutions of irradiated fuel were analysed by Isotope Dilution-Thermal Ionization Mass Spectrometry (TIMS). Concentration of Pu was determined after chemical separation of fission products and bulk of uranium.

Manufacture of mixer settler unit, consisting of twelve-stage extractor and stripper, required for actinide separation demonstration facility has been



Mixer Settler Unit for WIP

completed and delivered to Waste Immobilization Plant (WIP), Trombay.

Waste Management

A process based on solvent extraction has been indigenously developed for the selective separation of Cs from HLLW. Calyx Crown-6 solvent has been used for selective recovery of ^{137}Cs from



Cs-137 Pencil Production



Cs-137 Pencil 25.5 mm x 210 mm

HLLW thereby recovering "Wealth from Waste". Subsequently, the recovered Cs will be immobilized in borosilicate glass matrix as irradiation pencils for deployment in blood irradiator in the place of ^{60}Co.

A dedicated plant has been set up in the hot cells of Waste Immobilization Plant (WIP), Trombay for treating HLLW at 100 liter/hr for the recovery. The facility for making cesium pencils is modular in design with remote handling. All associated systems requiring remote handling of highly active cesium pencils, their top lid welding and decontamination of have been installed. WIP vitrified waste product cask loading station has been modified to facilitate transfer of active pencils from WIP to BRIT in a shielded cask. India will be the only country to deploy cesium in the form of vitrified irradiation source pencils.

A large inventory of problematic sulfate-bearing HLLW from spent fuel reprocessing



Shielded Ion Exchange Columns for Declad Waste Management



Remotely operated pump and valves in hot cell for Declad Waste Management

operations having high salt loading and relatively lower specific activity showed poor vitrification. R&D efforts were undertaken to enhance this waste loading and a solvent extraction process was developed and validated at laboratory scale. This process utilizes indigenously developed radionuclide selective solvents to treat the HLLW. Novel solvents such as NNNN-tetra-2 ethyl hexyl diglycol amide for selective removal of Sr, lanthanides and actinides were developed and tested in laboratory using simulated wastes. To validate the process flow sheet, laboratory runs were carried out with actual HLLW.

It is observed that the solvent extraction process results in very high waste loading per canister. The solvent extraction system has been installed in one of the hot cells of WIP, Trombay. Testing and cold commissioning were completed. Introduction of this process may result in more than 25-fold reduction in Vitrified Waste Product canisters destined for geological repository.

Alkaline declad waste (ILW) generated during the reprocessing of spent fuel from Research Reactors contains ^{137}Cs as the major radionuclide accounting for 98-99% of the radioactivity, high alkalinity, sodium and aluminum concentration. A Cs-selective ion exchange process is employed for the treatment of the waste in a dedicated facility. About 7, 50,000 l of alkaline wastes was processed. The process involves the use of indigenously developed Resorcinol Formaldehyde Polycondensate Resin for removal of Cs from ILW. The sorbed Cs eluted with dilute nitric acid and the

resin is conditioned for reuse. The Cs rich stream is pumped to WIP for vitrification in glass matrix. More than 12, 00,000 l of declad waste was processed. Cs decontamination factor of 2000-5000 was obtained in presence of very high sodium concentrations more than 4 M indicating the high efficacy of the process.

Dismantling and processing of un-serviceable alpha contaminated Glove Boxes (GB) were taken up. A mock set up of an alpha enclosure was erected to carry out inactive trials and an active demonstration setup was developed and six alpha contaminated GBs were dismantled. This experience has generated valuable data such as maximum air activity during cutting, maximum contamination levels, actual GB inventory by direct assaying, volume reduction factors, requirement of cutting tools and handling systems etc. Based on the alpha activity in various cut pieces, the GBs have been declared as Category I solid waste suitable for disposal in near surface disposal facility.



Dismantling & Decontamination of Alpha Glove Box under Alpha tight enclosure



Plasma air torch retrofitted to existing incinerator chamber at Trombay



Photo # 17 - Pig # 8 - Side A

Disused Am-Be source in Type - A package

Plasma gasification system developed is being considered for treatment of dry and wet Low & Intermediate Level (L&IL) solid radioactive wastes to achieve high volume reduction leading to homogenized stable end product. Processing of different types of organic wastes has been attempted using air plasma gasification.

To recover Americium from disused sources such as smoke detectors, lightning rods, moisture-meters and well-logging devices etc., remote cutting and recovery of long lived alpha radionuclides was demonstrated which will address the problem of their long term storage as a nuclear waste.

Advance Vitrification System (AVS), Tarapur (Joule Melter) continued to operate impressively and it has completed vitrification of 72 m^3 of High Level Waste and total 71 canisters were produced which is a record for this facility. Other back-end fuel cycle facilities like "Tank Remediation by Ion Exchange", "Liquid Waste Treatment Plant", "Tarapur Rad-Waste Augmentation Plant" and "Solid Waste Management Facility" operation continued satisfactorily to meet the waste management requirements at Tarapur.

Waste Immobilization Plant (WIP), Kalpakkam has processed more than 500 m^3 of Intermediate Level Waste in year 2014. The hot commissioning of Uranium Separation Process using Depleted Uranium is completed, and has processed High Level Waste received from KARP - Waste Tank Farm. Hot commissioning of Ion Exchange column resin fluidization and cementation also carried out in this year.



CWMF, Kalpakkam

Centralized Waste Management Facility (CWMF), Kalpakkam continued to operate satisfactorily to facilitate waste management support to all nuclear facilities at Kalpakkam. CWMF has received an Award for the Volume Reduction and Safe Disposal of Pressure Tubes received from Enmasse Coolant Channel Removal Campaign in MAPS-I' in recognition of its outstanding contribution to the departmental programme.

Various system design activities of waste management part of the WMP, FRFCF (Kalpakkam) project are under progress.

Safety Performance of Reactors

NPCIL is responsible for performing the deterministic and probabilistic safety assessment of nuclear power plants for regulatory clearances including design, siting, commissioning of new projects, safe operation, periodic safety review and extension of operating license/life management of operating plants. During 2014-15, following major activities were completed:

- For hydrogen management during postulated severe accident, the Passive Autocatalytic Recombiner Devices (PARD) developed at BARC and tested in Hydrogen Recombiner Test Facility (HRTF) at R&D Center, Tarapur are proposed to be used in Indian Nuclear Power Plants. The computer modules were validated against data obtained from HRTF that facilitated in optimizing usage of PARDs within containment of Indian PHWRs for effective hydrogen management.

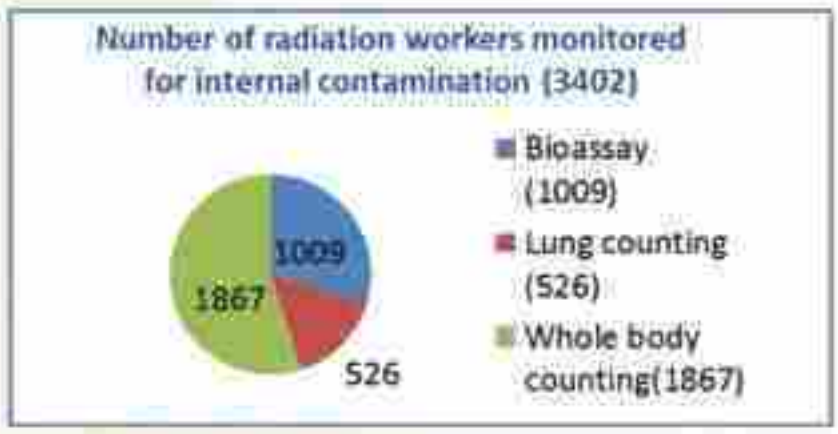
- In 700 MWe design, matrix of nine methodologies was used in strengthening the fire protection measures (both active and passive) to effectively handle and monitor fire hazards.

- As Post Fukushima safety level enhancement measure for TAPS-1&2, the Containment Filtered Venting System (CFVS) was designed based on full height scale experiments conducted and its installation is currently in progress.

- A comprehensive methodology for evaluation of storm surge and inundation was evolved with the help of experts of IIT Delhi. To verify the design basis flood levels for MAPS a study was conducted which included the ocean dynamics, assessment of storm characteristics - width and depth of eye, rotational and translational speed, tacking its route, and coastal topology.

HEALTH, SAFETY AND ENVIRONMENT

Assessment of internal exposure of occupational workers from BARC facilities at Mumbai and Tarapur was carried out by whole body/lung counting and bio-assay analysis. About 3402 radiation workers were monitored for internal contamination. Sensitive detection systems and analytical methods were used for the measurement of radionuclides incorporated in the body of radiation workers.



An automation system for the radiochemical analysis of biological samples (Urine/Fecal) of radiation workers for the determination of various radionuclides like thorium, uranium, plutonium, americium and strontium has been developed and commissioned. The system processes 12 samples simultaneously and can be operated 24x7, analyzing



Centralized Networked Low Background Gross Alpha Counters

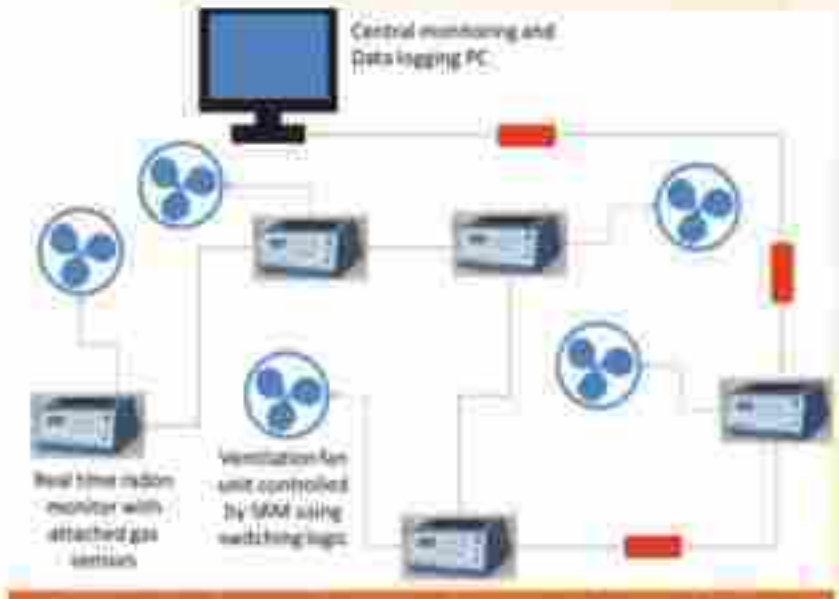
about 36 samples per day. The system will be extremely useful in cases of nuclear and radiological emergencies where the need is to analyze large number of urine samples collected from members of the public in a short span of time.

A networked alpha counting system consisting of ten gross alpha counters and a data acquisition system has been designed and commissioned for the determination of alpha activity in separated Pu/Am/U samples. The system increases the sample through put for use in emergency situations where large number of samples may be required to be counted and also helps to prevent contamination of detectors of alpha spectrometers. The detection limit is about 3 mBq/d for urinary excretion for a 10000 seconds counting time.

Knee and Skull are monitored for the internal contamination of actinides over a period of time by evaluation of overall skeletal activity concentration. For calibrating the Phoswich detector system, Knee and Skull voxel phantoms of International Commission on Radiological Protection (ICRP) reference male voxel phantom are used. Efficiency factors in the energy range of 18-238 keV are obtained using Monte Carlo simulation package FLUKA for covering the nuclides such as ^{239}Pu, ^{241}Am, ^{238}U, ^{235}U and ^{214}Pb.

To monitor concentration of noxious gases inside mine environment, Online Radon Monitoring Network (ORMoN) coupled with noxious gas sensors was developed and installed at Turamdih mines. Present system monitors radon concentration along with other gases and controls ventilation system if any of the parameter exceeds set value.

Personal dose monitoring of radiation workers in BARC facilities indicate that the collective dose and the per-caput dose are on a decreasing trend even though many new facilities have been commissioned recently. The exhaustive surveillance also indicated that environmental discharges from the facilities are only a fraction of the regulatory authorized limits.



Schematic diagram of mine ventilation control through ORMoN



Online Spot Air Monitoring System

CHAPTER-1

An Online spot air sampler is designed and fabricated for in-situ measurement of long lived alpha air activity. This device contains a high volume pump, sample carousel to contain 4 specially designed centripeter sample heads and an alpha counting set up with necessary micro control programming for automation. The system will help in evaluating air borne activity for plutonium or any long lived radionuclide inside a lab instantly with all preset alarming facility without any human intervention.

A flexible alpha wound monitor to locate and measure the alpha activity in a wound was conceptualized, designed and developed BARC. It uses a miniature ZnS (Ag) with dia 2mm to 8mm detector with a flexible light guide and necessary electronics. The detector with Minimum Detectable Activity (MDA) of 10 mBq has 18% efficiency. A number of such monitors are now being fabricated for use in various Pu handling facilities.

An indigenous radiation monitoring system has been developed for long term environmental surveillance which can provide time-correlated dose rate information of a location where it is placed. The system will monitor any elevated radioactivity in the



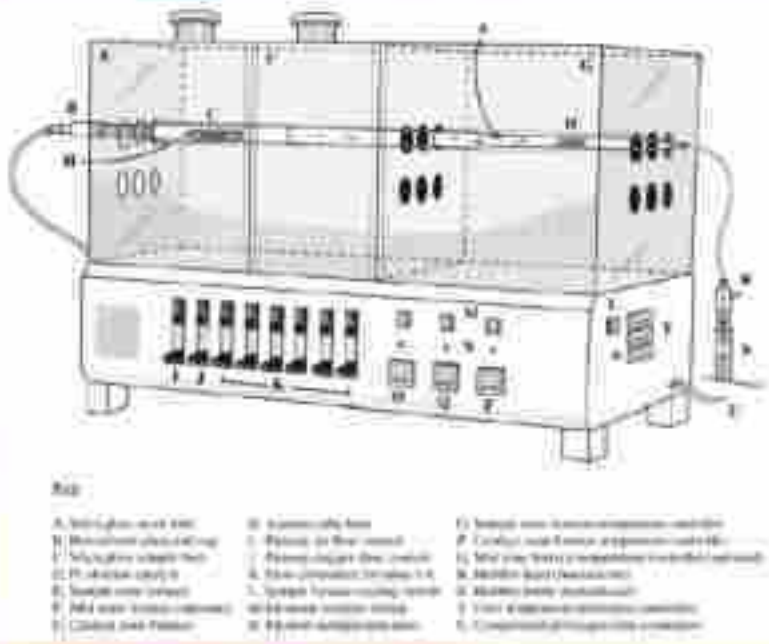
Measurement of Alpha Contamination on Wound



Gamma Register for Environmental Radiation Surveillance



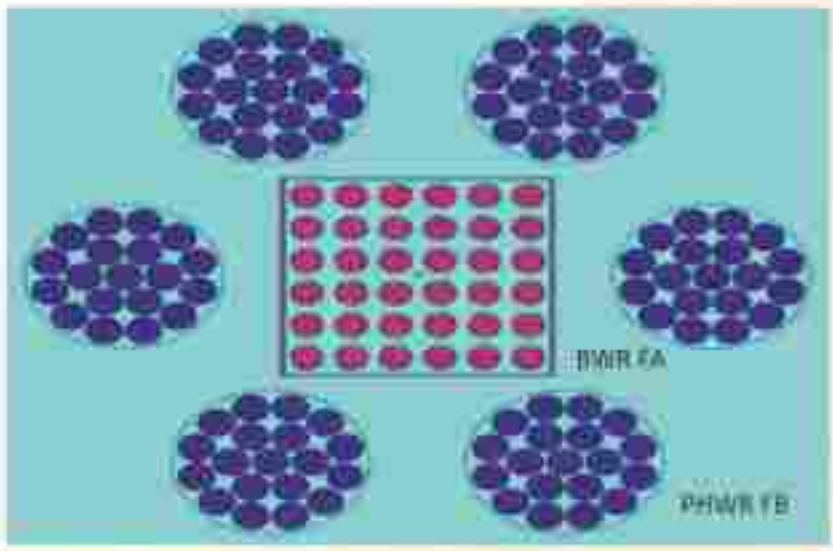
Alpha Wound Monitor



A sample oxidizer system for C-14 estimation

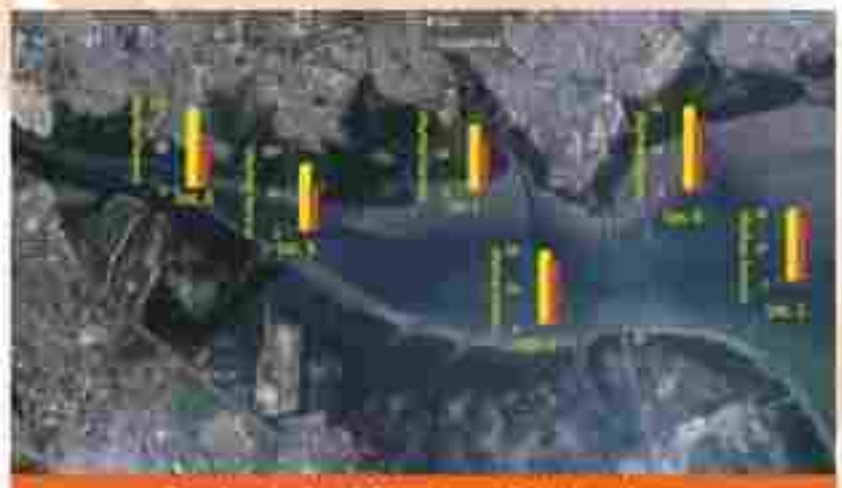
environment. It is a compact unit, easily deployable and consumes very low power and can log dose rate data at selectable intervals and radioactive profile can be generated for carrying out assessment. It can store 400000 data points of 1 minute interval and has a sensitivity of 1.2 cpm/100 nGy/h and a measurement range from background (100 nGy/h) to 5 mGy/h.

Carbon-14 is a long lived radionuclide released from all types of reactors and gets accumulated in the environment including biota. It is also a naturally occurring radionuclide. It is necessary to generate the data of C-14 concentration in environmental samples around the power plant to demonstrate that there is no undue build-up of C-14 due to the operation of the plant, over and above the natural levels. C-14 as CO_2 in air is sampled by bubbling through ultrapure NaOH solution, subjected to chemical separation and finally estimated by Liquid scintillation counting Criticality safety analysis for the storage of spent MOX fuel bundles of PHWR along with spent MOX fuel assembly of TAPS was carried out. Monte Carlo 3D Simulation of 12 PHWR fuel bundles and one BWR fuel assembly was carried out as shown in figure. The report presents the Keff values and establishes that the storage/handling of MOX fuel bundle/assembly of PHWR/TAPS is safe from the criticality safety point of view.



Monte Carlo 3D Simulation of 12 PHWR Fuel Bundles and One BWR Fuel Assembly (Axial View)

A combination of geochemical and geochronological analyses was carried out by BARC to establish substance specific contamination histories in a creek ecosystem. Quantitative geochemical investigation using radiotracer



Geochemical and Geochronological analyses of contamination history in a creek ecosystem

technique for dating the sediment cores allowed defining time dependent concentration patterns for environmental pollutants. Peak is observed in the year 1970-75 period when widespread use of DDT and HCH in agricultural pest control had begun in India due to beginning of green revolution.

Coal, Fly ash and bottom ash samples collected from various coal-fired power plants across India were measured for ^{238}U, ^{226}Ra, ^{232}Th and 40K radioactivity by HPGe γ spectrometer, while 210Po was radio-chemically extracted and counted by alpha spectrometer.

Environmental gamma radiation levels are measured using Thermo Luminescence Dosimeters (TLDs) ($CaSO_4$: Dy Teflon embedded disc based) on quarterly basis in and around all the DAE installations. Around 500 TLDs are deployed in each quarter.



Environmental TLD card and Environmental radiation monitoring around DAE installations

Under the XII plan project on nationwide gamma radiation monitoring, monitoring of natural background radiation levels was carried out in Andhra Pradesh, Assam, West Bengal, Jammu & Kashmir, Maharashtra, Kerala, Karnataka and Tamil Nadu through MOU with different universities.

One major application of biodosimetry is the identification, in the event of a large-scale radiation emergency, of the most severely exposed individuals. Gamma-H2AX assay is a sensitive indicator of DNA double-strand breaks and involves analysis of gamma-H2AX foci for rapid dose estimation. This assay has been standardized and optimized and a calibration curve has been established which can be used for obtaining preliminary dose estimates for facilitating early triage of casualties based on clinical symptoms.



Portable Neutron Yield Measurement Standard



Multisource Remote Operating Device

The portable transfer standard for neutron source yield measurement has been designed with a BF_3 counter and two concentric cylinders of high density polythene separated by a neutron absorbing layer of borated rubber. The system has a constant efficiency of 2.9 cps/(n/cm^2/sec) for all laboratory neutron source spectra.

Effects of high-dose neutron irradiation on chemical and optical properties of CR-39 were studied using FTIR (Fourier Transform Infrared) and UV-Vis (Ultraviolet–Visible) spectroscopy. Parameters such as absorbance, band gap, bond intensities, etc. were analysed. A correlation between optical absorbance and neutron dose was established, which can be used to estimate neutron dose without involving tedious procedure of track counting.

Multisource Remote Operating Device (MROD) is a fully computer controlled brachytherapy source storage cum source driving device which can store nine Ir-192/ Co-60 high dose rate brachytherapy sources. The MROD is useful in calibration of the hospital dosimeters against the similar source which is available to the hospital with minimum man Rem consumption and will help in enhancing the accuracy of the radiation dose delivered to the cancer patient during brachytherapy treatments.

An OSL based two element eye lens dosimeter badge was developed to generate the eye lens dose data of radiation workers. This dosimeter badge meets the design criteria (IEC and ISO) of a radiation monitor. Field trials have been conducted in medical, industrial and nuclear facilities. The data collected will be helpful for the regulatory body to take the policy decision about the revised ICRP dose limit for the eye lens of the radiation workers.

Lithium Magnesium Phosphate (LMP) OSL based badge was designed for environmental monitoring. This dosimeter has two discs covered with 1 mm copper filters. Field trials for environmental • radiation monitoring on quarterly basis in KAPS was carried out using TL dosimeters based on $CaSO_4$:Dy and OSL dosimeters based on LMP. Dose data acquired by these two dosimeters were found comparable.



Eye Lens Dosimeter Badge

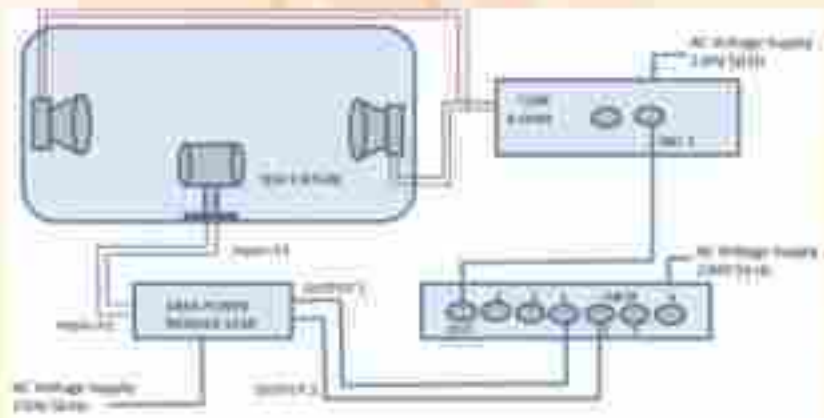

LMP based OSL Environment Monitoring Badge

A Multi-sample integrated TL/OSL reader system has been developed for advanced research in phosphor developments (TL/OSL), accident dosimetry, environmental and personnel monitoring and medical dosimetry. This system is capable of analyzing TL/OSL properties of maximum 36 samples for different TL/OSL modes. The operational aspects of the reader system have been tested using Al_2O_3:C and LMP phosphors. The minimum measurable dose using Teflon embedded disc (8 mm dia, 0.4 mm thick) of both the materials was found to be 1 μGy. The reproducibility of the reader system is found to be less than 2.5%. The reader system has been designed indigenously at 1/3rd cost to that of commercially available reader system.


Multi-sample integrated TL/OSL Reader

To carry out performance test of ear protectors such as ear plugs and ear muffs, an Acoustic Test Module has been installed and commissioned at BARC. The system includes artificial head form with ears and other allied equipment/implements such as Acoustic signal generator/receiver. In addition to testing of ear protectors, the studies on sound attenuation offered by different elastomers can be carried out using this facility.

NPCIL recorded about 400 reactor years of safe operation of reactors by the end of November 2014. The review of safety of operating stations was carried out on a regular basis. The individual and collective occupational exposures of radiation workers at various Nuclear Power Plants (NPPs) were maintained within the budget approved by AERB by following the principle of ALARA (As Low as Reasonably Achievable) and maintaining the highest standards of safety within the NPPs. The radioactive effluents from NPPs to the environment were maintained very low in comparison to the 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


Schematic of Acoustic Test Module used for sound attenuation studies

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 were maintained and regular audits (internal & external) & management were carried out for continual improvement.

The updated Environmental Impact Assessment (EIA) reports for NPPs at Mithivirdi, Gujarat and at Chutka, Madhya Pradesh after addressing the observations of Expert Appraisal committee (EAC) were submitted to MoEFCC (Ministry of Environment & Forest and Climate Change). Consent to Establish (CTE) from Haryana State Pollution Control Board, Wild Life Clearance for plant site from State Government of Haryana and relevant modifications in Environment Clearance from EAC, MoEFCC were obtained for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP). Submissions of marine impact assessment report along with other documents were made to EAC (CRZ), MoEFCC and appraisal of the documents were undertaken by EAC, MoEFCC for CRZ clearance for NPP at Mithivirdi. No Objection Certificate (NOC) from Gujarat Government was obtained as a part of Forest Clearance for NPP at Mithivirdi, Gujarat. Approval of Terms of Reference (TORs) for EIA study for NPP at Mahi-Banswara, Rajasthan was obtained from MoEFCC and EIA studies were initiated as a part of environmental clearance for the project. As a part of environmental clearance stipulation compliance, Special Plan for Fisheries (SPF) based on the detailed field and laboratory studies for Jaitapur region were completed and submitted to MoEF in line with the requirements of environmental clearance for Jaitapur Nuclear Power Project (JNPP), Jaitapur, Maharashtra.

NPCIL has launched its Environment Stewardship Programme (ESP) in 2006 as a voluntary initiative with a mission to preserve the environment, particularly, the environs of its nuclear plant sites. The programme which is beyond the regulatory and statutory fulfillments, focuses on the scientific studies on bio-diversity, improvement of habitat and conservation of nature within and around the exclusion zones of Indian Nuclear Power Plants.



ESH members of NPCIL curiously watch birds during the Kaiga Bird Marathon 2014



Preliminary studies on the turtle eggs at the turtle breeding center in Narora

ESP also includes training of local volunteers, organising public awareness campaigns to sensitise the members of public on environment and communication of environmental affair.

Under the ESP, a nature club at each NPCIL site has been setup and named after a threatened bird of that area. Members of these clubs actively participate in various activities from nature watch to public awareness campaigns, butterfly surveys to bird marathons, habitat improvement to nature conservation.

In 2014, an exclusive garden for butterflies has been established inside the exclusion zone of Kaiga Generating Site. With nectar and host plants, the garden acts as a safe habitat for numerous butterflies. This year in Narora, a turtle breeding project has also been taken up by NPCIL. The turtle

project aims to increase the population of two turtle species by involving an expert conservation agency.

All plants of Heavy Water Board were 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.

The Manuguru plant, achieved 1856 accident free days which is highest ever achieved. It completed three million man hours of continuous working without any RDI and is still counting. The overall safety record of the HWP, Hazira was excellent and it was in continuous operation for 2231 days till December 2014 without any reportable loss time injury or accident. The HWP, Thal completed 1850 accident free days in December 2014 since last reportable injury and continued to operate with excellent safety records.

In the field of environment management, the Manuguru plant has drawn up road map for fly ash management in the next five years including complete disposal of dry fly ash through supply of fly ash to cement industries, ash bricks making, land filling and other uses. About 61% of fly ash generated during the reported period was utilized by HWP, Manuguru.

Further, report endorsing suitability of bottom ash for mine stowing from CIMFR, Dhanbad was obtained and HWB is pursuing with M/s. SCCL for stowing bottom ash in their mines.

RESEARCH & DEVELOPMENT

NPCIL's Technology Development activities are grouped under four verticals of R&D Facilities, Remote Tooling, Indigenization and Construction Time Minimization with responsibilities for design, analysis, development, engineering, procurement, construction, installation, commissioning, O&M, experimentation and equipment qualification related to these verticals. The inputs are provided from headquarters and corporate R&D center, Tarapur, Maharashtra site 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.

The in-house design and development efforts in R&D electronic systems are concentrated towards electronics and computer based controls and instrumentation systems for 700 MWe projects. The efforts are mostly application-oriented, design & development specifically addressing the Control & Instrumentation (C&I) requirements emanating from power plants under construction and from operating stations.

Major achievements and ongoing activities during the financial year 2014-15 were as follows:

Test Facilities

Post-Fukushima Hard Vent System

Design of Containment Filtered Venting System (CFVS) required for depressurization of primary containment in the event of Beyond Design Basis Accident (BDBA) scenario. Iodine scrubbing tests were completed with single venturi, bubble breaker and mist extractor inside a scaled down vessel. Full size CFVS vessel including internals developed, designed, fabricated and delivered to TMS for planned full scale prototype tests.



Schematic of Containment Filtered Venting System Vessel



CFVS Vessel under fabrication seen with Bubble Breaker Support Provision

Hydrogen Recombiner Test Facility (HRTF)

Large number of tests of three types indigenous Passive Catalytic Recombiner Devices (PCRDs) with up to 8% hydrogen have demonstrated their efficacy in steam and air environment. Report issued short listing the PCRD which can be further tested and productionized for implementation in Indian PHWRs.

Iodine Scrubbing thru Containment Spray System

The scrubbing tests on efficacy of iodine scrubbing by spray droplets and the effect of spray on containment pressure are in progress at IIT-Bombay.

Integrated Thermal Hydraulic Test Facility (ITFT)

This facility comprising of BARC's AHWR Thermal Hydraulic Test Facility (ATTF also known as



View of Test Carriage Bridge and column assemblies and Channels of 700MWe FMTF



View of Process systems and valve station of 700MWe FMTF

PARTH), AHWR Fuelling Machine Test Facility (AFMTF) and NPCIL Thermal Hydraulic Test Facility (NTTF) made significant progress on all fronts in spite of several challenges and respective facilities are likely to see significant testing/experimentation from 2015 onwards. NTTF is being readied with simulation test of Passive Decay Heat Removal System (PDHRS) for 700 MWe PHWR which is expected to take place in early 2015. AHWR fuelling machine assembly is progressing well.

Fuelling Machine Test Facility (FMTF) for 700 MWe PHWR

Construction of this facility has been completed to enable carrying out test at low temperature and high pressure on first KAPP-3&4 fuelling machine head. Along with this a table top scale Potentiometer Test Facility has been designed which will be useful for calibration of potentiometers at all operating units.

Environmental Qualification (EQ) activities

Utilizing the Radiation chamber, thermal chambers and LOCA Test Facility, a large number of EQ tests have been carried out for assessment of performance of safety related equipment, components, cables and coatings under severe environment. This has helped to determine residual life of relevant items for operating stations and also has proven the indigenously developed items for their suitability under radiation environment e.g. Delta- P transmitters, Electrical Penetration Assemblies (EPAs) etc.

Indigenization initiatives

Steam Generator (SG) Forgings Critical Heavy Forging

A total of seven (comprising five different types) 700 MWe PHWR SG forgings are being developed. Out of these, two types are fully developed and four shells are delivered. Tooling for conical shell, torrispherical head, spherical primary head and trial forgings are made. Other forgings are at advanced stage of development requiring further heat treatment, final machining, mechanical testing and NDT activities.



Forging of Shell



SG Shell-V



SG Shell-II

FM Heavy Duty Bearings and Proportional Flow Control Valves (PFCV)

These have been indigenously developed to a high level of precision machining. The bearings, PFCVs and test setup have been delivered.



Indigenous Heavy-Duty Bearings under Performance Test

Aluminium (Al) Bronze Forging

These are required for high strength and excellent corrosion and wear resistance. Development of Aluminium Bronze forging for 700 MWe fuelling machine application was completed and it is being delivered.



Al-Bronze forging under UT



Al-bronze finished product

Indigenous vendor base broadening

For several major equipment such as Primary Coolant Pump (PCP) motors, Shut Down cooling pumps and FM pumps actions are under progress for alternate vendor development to strengthen broaden the supply chain. Development order are placed for Bleed Condenser (BCD) forging, and documents are under approval. End Shield/ Lattice & SG tube sheet forging development are being taken up and are under placement of order.



PT under LOCA Test

Cobalt Absorber Rods (CoARs)

Cobalt Absorber Rods will facilitate ease of production of Cobalt for medical purpose. Fabrication of first mock-up CoAR assembly was completed by Nuclear Fuel Complex, Hyderabad. This mock-up CoAR assembly has undergone testing for assurance of wetting under flow condition in a full scale test facility set up for the same in the ITFT structural tower building. Full mock-up of handling of these highly active rods for 700 MWe units is also part of the development process.



Cobalt Absorber Rods (Co AR) assembly



Rope Attachment Coupler

CoAR Handling Tools for 700 MWe PHWRs

The design of the flask along with associated features has been completed and the flask drawings have been issued. Tendering has been initiated for the same. This dummy flask will be used for carrying out trials related to removal of CoAR as well as other related operations. CoAR bundle dismantling tool

trials have been done and are under modification. Drawings have been finalised for prototype tool fabrication for under water CoAR handling. Action has been initiated for tendering.

Radiation Resistant Pressure Transmitters (PT/DPT)

All functional and type tests including Climatic, EMI/EMC, Seismic, Thermal Ageing, Radiation Ageing, LOCA /MSLB steam profile on Electronic Pressure and Differential Pressure Transmitters (PT/DPT) for nuclear application was completed and development is completed for Total Integrated Dose (TID) of 1.5 MRad at higher dose rate of 0.37MRad/hr against target as 1 MRad at dose rate of 0.1 MRad/hr.

PCP Development and setting up Test Loop for qualification

After Expression of Interest (EOI), Board approval has been obtained for PCP developemnt. The tender documents have been finalised and enquiries are being sent. Design, work detailing & 3-D for setting up test loop at R&D center are finalized.

Remote Tooling

Reactor Channel Inspection Campaigns

Full technical support, detailed training and qualification for all inspection campaigns were rendered to respective operating units in 2014 for successful coolant channel inspection by using BARC Inspection System (BARCIS). All the schedules planned have been successfully met for In-service Inspection Campaigns (ISI) for 220 MWe PHWRs (RAPS-3, RAPS-5, KGS-1, MAPS-1, KAPS-2 & NAPS-1).

Triangular Block Cutting

A Laser based cutting tool was developed in collaboration with RRCAT and tested on 16 channel mock-up. First time successful deployment of triangular block cutting in RAPP-3 during August 2014 Biennial Shut Down (BSD) has led to regulatory clearance for continued operation of this unit in a timely manner.

Carrier Tube Assembly (CTA) removal scheme

This is a requirement from TAPS-3&4 where a few Vertical Flux Unit (VFU) which comprise of 13 meter tall CTA of about 50 mm Dia having 11+1 tubes of 6&10 mm Dia in which Self Powered Neutron Detectors (SPNDs) reside are required to be replaced for ease of operation. In-situ pulling out, cutting and putting the contents of these multiple tubes in the pump room is a highly challenging task. An integrated team of NPCIL is working jointly with DRHR, BARC to accomplish this task. Design of removal tool by cutting and indexing has been completed and manufacturing process is under progress. Trials with dummy flask are planned. Modified design of shielding flasks & doughnuts completed and order for shielding flasks & doughnut have been placed. Efforts are being made to develop the system and qualify it in mock up at R&D center.

LASER Cutting of SG Tubes

For inspection and removal of debris and also for health monitoring, SG tube cutting has been necessitated. A tool utilizing laser cutting and removal of SG tubes was developed in collaboration with RRCAT. Initial lab trials were successful and field trials at mock up in KGS-4 is partially successful. A new methodology is being evolved for tube removal.

Construction Time Minimization

With a view to minimizing construction time major modularization is being pursued. Other ideas being pursued includes auto welding, new approaches which can ease construction time as well as critical equipment supply times.



PHL lifting in KAPP-3&4

CHAPTER-1



Pump room (SSFM) module erection in progress

Preformed Ring Liner (PRL) Concept

The Preformed Ring Liner (PRL) concept has been implemented for the first time in KAPP-3&4 with several rings having been successfully installed and it proved that this concept can not only save significant time in construction of inner containment wall of reactor building but also provide better quality.

Pump Room Floor Module

The concept of assembling large Structural Steel Floor Module (SSFM) along with primary system headers at the ground and lifting into place to ease construction/erection process was partially implemented at KAPP-3 without the heade₹ Two such modules for north and south pump room floors constitute significant modularization.

Integrated Calandria End Shield Assembly

Erection and welding of Calandria End Shields assembly is an important critical plan activity in PHWR project. Relevant studies and 3D modeling of concept of Calandria End shield modular installation in future 700 MWe PHWRs is in advanced stage and design and stress analysis of module handling is taken up. This has potential to accelerate related site work by few months.

Cable Tray implementation at 700 MWe projects

The relatively simpler cable tray design concept which was tested at R&D center and also implemented in ITFT was implemented in KAPP-3&4 project. This has eased the construction/erection process.

Automatic Narrow Groove TIG welding of large pipes

This is proposed for primary system main circuit pipes and steam lines of future projects. Welds on 600 mmNB Primary pipe of 45 mmWT was carried out and qualification was successfully carried out with required radiography, bend tests etc.

Modular Electrical Penetration Assemblies (EPAs)

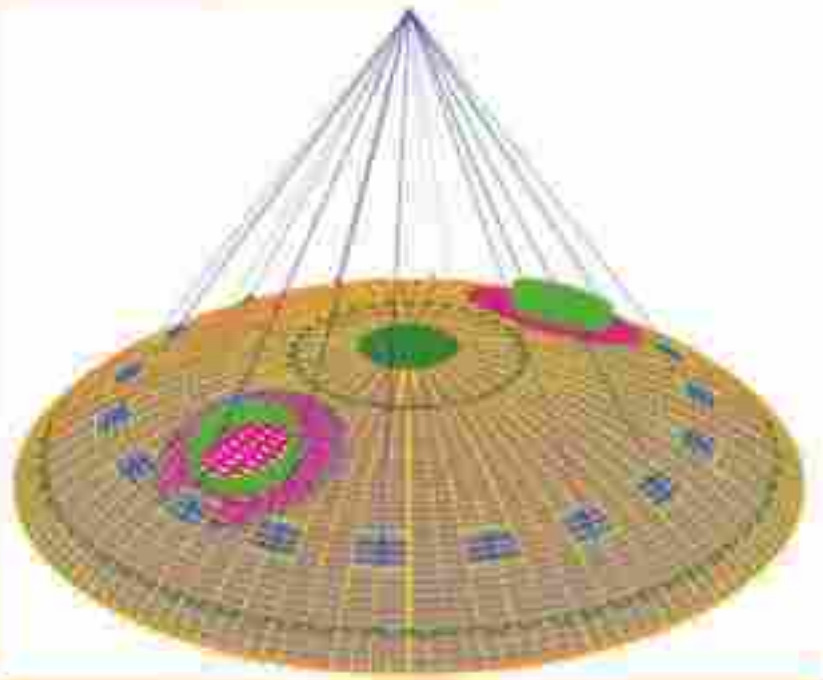
These have been successfully indigenously developed and proposed deployment from KAPP-3&4 onwards for the first time in PHWR is expected to provide ease of construction.

Engineering

Ongoing 700 MWe Projects

3D model based engineering for KAPP-3&4 in Cadmatic software was completed. Civil construction drawings for the main plant buildings and structures have been issued for KAPP-3&4 and RAPP-7&8. Construction drawings for other disciplines for the main plant were issued for KAPP-3 and are in the advance stage of issue for other projects.

The entire engineering process consisting of conceptualization, analysis and design, preparation of detailed construction & fabrication drawings of the



Double curvature toro-spherical dome with two large openings as a single unit

Inner Containment ring beam and dome liner assembly were completed. The self-supporting IC Dome liner system has been engineered to be lifted as a single unit of 375 MT with the help of heavy duty crawler crane. Installation of this 8m high and 46 m diameter, double curvature toro-spherical dome with two large openings as a single unit, is First-of -Its-Kind in the world.

Clearance for major equipment erection of KAPP-3&4 was obtained from AERB. Design analysis & qualification for all major equipment and integrated main Primary Heat Transport System piping was completed. Study of feeder rupture and its impact on neighbouring feeders and leak-before-break analysis on PHT System piping were carried out. Manufacture of FM Bridge & Column assembly and first Fuelling Machine Head for KAPP-3 was completed and delivered to site. Design, development and testing of weir for snout level control in FM Head and installation, commissioning and acceptance testing of FM Control system in FM test facility at R&D center, Tarapur was also completed. Design and engineering of 5m diameter condenser cooling water piping was carried out for the first time by NPCIL.

Engineering scheme for monitoring critical parameters during severe accidents for 700 MWe is completed. Environmental qualification of required sensors, JBs, cables etc. for monitoring the severe accident parameters is in progress.

Development of the replica Operator Training Simulators for KAPP-3 (700 MWe) is underway. Models for the process and C&I of various systems have been developed, tested and integrated. The working of the integrated simulator has been demonstrated. For the first time, Fuel Handling System (FHS) simulations have been taken up as part of this simulator and modelling all manual operations along with selected programs was demonstrated.

GHAVP-1&2

The requisition along with technical specification and drawings for major equipment like Steam Generators, End Shields, Calandria, PHT headers, Pressuriser, FM bridge & columns, FM heads, Moderator Heat Exchangers, Primary Coolant Pumps for GHAVP 1&2 were issued for taking up procurement action. Submissions were made to AERB for seeking siting consent of GHAVP-1&2. Application for excavation consent was submitted to AERB. Seismo-tectonic studies for GHAVP site were completed and Design Basis Ground Motion (DBGM) has been generated and submitted to AERB. The tendering process and bid evaluation was completed for the work of 3D modelling and plant engineering and ready for award of contract. Tender for main plant civil work is prepared and ready for tendering process. Generic study of the piled raft foundation for GHAVP 1&2 is completed.

Stations / Sites

Full scale seismic test of PSS assembly of 220 MWe design was conducted successfully at SERC, Chennai using design basis ground motions of hard rock and soil sites by simulating the seismic motions at multi support locations. Annual upgrades of simulator software for the three existent training simulators at KGS, RAPS and TAPS to match the changes in their respective reference plants were released. For KGS and RAPS simulators new Computer Based System (CBS) system hardware was also commissioned to match the changes in the reference plants. Installation and Commissioning of Electrical Supervisory Control and Data Acquisition (ESCADA) and Reactor Regulating system in KGS unit -2 was completed. The Safety Critical Application Development Environment (SCADE) based new Reactor Regulating System was developed, tested and commissioned in the TAPS-4 simulator environment. Design Basis Ground Motion (DBGM) was generated in-house for KKNPP-3&4 and submitted to AERB. The design & customization activity of the Plant Lifecycle Management software have been completed for implementation across Directorates of Engineering, Procurement and Projects. The required hardware & software have been supplied and the training is imparted to all the user

Development in R&D-Electronic Systems

The in-house design and development efforts in R&D-ES are concentrated towards

electronics and computer based controls and instrumentation systems for 700 MWe projects. The efforts are mostly application-oriented design and development specifically addressing the Control & Instrumentation (C&I) requirements emanating from power plants under construction and from operating stations.

R&D relating to PHWRs

In-situ measurement of mechanical properties of a reactor operated pressure tube eliminates the need to prepare samples for conventional tests and personnel radiation exposure. A ball indentation based system, developed by BARC was used to estimate the mechanical properties of Q10 pressure tube removed from KAPS-2 after 15 hot years of operation.

A fuelling machine based tool is developed for remote repair of end fitting E face. The tool has been manufactured and tested using fuelling machines at KAPS. Deployment of this tool will result in saving of reactor shut down time and man-rem. Inside Diameter Measurement Tool (IDMT) is a



In-situ property measurement system (IPyBMS)



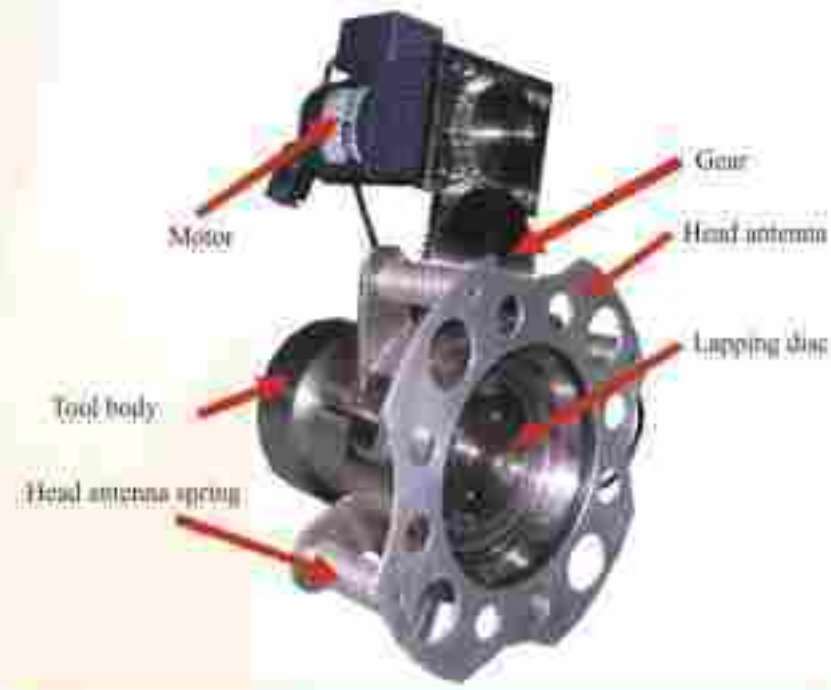
IPyBMS being inserted into Q10 for testing



Inside Diameter Measurement Tool for 220 MWe PHWRs



Inside Diameter Measurement Tool (Mark-2) for 220 MWe PHWR

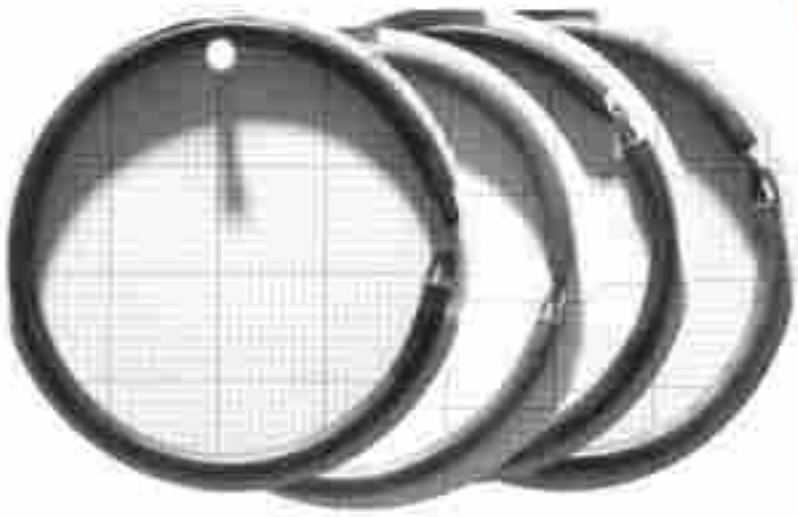


E-face Lapping Tool for 220 MWe PHWRs

Fuelling Machine (FM) operated tool for ID measurement of Coolant Channel Pressure Tube. Upgraded version of the tool was deployed for measurement of 41 channels at KAPS-2.The performance of the tool was found to be satisfactory. A new tool Mark-2 for 220 MWe PHWR is designed and manufactured to further enhance performance of tool in sagged channels.

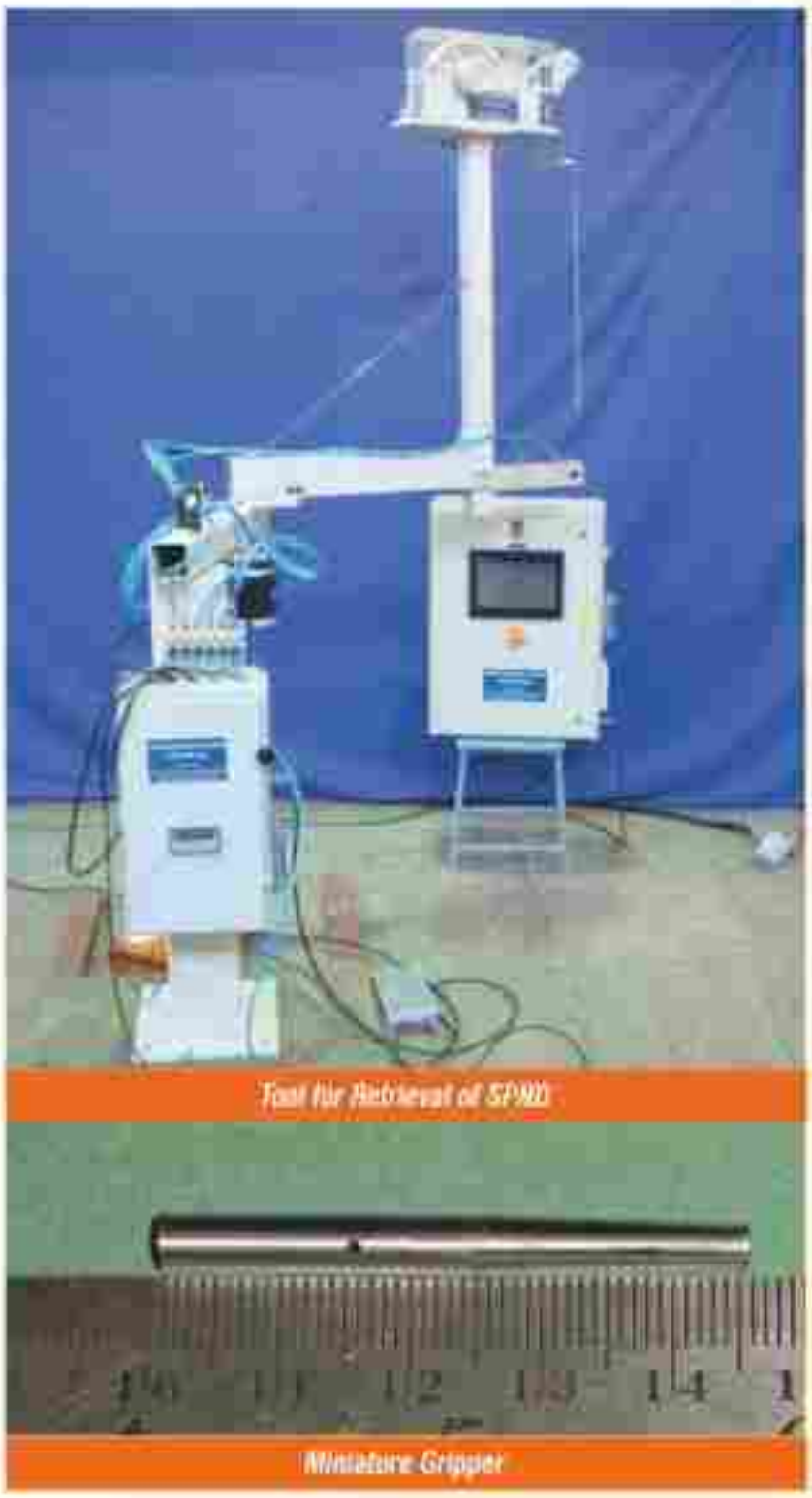
A new hot cell facility for evaluating the performance of irradiated LWR fuel bundles, PHWR pressure tubes and structural components was commissioned at BARC, Trombay. Post irradiation examination has been done on two PHWR fuel bundles and a full length irradiated pressure tube.

As a part of PHWR life management, one of the coolant channels was removed for detailed post irradiation examination after 8 years (S-7) and another channel (Q-10) after 15 operating years.



Tight fit Zr-2.5Nb-0.5Cu irradiated garter springs from the Q-10 channel

Role of trace element impurities on the toughness level was observed. Garter springs of the Q-10 channel were studied in detail to demonstrate their suitability for continued operation.



Tool for Retrieval of SPND

Miniature Gripper

A customised tool has been developed having a miniature gripper of 4.5 mm outer diameter for retrieval of Self Powered Neutron Detectors (SPND) from the carrier tube at TAPS-4.

The fracture toughness parameters of IPHWR Zr-2.5Nb alloy pressure tubes were evaluated by attaining the test temperature by heating from ambient or cooling from a peak temperature of 400 °C to the test temperature between 25 °C and 300 °C. Fractographic examination of Zr-2.5Nb alloy pressure tubes of IPHWR revealed that the alloy is less susceptible to hydride embrittlement.



Fractographs for (a) heating (showing higher number of splits) and (b) cooling tests

Microstructure and mechanical properties of a rejuvenated ammonia cracker tube after service exposure of 55,000 h for the second time were characterized for its behavior after rejuvenation.

The effect of irradiation on the deformation mechanisms in zirconium alloys were studied in collaboration with University of Manchester, under Indo-UK partnership for civil nuclear power cooperation.

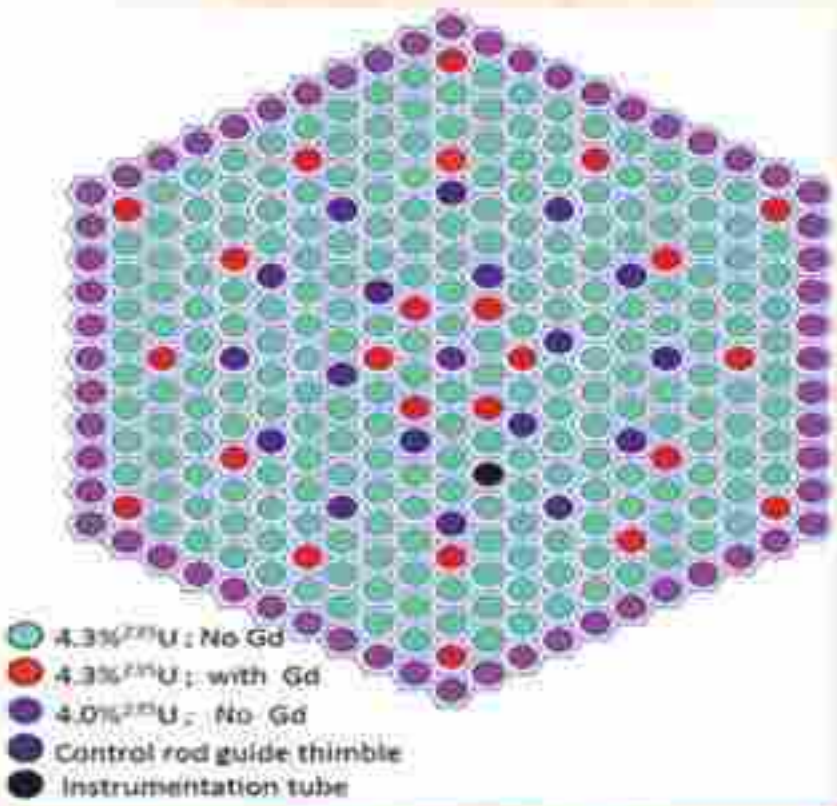
The relative rates of oxidation and sensitivity towards dissolved oxygen content for Zr-2.5Nb pressure tube manufactured through different fabrication routes for PHWR's and AHWR were established. A beneficial effect of surface machining and bulk cold working on the oxidation behaviour of Zr-2.5Nb pressure tube was established and cold working was shown to be beneficial.

Simultaneous determination of diffusion coefficients of hydrogen and deuterium in Zr-2.5% Nb alloy carried out indicated that the activation

energies of diffusion for H_2 and D_2 are nearly the same although the diffusion coefficient for H_2 was observed to be more than that of D_2. These observations are extremely useful in understanding the ingress of H_2 and D_2 in such alloys.

R&D relating to LWRs

The 900 MWe Indian Pressurised Water Reactor (IPWR) has been re-optimized with the use of differentially enriched fuel assembly for enhanced fuel utilization. The assembly uses 4.3% ^{235}U in the inner 251 pins and 4.0% ^{235}U in the outermost 60 pins. This assembly also uses 4.5% Gd in 24 of the inner 252 pins. With an average ^{235}U content of 4.24%, it



Profiled fuel assembly for IPWR configuration

was possible to achieve the same discharge burnup and cycle length of 410 Full Power Days (FPDs). The critical boron concentration at Beginning of Cycle (BOC) was found to be 763 ppm. The initial core of IPWR has been designed with three different fuel assemblies with varying ^{235}U enrichments, namely 1.6%, 2.3% and 4.5% with 5.0% Gd_2O_3.

An Integrated Test Facility (ITF) for validating the Control & Instrumentation systems of Compact LWR has been setup. ITF will enable validation of control system performance with respect to system requirements, accident responses and failures in processes, equipment & sensors prior to their commissioning in the platform. It will also serve as a platform for training of operators and commissioning crew.

An underwater Weld Inspection Manipulator called BARC Vessel Inspection System (BARVIS) based on Multi Ultrasonic Sensor InspeCtion (MUSIC) methodology was developed for Ultrasonic Testing (UT) and in-service inspection of welds in



BARVIS assembly



BARVIS PROBE holder



BARVIS on parking stand

upper shell region of Reactor Pressure Vessel (RPV) for TAPS-1&2. MUSIC comprises of eight miniature ultrasonic sensors of various configurations for detection of different types of flaws in weld, heat affected zone and parent material. The design has addressed all the complexities and hindrances in approaching the core belt region welds. The manipulator operation has been automated with safety interlocks to perform weld cleaning, horizontal scan and vertical scan of the weld using multiple probes. BARVIS has been qualified for underwater application and for reactor worthiness. The operators were trained for underwater installation and operation of BARVIS.



Reactivity Meter for Experimental Reactor Critical Facility



C&I for Experimental Reactor Critical Facility



Hanger Assemblies with Gamma Compensated Boron lined Ionization Chambers

A Digital Reactivity meter has been developed for accurate, direct, online and real-time indication of the nuclear reactor's core reactivity using neutronic signals and deployed during the physics experiments in Experimental Reactor Critical Facility. C&I system for Experimental Reactor Critical Facility was commissioned and deployed during the experiments in multiple reactor configurations in the facility.



High Sensitivity Helium-3 (^{3}He) neutron detector

Hanger-assemblies with Gamma Compensated Boron Lined Ionization Chambers have been developed, tested and qualified to meet the vibration and shock conditions.

In-house developed ^{3}He detectors of 200cps/nv nominal sensitivity & gamma tolerance of 100mR/hr were used for conducting the physics experiments to measure the fission power by monitoring the reactor core neutron flux and during approach to criticality without presence of external neutron source. Measurement of dρ/dh at different temperatures from ambient to 289°C without activating the fuel could be achieved using these detectors within reactor power of 10mW to 100mW.

CHAPTER-2

NUCLEAR POWER PROGRAMME STAGE-II



Overall View of PFBR



Overall View of Turbine Floor

FAST REACTORS

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

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

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

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

Prototype fast breeder reactor

PFBR is a 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.

The civil construction of nuclear island buildings has been completed. The reactor assembly of PFBR is nearing completion with all major reactor equipments in its place.

Control Plug which houses the absorber Drive Mechanisms has been erected and subsequently the control safety rod Sub- assembly and diverse safety rod sub- assembly have been erected. High Temperature Boron coated neutron detectors required for Initial Fuel Loading Operation was received and erected in Control Plug.



AHX Type - B Erection

Transfer Arm which is used for in-vessel transfer of sub-assemblies was received and erected. Pre commissioning of the same was under progress. Inclined fuel transfer machine which is used for ex-vessel transfer of sub-assemblies was erected and the trial runs of transfer pot movement in primary and secondary systems were completed. Both the fresh and spent sub-assemblies Cell Transfer Machine were commissioned from Local control Panels.

Major sodium system components including intermediate heat exchangers (4 nos.), sodium to air heat exchangers (4 nos.) were received and erected. Commissioning of integrated secondary sodium system first loop in steam Generator Building -1 which consists of seven sodium circuits were commenced and pressure hold test of argon lines were completed successfully. Primary Sodium Pumps were erected and pre-commissioning of the motor drives with variable frequency drive was completed. Steam blowing for steam lines in Steam Generator building -2 was completed.

The construction of fuel building was completed and erection of major fuel handling components was also completed. Most of the equipment were commissioned locally from local control panels. Fuel handling equipments commissioning from control room console was under progress. Commissioning of switchgear interface programmable logic controllers was completed. Pre-commissioning of all Main control room, Handling control room, Local control panels were completed.

Commissioning of the conventional and auxiliary supporting systems such as raw water,



Sea water intake tunnel

emergency service water, demineralized water, compressed air were completed. Service building Air washer system was commissioned. Preheating of the main vessel by air was completed.

The civil construction work of turbine building was completed and erection of turbine equipments and erection of all auxiliary equipments were also completed. Turbine box-up and main steam piping was completed and major milestone of Turbine rolling on barring gear was also completed. Auxiliary boiler burn up and steam blowing activities were completed. Condenser water fill test on shell side was completed. In Turbine Plant, no load test for Motor Driven Boiler Feed Pump (MDBFP) was completed. No load test of jacking oil pump for Turbine Driven Boiler Feed Pump (TDBFP) was also completed.

The construction of forebay is nearing completion. The civil construction works of sea water pump house was completed and erection of condenser cooling water pumps, auxiliary sea water pumps were also completed.

In Sea water intake structure , the lining concrete of sub marine tunnel was completed up to 567m. Excavation of hard rock was completed. The horizontal sea water intake tunnel and vertical shaft of the tunnel was connected and made through. Concrete of column & wall of intake super structure was completed up to RL 13.95 m

The project has achieved an overall physical progress of 97.635% at the end of November-2014.

FBR 1&2 pre project activities

Site selection committee constituted by DAE has approved Kalpakkam site for FBR 1&2.

BHAVINI completed the "Environmental Impact Assessment" studies in line with the directives given by the Ministry of Environment and Forest (MoEF) while approving the Terms of Reference (ToR) for Environmental Impact Assessment studies.

Based on further review by MoEF, additional data was collected. BHAVINI has prepared the siting consent document and submitted to AERB for 'siting clearance'.

BHAVINI has approached Tamil Nadu Pollution Control Board for clearance of FBR 1&2. BHAVINI is also planning to arrange public hearing in the near future and will seek MoEF clearance subsequently for FBR 1&2 at Kalpakkam.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

Fast Breeder Test Reactor (FBTR)

During 2014-15, Fast Breeder Test Reactor (FBTR), continued to play a significant and critical role as a test bed for various materials including fuels. The twenty third irradiation campaign was successfully completed during November 2014 and for the first time the reactor power was raised to the highest ever level of 24.5 MWt, generating an electrical power of 5 MWe. The total operating time of the reactor and turbo generator was 669 hours and 481 hours respectively and the total thermal energy and electrical energy generated was 12937 MWt and 1.973 MU respectively. With the expected duration of the 23rd irradiation campaign of about 75 days, it is planned to start the 24th campaign in March 2015.

A new device for fast flux activation studies above the core was installed and commissioned. Experiments were carried out by introducing the foil, one of the secondary loops was drained and weld joints of expansion tank were inspected. As a part of biennial surveillance, level measurements of grid plate were carried out. Filter banks of the Reactor containment building were replaced and tested. As a

part of post-Fukushima retro-fits, entry points to the building were elevated to take care of the revised design basis flood level of 1000 years return period as per current safety norms.

R&D relating to PFBR

At BARC, Uranium based alloys containing Zr and Nb were synthesized by arc melting technique and their phase transition temperatures and specific heat were determined using high temperature calorimeter. Microstructure evaluation of as-cast and annealed U-Zr (Zr= 2, 6 and 10 wt. %) alloys, promising candidates for core materials in Generation IV reactors, has been carried out using positrons as a probe.

Melting point of 19.9 mol% NaF-35.2 mol% KF-44 mol% RbF salts was calculated to be 563 °C based on previously developed thermodynamic database. Viscosity of this molten salt is lower than that of molten salts containing BeF_2.

IGCAR continued its technical support to BHAVINI towards completion of PFBR construction, commissioning and safety clearance from AERB. Some of the notable contributions made for BHAVINI included establishing preheating procedure for reactor assembly components based on a scaled down mockup studies, full scale mock tests and evaluation for core subassemblies, successful erection of inclined fuel transfer machine, seismic qualification of electromagnetic pump, solving technical problems raised during commissioning of the primary sodium pump coupling, trailing cable system for rotatable plugs and qualification of leak collection trays and sodium bubblers. In addition, strategy/procedure for the first approach to criticality of PFBR with an initial core configuration (limiting the number of fuel subassemblies to 120) were finalized. Towards these activities, all the twenty chapters of the Preliminary Safety Analysis Report were prepared and were reviewed by the Internal Safety Committee. BHAVINI and IGCAR participated in the AERB Specialists Group meetings to obtain approval for technical specifications towards nominal power operation.

Acceptance Criteria for PuO2 agglomerate size in MOX fuel Matrix

Issues related to physical appearance of larger size PuO_2 particles (more than 100 µm) during manufacture of MOX fuel pellets through powder metallurgy technology were investigated in detail with respect to ASTM specification, reprocessing aspects (dissolutions) and thermo-mechanical effects. Based on the study, acceptance criteria for PuO_2 agglomerate size in MOX fuel (max. allowable size of 300 µm) were established.

Testing of Inclined Fuel Transfer Machine

Testing of Inclined Fuel Transfer Machine (IFTM) in hot air for 535 cycles was carried out at M/s MTAR, Hyderabad under simulated temperature conditions similar to that in the reactor during fuel handling. Heating of the various components of the machine to 120-200°C was done and temperatures at various locations were achieved as per intended design. The performance of the machine was verified to be smooth. After dismantling, the machine was dispatched and erected at BHAVINI site.



Erection at site and subsequent tests of IFTM

Seismic Qualification of Special Components and Equipment

Seismic qualification was carried out, using the 10 t capacity tri-axial shake table of size 3x3m, for high resolution differential pressure monitoring system and the control panel used to ensure the automatic operation of the material airlock in Reactor Containment Building. Both functional and structural integrity were demonstrated during and after seismic qualification.



Annular Linear Induction Pump



Differential Pressure Monitoring System

Confirmation of Pre-heating Scheme through Mock-up Studies

A dedicated mockup facility was established to confirm the preheating strategy on 1/13th scale down model of reactor assembly with all internals and one full scale mockup for fuel subassembly was also established.

Air flowing in open loop was used as preheating medium to simulate the preheating scheme in both the models. During the mockup, it was observed that all the structures are simultaneously heated up at uniform rate and the ΔTs (295 K max.) are within allowable limits (303 K max.). There was sufficient margin for any differences from model to full scale results. During fuel sub-assemblies mockup studies, all the parts above 423 K and variation in radial direction is within the limits and axial temperature variation is within the estimated values.



Reactor Assembly Preheating Mockup



Full scale mockup for Fuel sub-assemblies

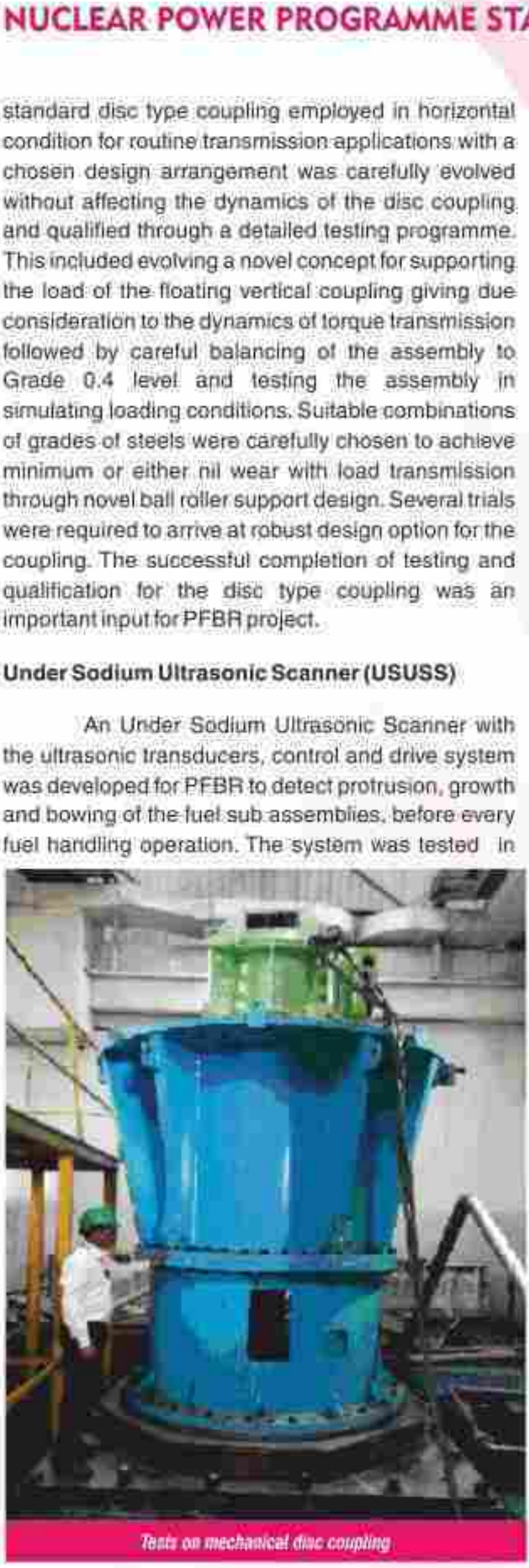
Qualification of coupling for Primary Sodium Pump

Primary Sodium Pump is a vertical centrifugal pump with a long shaft of about 11 meters with impeller at the bottom end. Primary Sodium Pump is supported at the top over the reactor roof and the top end of the shaft is connected to 3.6 MW / 690 rpm motor through a mechanical coupling. A

standard disc type coupling employed in horizontal condition for routine transmission applications with a chosen design arrangement was carefully evolved without affecting the dynamics of the disc coupling and qualified through a detailed testing programme. This included evolving a novel concept for supporting the load of the floating vertical coupling giving due consideration to the dynamics of torque transmission followed by careful balancing of the assembly to Grade 0.4 level and testing the assembly in simulating loading conditions. Suitable combinations of grades of steels were carefully chosen to achieve minimum or either nil wear with load transmission through novel ball roller support design. Several trials were required to arrive at robust design option for the coupling. The successful completion of testing and qualification for the disc type coupling was an important input for PFBR project.

Under Sodium Ultrasonic Scanner (USUSS)

An Under Sodium Ultrasonic Scanner with the ultrasonic transducers, control and drive system was developed for PFBR to detect protrusion, growth and bowing of the fuel sub assemblies, before every fuel handling operation. The system was tested in water and in sodium and the same was shifted to BHAVINI for use in PFBR, after satisfactory performance.



Tests on mechanical disc coupling



Under Sodium Ultrasonic Scanner

Transfer Arm

The performance qualification of the Transfer Arm in sodium was completed. The machine was tested for 10% (600 cycles) of the total number of

cycles expected in the life time of the reactor at a fuel handling temperature of 473 K in two phases of 300 cycles each. In between the two phases, endurance testing of the machine, at the reactor operating temperature of 820 K was also carried out, thus simulating the parked condition of the machine during reactor operation. The transfer arm was transported to BHAVINI for installation in reactor, after successful testing.

Calibration of Permanent Magnet Flow Meters

Sixty two permanent magnet flow meters of different categories required for PFBR, were calibrated analytically by dimensional and flux density measurement with an accuracy of ±7 units. Sodium calibration of various sizes of flow meters was completed.

Development of SONAR Device

Functional testing of SONAR device of PFBR required for the measurement of subassembly vibration during commissioning was completed in water. The device is expected to be delivered to BHAVINI after completing the modifications pertaining to enhance the performance of the system.

In-situ regeneration of secondary cold trap

Cold traps are used for purifying sodium in the fast reactors. Hydrogen is one of the main impurities to be removed in secondary system of FBR. Vacuum decomposition method was demonstrated to regenerate the secondary cold traps in-situ, using a model of the PFBR secondary cold trap, in the Steam Generator Test Facility. The first campaign of in-situ regeneration of model secondary cold trap of PFBR was successfully completed. Around 70 % of hydrogen could be brought out and accounted for using an electro-chemical hydrogen burner during the regeneration.

Hot air testing of Inclined Fuel Transfer Machine

Inclined Fuel Transfer Machine (IFTM) is used for handling and transferring of subassemblies in and out of the main vessel of PFBR. It was planned to test 10% of envisaged life in reactor (600 cycles) to qualify the performance of the machine. Qualification of secondary side components of IFTM was carried out through integral testing of IFTM. 65 out of 600 cycles were done in air at room temperature and remaining 535 cycles were carried out in hot air with simulated temperature distribution. During testing the movement of transfer pot was smooth. The motor current and torque recorded were found to be within the specified limits for both hoisting and rotatable shield leg (RSL) rotation. Smooth locking and unlocking of RSL was also achieved and the IFTM was delivered after testing.

Lifetime studies on PFBR inflatable seals

In the Prototype Fast Breeder Reactor (PFBR), elastomeric seals are provided to seal the annular gap between rotating and stationary parts of the rotatable plug support arrangement. Towards qualification of the seals, tests were carried out, to ensure safe operation of PFBR seals for their entire expected life of 10 years, simulating and reactor operation requirements. About 120 cycles of operation were completed and the seals were qualified for two fuel handling campaigns.

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

The conceptual design of FBR 1&2 was revised to meet the safety criteria evolved internationally after Fukushima, while improving the breeding potential. The salient aspects included in the revised conceptual design were: heterogeneous core to achieve sodium void reactivity coefficient less than unity and breeding ratio around 1-2, simplification of decay heat removal systems and introduction of passive shutdown and safety decay heat removal systems to ensure reactor safety under Design Basis Events as well as Design Extension Conditions. Design features were conceived for the 'Practical Elimination' of those events which have potential to cause severe core damage and consequently high radioactivity release. In addition, important changes were made on the reactor assembly, secondary sodium systems including pumps and steam generators and fuel handling systems. The materials for secondary sodium piping were changed for the cold leg components. The number of steam generator units was optimized with respect to number of units and height taking into account the manufacturability and transportation

aspects. Based on an elaborate optimization studies, the capacity of FBR 1&2 was increased from 500 to 600 MWe. As a result of these efforts, a significant specific cost reduction of 25 % was indicated. The conceptual documents were reviewed thoroughly by independent experts.

The first approach to criticality is in progress. Chapters of Preliminary Safety Analysis Report on reactor physics, core engineering, reactor assembly, steam water system and events analysis need re-evaluation and detailed study. Accordingly, all the analyses were completed and Preliminary Safety Analysis Report chapters were prepared.

The core physics parameters for the core was estimated by using FARCOB, ERANOS and MCNP4C codes system. Core mapping, minimum core for criticality, approach to criticality, batch and sub-batch sizes including the detectors count estimation and absorber worth estimation during the core loading, subassembly loading scheme, power distribution, perturbation worths, absorber rod worths and shutdown margin estimation, S-curve, reactivity coefficients, neutron flux distribution, neutron spectrum, plutonium buildup, decay heat, burnup management, scheme for core expansion to nominal core were some of the aspects that were studied.

Issues related to thermal hydraulics and structural mechanics were reviewed critically. The primary sodium pump flow through reactor core was fixed at 63% from thermal striping considerations. Due to change in the sub-assemblies thermal power and flow through the sub-assembly belonging to all flow zones, the temperature distribution in the sub-assemblies for all the zones were evaluated and adequacy with respect to design safety limits on the fuel, clad and coolant were checked. The analyses for the power, flow, nominal and hot spot clad temperatures and coolant temperatures were evaluated in detail. The chapter on core engineering reflecting the above aspects was completed.

Chapter on Reactor Assembly reflecting the updated technical data, operating conditions, adequacy and the results of structural mechanics and thermal hydraulics was completed. Structural mechanics and thermal hydraulics limits were checked and verified. With 63% primary sodium pump flow, the amplitude of fluctuation of sodium free level was less than ±40 mm which corresponded to the nominal flow. The hot pool sodium level was low by 200 mm, compared to that of full core. By thermal hydraulic analysis, it was established that there is no risk of gas entrainment. As the sodium pool temperature is 764 K, the heat flux to bottom plate of top shield was found to be 930 against 1150 W/m^2 with full core, whereas to the vertical shells, it is 0.86 times that of full core.

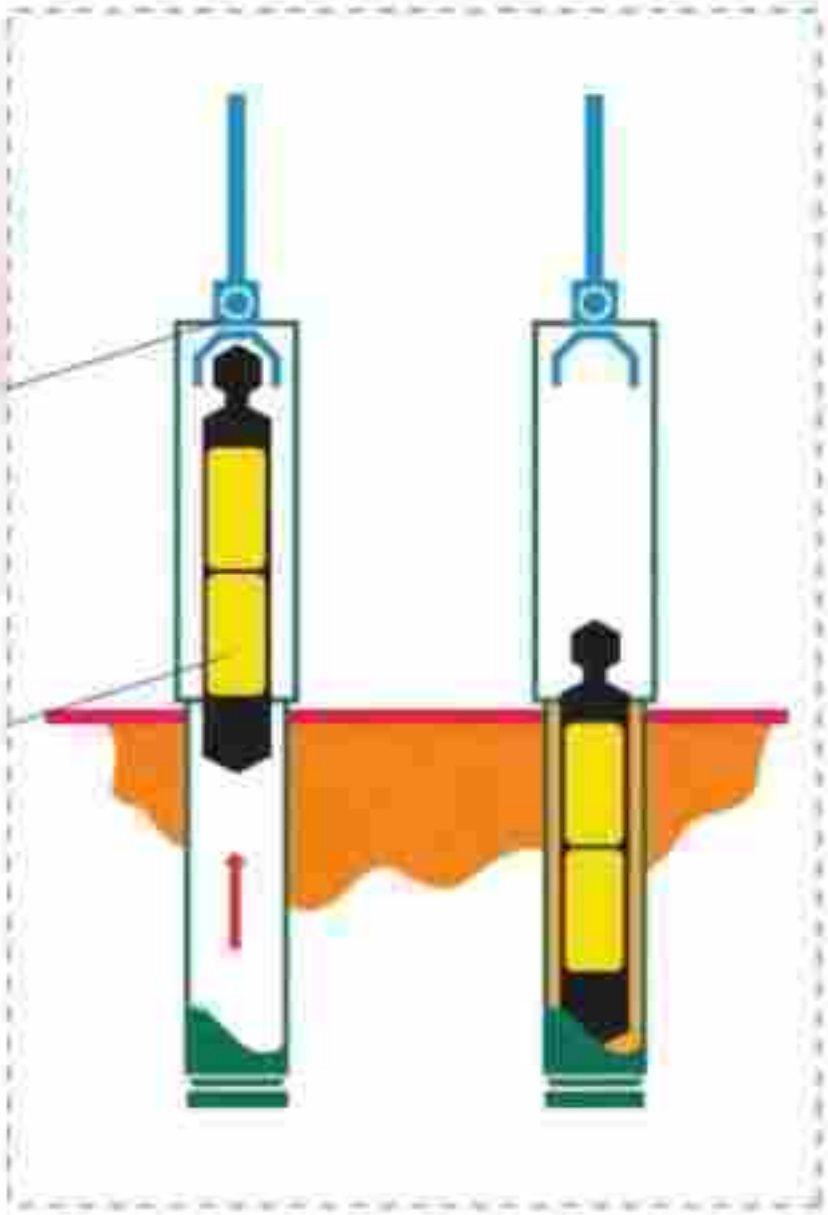
Steam water system parameters including for the turbine were evaluated for the operating temperature conditions. BHEL turbine designed by Siemens was analyzed and confirmed for operation considering the minimum flow requirements, wetness at different stages of the turbine and heating of turbine due to churning at low flows.

Improved Reactor Shutdown System

Enhancing the reliability of Control & Safety Rod Drive Mechanisms (CSRDMs) and Diverse Safety Rod Drive Mechanisms (DSRDMs) (as in PFBR) with the introduction of passive safety features and adequately addressing the re-criticality issue were the major improvements under consideration. Towards further improving reliability of shutdown systems (at least by one order with respect to PFBR), passive safety features were introduced. Stroke Limiting Device to limit the uncontrolled withdrawal of control and safety rods in their drive mechanisms and temperature sensitive magnet / magnetic switch (Curie point magnet) in the Diverse Shutdown Rod Drive Mechanisms. Further, introduction of Hydraulically Suspended Absorber Rods that would be dropped immediately once the primary sodium flow reduction is caused by the initiating events such as rupture of more than one primary pipes, seizure of all primary pumps, etc. is under consideration. In order to avoid re-criticality,



TSEM in diverse safety rod drive mechanism

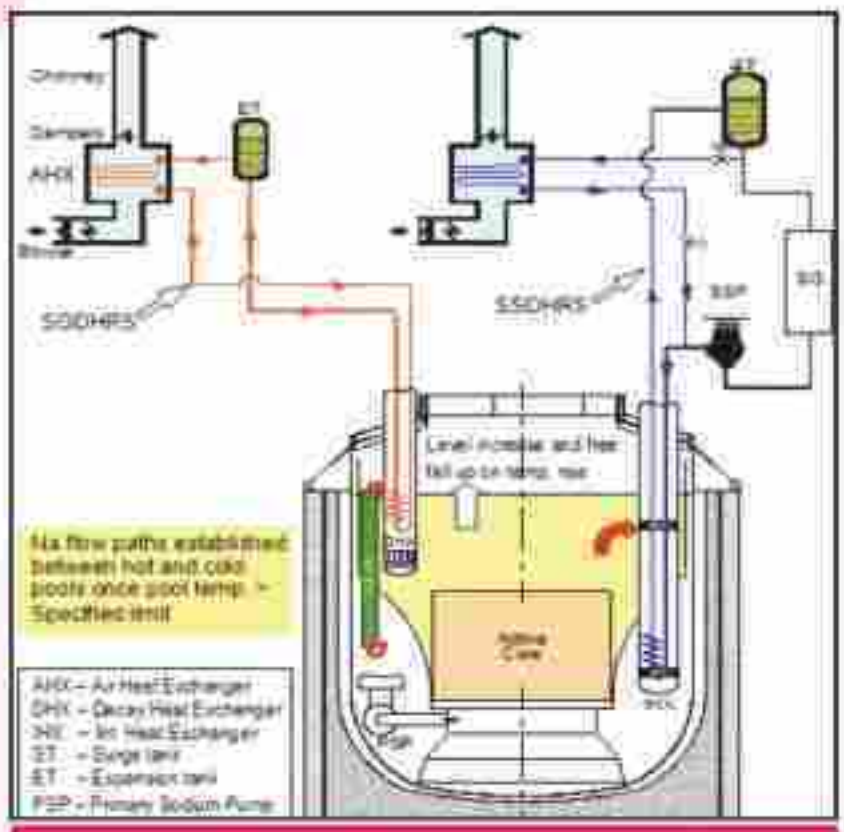


Hydraulically Suspended Absorption Rod

adequate number of Ultimate Shutdown System (USD) that work on dropping of either liquid (^{7}Li) or granules (enriched B_4C powder) will be introduced.

Judicious Combination of Active & Passive Features for DHR Systems

For accomplishing Decay Heat Removal (DHR) functions during various operations; four DHRs, each of 10 MWt capacity will be introduced in the secondary sodium circuits (SSDHR) instead of OGDHR. For taking care of DHR during Station Blackout (SBO) and Design Extension conditions, presently incorporated Safety Grade Decay Heat Removal (SGDHRs) in PFBR will be retained. For the Post Accident Heat Removal (PAHR) condition, a few pipes penetrating through inner vessel under consideration to augment the flow paths (large



Decay heat removal provisions in FBR-500

perforation) created during fuel melt-through scenario to provide adequate natural circulation

Functional Performance of Sodium Bubbler

Due to explosive nature of potassium oxide, it was proposed to opt for sodium bubbler instead of



Sodium bubbler experimental set up



Experimental Setup for performance evaluation of fusible plug

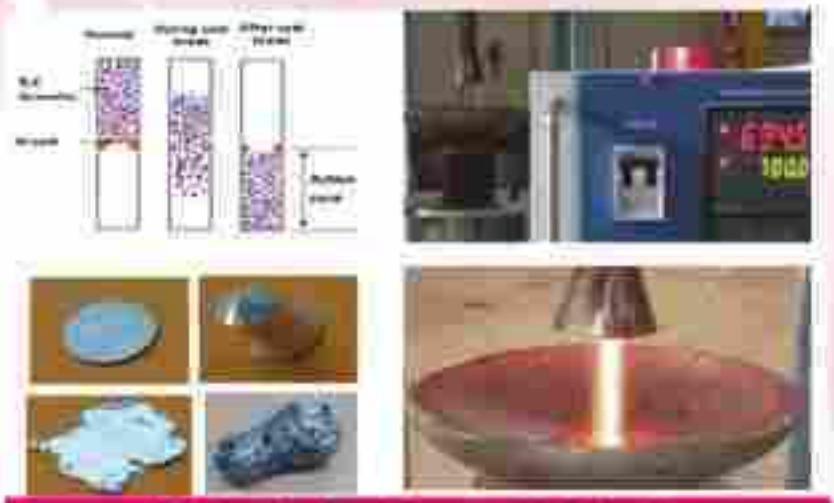
sodium-potassium bubbler for purification of argon from the cover gas. Design of sodium bubbler was completed to match the process requirements. In order to validate the functional performance, a mock-up study was conceived. The tests have provided some important guidelines for modifications towards achieving improved performance.

Evaluation of Innovative Fusible Plug for Sodium Leak Collection Trays (LCTs)

A large number of Leak Collection Trays are strategically arranged under the secondary sodium piping to collect leaking sodium into a sodium dump tank connected through a low melting fusible plug system. The sodium fire will be extinguished due to oxygen starvation. Transient thermal analyses were carried out to arrive at the suitable thickness of the woods metal fusible plug required in the header – transfer tank junction, for effective melting of the fusible plug and complete draining of the leaked sodium. Series of experiments were conducted to confirm the functionality and performance evaluation of fusible plug and subsequent draining of sodium into dump tank by leaking 10 kilograms of sodium at different temperatures. Observation showed that melting of fusible plug within 10 seconds and collection of leaked sodium into dump tank. The collection of hot sodium in dump tank was also confirmed by LVDT measurement and video image of stainless steel bellow on which dump tank is hanged. The experiment qualified the fusible plug for leak collection tray system.

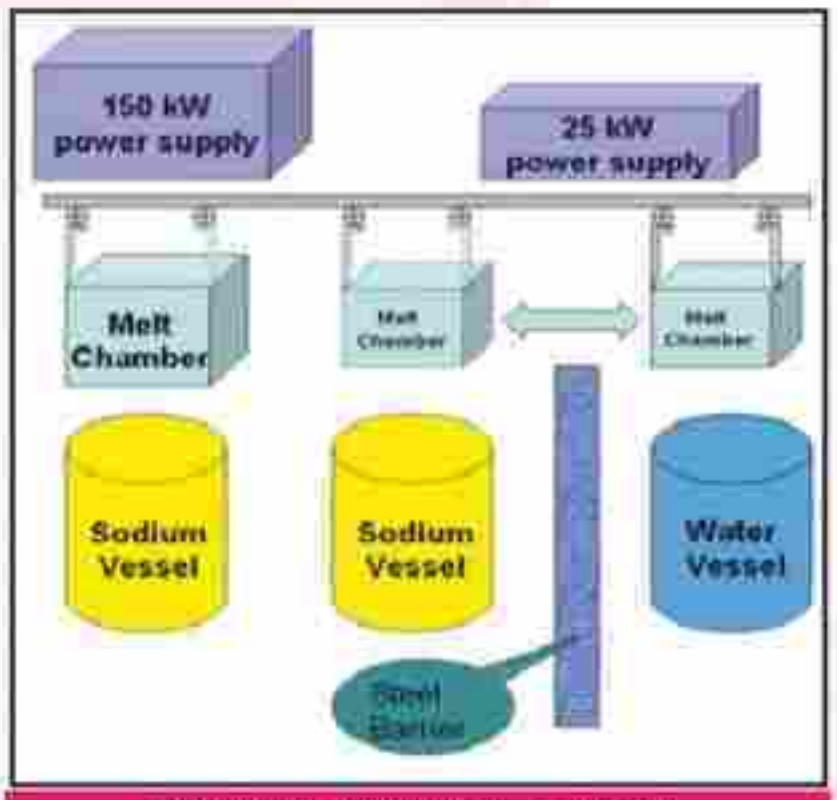
Benchmark Experiments on Ultimate Shut Down System

In addition to the CSR & DSR shutdown systems, it is envisaged to have a passive system which is independent of other systems, which acts based on the feedback from the core and is referred as ultimate shutdown system for the FBR 1&2. The proposed ultimate shutdown system uses a thermal



USS based on drop of Boron carbide Granules

fusible seal, which holds the boron carbide granules above the active core during normal operation. During untoward event, when the sodium temperature goes beyond the melting temperature of the seal, the granules get released into the active core and thereby shutting down the reactor. The experimental simulation of a single pin with an aluminum seal was carried out for concept validation and to choose optimum fusible seal. The experiment was done with two types of fusible seals viz. circular disc and conical plug. The experimental results are encouraging and further detailed engineering is in progress.



SOFI Platform – Indigenous furnace with high capacity power generator

Molten fuel coolant interaction (MFCI) in SOFI Platform

Under severe accident conditions, melting of

Development of Wireless Sensor Networks for Nuclear Reactor Applications

Development of Wireless Sensor Networks was taken up towards minimizing cabling in congested areas, avoiding cell penetrations in nuclear facilities and also towards cutting down the costs. Twenty seven Wireless Sensor Nodes were designed and developed in-house. The nodes were tested for EMI/EMC compliance and deployed for monitoring temperature and humidity, detecting the sodium leaks, measuring electrochemical cell potential, actinide drawdown process temperatures, vibration signals, flow rate signals etc. at various facilities of the center.

STUDIES ON MATERIALS FOR FBRS

The influence of Dynamic Strain Ageing (DSA) on the ratcheting behavior of the 316LN austenitic stainless steel was investigated as a function of mean stress (m), stress amplitude (a) and temperature. Test results obtained under different combinations of m- a were analyzed at 823 K in order to arrive at a map delineating different deformation regimes occurring in presence of dynamic strain ageing viz. Ratcheting (continuous accumulation of strain), Strain Burst (sudden avalanche of strain) and Elastic Shakedown (fully elastic deformation). Elastic shakedown was observed in the temperature range 623-823 K for cycling at low stress amplitudes.

Modified 9Cr-1Mo steel, used in steam generator of PFBR was subject to thermomechanical treatment and it was observed that processing decreased creep rate and increased rupture life significantly compared to those of normalised and tempered steel.

The influence of prior deformation on the sensitization kinetics of nitrogen modified 316L SS was studied. TTS diagrams established for high nitrogen alloyed 316LN SS indicated that sensitization temperature range is 823-973K and the nose temperature is at 923K. The Electrochemical noise studies carried out showed that with increase in the nitrogen content, the standard deviations of partial signal of low-frequency crystal decreased significantly, indicating control in the propagation of pits. Electrochemical noise studies in modified 9Cr-1Mo steels with different boron and nitrogen contents in air-saturated 0.05M NaCl solution showed that the material with low boron (60 ppm) and high nitrogen content had the lowest number of high current transients indicating improved passivation.

To demonstrate the feasibility of thixo-casting of austenitic stainless steel, a cooling slope was specially designed and fabricated. Thixo-casting of AISI 304L stainless steel was carried out successfully using the slope, for the first time in the country and an ingot of 10 kilograms was produced.

Activated Tungsten Inert Gas (A-TIG) welding was employed successfully, for the first time, for welding Alloy D9 hexcan with 316LN stainless steel foot of the sub-assembly using a single-pass welding procedure without any filler addition and edge preparation. The welding parameters were optimized and the weld joint passed all the test requirements as per the PFBR specification.

As part of the development of the setup for determining the in-pile creep rupture behaviour of fast reactor cladding tubes, an out-of-pile experiment was carried out in an electrical furnace using pressurized capsule attached with thermocouple in its gas region to detect the rupture event. A definite shift in the temperature profile was observed at the time of rupture which can be used to identify the rupture of pressurized capsule during an in-pile experiment.

Pressurized capsule using the modified 9Cr-1Mo (T91) steel cladding tube for metallic fuel pins was developed to determine the in-pile creep behavior the T91 steel cladding tube material.

Mortar bars were cast and cured in water and then immersed in sodium hydroxide solution at 353 K for 14 days, showed that the alkali-aggregate reaction leads to drastic expansion and reduction in flexural strength and cracking.

FBR - FRONT END FUEL CYCLE

As per requirement, the uranium-plutonium mixed carbide fuel pins for FBTR at Kalpakkam were supplied by BARC. Fabrication of (U-Pu)O_2 Mixed Oxide (MOX) fuel pins for 500 MWe Prototype Fast

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Microwave dissolution system inside glove box



Injection Cast Hollow Natural Uranium Slug

Breeder Reactor (PFBR) of BHAVINI was continued and target of fabrication and supply of fuel pins for zero power criticality was completed. Setting up of fourth fabrication line under XII plan is in progress. Nearly one ton MOX were recycled using wet and dry recycling techniques. One more microwave system was commissioned at AFFF, BARC, Tarapur to enhance the recycling of the Clean Reject Oxide (CRO).

As an alternative design to grooved fuel slug being tried at present for mechanically bonded metallic fuel, hollow metallic uranium slug with required smear density could be produced in a specially designed set-up. Figure shows a typical hollow uranium slug fabricated. Development & Fabrication of mechanically bonded metallic fuel for fast reactor was initiated and test run carried out. A glove-box facility needed for fabrication of mechanically bonded U-15Pu binary fuel was installed. Reference Defect Standards were fabricated to qualify co-pilgered Zr lined T91 tubes being manufactured at NFC for mechanically bonded metallic fuel by eddy current testing.

Machining of uranium rods with dimension of 4.9 mm diameter and 1 meter long was carried out to study slumping behaviour of metallic fuel for FBR and delivered to IGCAR.

Studies related to development of (U-PuC) Cermet fuel were initiated. Pellets were fabricated on laboratory scale and characterization studies progressed.

A method was developed for quantification of trace elements including chlorine and fluorine in HEU used for making high temperature neutron flux detector. The method helped remarkably in revealing the cause for failure of one such detector used in PFBR. As a part of quality assurance of FBTR fuel, fifty nine (U,Pu)C samples were analysed for Pu, U contents and isotopic compositions of Pu and Am by using biamperometry, thermal ionisation mass spectrometry and alpha spectrometry.

Irradiation of sphere-pac MOX fuel

A capsule containing two sphere-pac MOX fuel pins and a reference pellet fuel pin was test irradiated for 300 hours in FBTR successfully.

Determination of solidus-liquidus temperatures of fuel materials

The peritectic transformation temperature of the FBTR Mark-II fuel as well as the solidus and liquidus temperatures of the U-Pu-Zr fuels was successfully measured in the glove box using the spot technique. The peritectic transformation temperature of the Mark-II fuel was found to be 2191 5 K while, the solidus and liquidus temperatures of U-19Pu-6Zr were found to be 1305 ± 5 and 1643 ± 10 K respectively.

Oxygen potential measurements on fuel materials

Oxygen potential of (U,Pu) mixed oxide with Pu/(U+Pu)=0.44 was measured over the temperature range 1073 – 1473 K, by gas equilibration technique. Experiments were carried out covering the O/M range from 1.980 to 2.000. It was observed that this composition has higher oxygen potential as compared to the Pu/(U+Pu) = 0.21 or 0.28 fuel at a given temperature and for a given O/M.

Chemistry of boron carbide

Nanocrystalline boron carbide powder was prepared based on modified carbothermic synthesis and microwave assisted combustion synthesis. The

chemical compatibility of boron carbide with D9 clad in the presence of liquid sodium was studied by equilibration experiments.

Decontamination, actinide removal and waste management

The development of electro-deposition method for in-situ treatment of radioactive liquid waste generated during the decontamination of sodium-wetted components of fast reactor was pursued. Trial experiments were carried out for the removal of Cs using Ni foam as electrode material. The solubility of TBP and TiAP was measured in supercritical carbon dioxide medium for effective use in the recovery of actinides from various matrices.

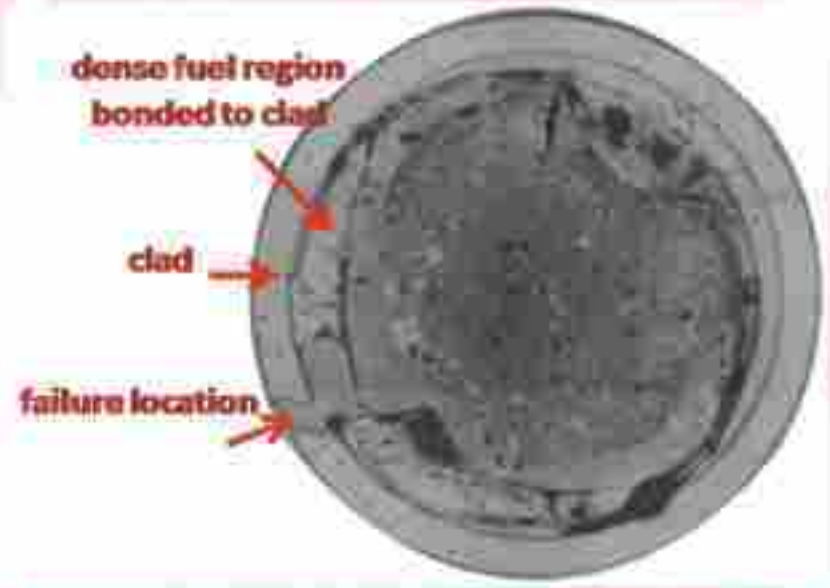
As Iron Phosphate Glass (IPG) is a potential candidate for the immobilization of waste generated from fast reactor, studies were carried out to understand the properties and structure of the glass containing simulated waste. The results indicated that the thermal characteristics remain largely unaltered by the addition of 20 wt.% simulated fast reactor waste.

Sodium cold trap regeneration studies and hydrogen sensing

In order to optimize the process parameters for PFBR cold trap regeneration, studies were carried out in a one-kW Proton Exchange membrane based fuel cell stack, to understand the process of decomposition of sodium hydride. The stainless steel housing for electrochemical hydrogen meters were incorporated in the secondary sodium piping of PFBR along with dummy probes.

Ultra-trace level detection of explosives

An Ion Mobility Spectrometer (IMS) was developed, as an analytical tool, for the detection of materials used as explosives. Detection of a mixture containing 10 ng of TNT and RDX and 50 ng of PETN is feasible with this technique.



Microstructure of transverse section of failed fuel pin taken at the failed location

Post-irradiation examination (PIE) of a Mark-I carbide failed fuel subassembly

Post-irradiation examination (PIE) of a Mark-I carbide Failed Fuel Subassembly (FFSA) was carried out in the hot cells to investigate the cause of failure. The FFSA was irradiated in the third ring of the core and had achieved a burn-up of 148.3 GWd/t. PIE results obtained from this FFSA were compared with that of another FSA with a burn-up of 155 GWd/t from the first ring of FBTR. Non-destructive examinations revealed failure in a single pin. It was concluded that higher fuel swelling and lower clad swelling in the third ring as compared to the first ring led to severe FCMI stresses on the cladding. The increased diametral strain combined with local bending would have led to coolant flow constriction at a localized spot between adjacent pins resulting in local fuel and clad temperature increase. The higher stresses combined with higher clad temperature resulted in failure of the clad by creep rupture. Fig. 2 Axial distribution of Cs137 showing extensive migration



Ion mobility spectrometer developed at IGCAR

FBR- BACK END FUEL CYCLE

Several campaigns of mixed carbide spent fuel of FBTR, irradiated to more than 155 GWd/t were carried out in the pilot plant facility CORAL.

CHAPTER-2

Reprocessing of one campaign with 200 days cooled fuel was carried out successfully. The product purity, recovery and radiation exposures were similar to those of the longer cooled spent fuel.

About 90% of the construction activities related to Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP) were completed.

The design of dismantling machine was finalized and procurement action was initiated. The Chopper-Dissolver system was tested and erected. A hull system was designed based on the experience of hull assaying in CORAL and the manufacture of the system was in progress.

Mock-up testing of robotic sampling system comprising sample handling robot, capping-decapping robot and tip rack and pipette robot was in progress. The stainless steel in-cell cranes based on the operational feedbacks from CORAL were manufactured and erection was in progress.

The seismic re-evaluation of structure, system and components of DFRP which is a requirement based on the review of "Fukushima accident" was also completed and wherever strengthening was required, same was incorporated.

Pre-commissioning activities of various systems were started, wherever construction was completed. Commissioning manuals for various process and process support systems were prepared and submitted to Internal Safety Review Committee. It is targeted to complete all construction activities by December 2015 and start the integrated commissioning activity immediately thereafter.

Conceptual design of hot cell equipment and systems was completed. Design and analysis of various critical equipments were in progress. Procurement action for long delivery items was initiated.

Materials research for Back End Fuel Cycle

Analysis of the average corrosion rate in a boiling 65% nitric acid medium of 304L austenitic stainless steel subjected to sensitization heat treatment at 948 K for 100–260 hours showed that higher nitrogen content coupled with longer sensitization duration led to accelerated corrosion.

Testing of U-bend samples of zircaloy-4 in boiling 11.5 molar nitric acid for up to 15000 hours showed corrosion rate lower than 1 miles per year in liquid, vapour and condensate phases. Optical microscopic examination of the samples after 13000 hours testing did not reveal any cracking.

Metallic glassy alloys ribboris, prepared by arc-melting and subsequent planar flow melt spinning tested in both boiling nitric acid and fluorinated nitric acid environments showed that the $Ni_{36}Nb_{36}Ta_{28}$ alloy has corrosion resistance of at least one order higher than that of the $Ni_{64}Nb_{36}$ alloy.

Yttria-coating on high-density graphite, with NiCrAlY bond-coat, being considered for crucibles for cathode processing step of pyro-chemical reprocessing were found to fail only after 35 one-hour thermal cycles at 1273 K and 19 cycles at 1373 K in vacuum.

R&D for Reprocessing

R&D activities mainly related to improving the reliability of equipment and reducing the process losses were in progress. Development of metallic fuel reprocessing through aqueous route was also taken up. A laboratory scale simulated mixer settler run of the flowsheet with the feed solution of metallic fuel composition, U (84%) + Pu (6%) + Zr (10%) was carried out and the results were encouraging.



Mixer settler experimental setup in a Glove box

Development of alternate extractants

Towards development of a flow sheet for PFBR fuel reprocessing, based on the hydrometallurgical reprocessing of fuel, the extraction behaviour of U (VI) and Pu (IV) from Tri-isoamyl Phosphate (TiAP) as well as Tri-butyl Phosphate (TBP) under high solvent loading conditions, was investigated. The third phase phenomena was studied using small angle X-ray scattering in Zr (NO_3), –TBP and TiAP-Nitric Acid system. Solvent extraction studies of U (VI) with Zr (IV) were carried out from TiAP/DD towards aqueous reprocessing of metallic fuels and the results were compared with those of the TBP/DD system. The solvent TiAP was found to be better as it did not form third phase like the TBP system. A chemical method was also developed for the determination of zirconium (IV) in the presence of a large excess of U (VI), and Pu (IV) from the dissolver solutions of U-Zr and U-Pu-Zr alloys.

Actinide-lanthanide separations

Partitioning of trivalent americium from fast-reactor simulated high-level liquid waste was demonstrated using a modifier-free organic phase. The study established the possibility of using the modifier-free reagent for the separation of trivalent actinides from fast-reactor simulated high-level liquid waste. Feasibility of using completely incinerable reagents for the single-cycle separation of Am(III) from simulated high-level liquid waste were also studied and the results indicated the possibility of intra-lanthanide as well as lanthanide-actinide separation in a single-processing cycle.



Structure of Pyro-reprocessing facility



Electrode assembly for electro refining of U-Pu-Zr fuel material

Iron oxide (Fe_2O_3) particles functionalized with diglycolamic acid and thiodiglycolamic acid indicated the feasibility of using the sorbent for the magnetic separation of Eu (III) from Am (III) with high separation factors. The ligand, Bis (2-ethylhexyl) diglycolamic acid (HDEHDGA) was developed for the mutual separation of lanthanides and actinides. The results confirmed the possibility of using diglycolamic acid for the separation of trivalent actinides from the chemically similar lanthanides.

Construction of Pyro-reprocessing facility

Pyro-reprocessing or molten salt electrorefining is ideally suited for treatment of spent metal fuel. A new facility comprising an argon atmosphere containment box of 500 m^3 volume with a High Temperature Electro Refiner, a Vacuum Distillation and Melting system with requisite in-cell crane and remote handling equipments is being established to demonstrate the molten salt electrorefining process. Construction of the facility with Argon Recirculation and Purification, Argon Pressure Control, Salt Handling and Purification System and various utilities are in progress.Pyro-**metallurgical processing of fuels**

Towards development of pyro-processing technology and all its unit operations, studies were continued on U-Gd-Zr and U-Pu-Zr alloys in the

engineering scale and the laboratory scale facilities respectively. Electro-refining of U-Gd-Zr in 600 gram scale was carried out in the engineering scale facility using LiCl-KCl-UCl_3 as electrolyte. The cathode deposit was further consolidated by vacuum distillation and induction melting to yield uranium ingot. The recovery of actinides from the salt phase was demonstrated (actinide drawdown) and the efficiency of uranium recovery was found to be 99%.

Fast Reactor Fuel Cycle Facility

The civil construction work of Fast Reactor Fuel Cycle Facility (FRFCF) was commenced after obtaining all the mandatory statutory clearances. Excavation work with associated dewatering for the foundations of the main plant buildings was started and construction of a few infrastructure buildings was also taken up. Pig Lead ingots required for fabrication of radiation shielding bricks were procured and other long delivery items were in various advanced stages of procurement.



Excavation activity on trial pit in plant area of FRFCF



Backfilling in progress for extension of stores building of FRFCF

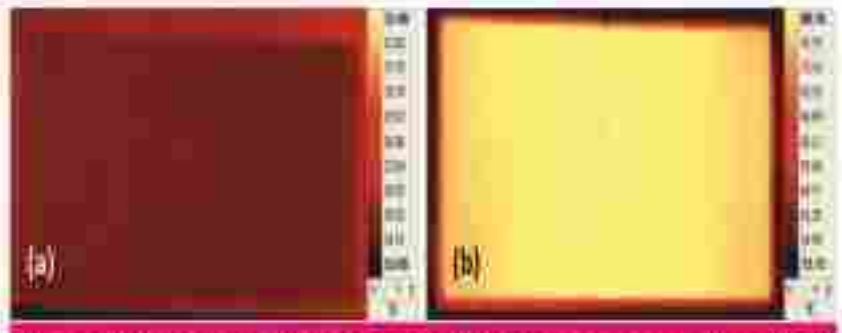
REPAIR & INSPECTION TECHNOLOGIES

Electromagnetic Acoustic Transducers (EMAT) are useful for couplant-free high-temperature ultrasonic inspection of main and safety vessel of SFRs. A hybrid finite element model of spiral coil EMAT transmitter for generating bulk wave modes (shear and longitudinal) was developed. Experimental validation of the model predictions was carried out. The study provided useful information for the development of EMAT system for inspection of main vessel and safety vessel welds of SFRs.

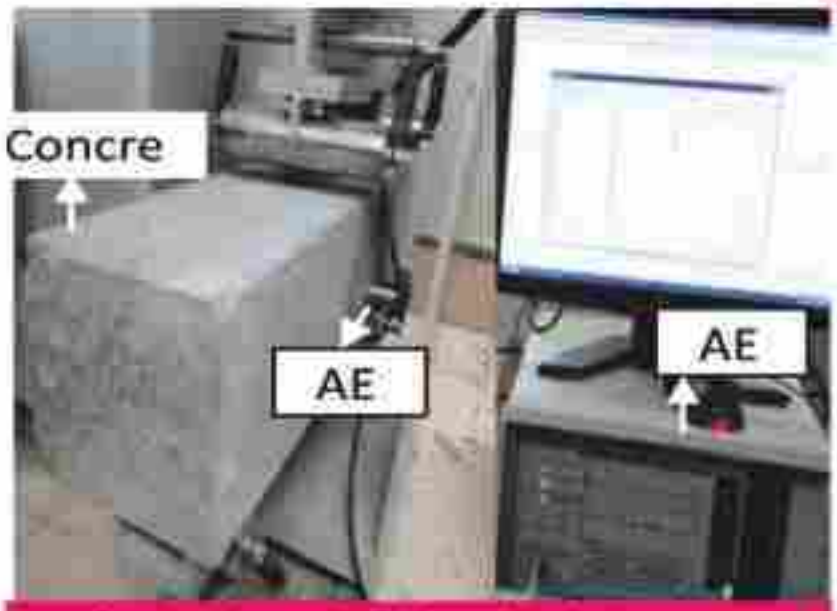
Non-destructive detection of embedment of Mild Steel (MS) 'can' material into the surface of 18% Cr Oxide Dispersion Strengthened (ODS) steel during manufacturing stages is important for optimising the tube drawing process for producing MS-inclusion-free tubes. Towards this, low-frequency and high frequency Magnetic Barkhausen Emission techniques were developed. These techniques led to evolving the procedure for quality assurance of ODS steel, a candidate material for fuel cladding that would enable enhancing the fuel burn-up and in turn reducing the fuel cycle cost of FBRs.

Using a steel calibration sample, an active thermography technique was developed for detection of defects in ferromagnetic steels. The result obtained was within an error margin of ± 7%. This technique is easily deployable and facilitates faster non-contact inspection of large ferromagnetic surfaces.

In-situ eddy current inspection of AISI type 316 stainless steel sleeves of sodium heater vessels was carried out in creep/fatigue loops of INSOT facility, using a reference-differential type encircling



Typical infrared thermal images of a mild steel specimen with a slot of depth 0.0 mm at (a) 0 sec and (b) 100 sec during low frequency alternating magnetic field induced heating



Experimental set up for AE damage detection in concrete

probe. The testing procedure was optimized and detection sensitivity was confirmed. About 80 sleeves were inspected and no indications were observed on any of the sleeves.

Pulsed Eddy Current (PEC) instrument and probes were developed for detection of sub-surface defects in thick stainless steel plates. It was found that PEC technique is able to detect sub-surface defects located at 6 mm below the surface.

Acoustic emission technique was used to monitor the damage growth in plain and 30 % fly-ash containing concrete beams subjected to cyclic incremental loading. Studies revealed that in fly-ash concrete, shift of damage level from minor to intermediate level was delayed compared to that in plain concrete. The results clearly indicated that Acoustic emission technique had potential for the assessment of damage level in concrete structures subjected to cyclic loading.

HEALTH, SAFETY & ENVIRONMENT

Radiological Safety

During the year, effective and efficient radiological surveillance and health physics services were provided for the radioactive facilities of IGCAR. TLD personnel monitoring services, covering about 2300 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 and contract workers engaged by active facilities and bioassay services for over 200 occupational workers were also provided.

In-situ/in-house testing of more than 65 HEPA filters was completed. Dose data in NODRS and personnel data along with the finger print and photograph of the radiation workers were periodically updated.

IGCAR participated in the international intercomparison exercise organized by EURADOS for the evaluation of the TLDs used for personnel dose monitoring and also in a national intercomparison exercise for the plutonium estimation in body through urine matrix.

Nuclear counting and calibration facilities were extended to various institutions involved in BRNS projects, researchers and industries in southern region. The first Inter-Laboratory Comparison study on Dicentric Chromosomal Assay for both routine and triage biodosimetry applications was undertaken between biodosimetry laboratories located in and around Kalpakkam towards capacity building.

A theoretical model was developed for the estimation of sodium aerosol mass concentration in the cover gas region and the same was correlated with experimental values. The theoretically predicted and experimentally measured mass concentration was in good agreement (±20%) for all the pool temperatures.

Source term modeling for Decision Support System (DSS) employing real-time meteorological data, weather and dispersion model predictions to assess the spatio-temporal evolution of the radioactive plume of accidental releases was taken up successfully for the first time. Source term which is an important input in DSS for predicting the consequences of accidents was developed and incorporated in the DSS.

Radiation awareness training programs were provided periodically for the staff, general public and students by conducting popular lectures, quiz programmes and exhibition.

CHAPTER-3

NUCLEAR POWER PROGRAMME STAGE-III



Prototype SFDM with Test Console on full-scale test facility



EED cell for hydrogen production

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 physics and thermal-hydraulic studies were carried out for the transition phase of AHWR-LEU core from the beginning of onset of refuelling to the attainment of equilibrium state. The Minimum Critical Heat Flux Ratio (MCHFR) was estimated at 120% full Power and it was observed that the MCHFR was greater than 1.5 for all the channels of above mentioned cases.

Xenon dynamics with coolant density feedback for AHWR-LEU equilibrium core were studied and growth factors estimated for a few power transient cases using modified 3D neutron diffusion code FEMINA.

A feasibility study for the adoption of off power refuelling with the equilibrium core of AHWR-LEU was carried out for cycle lengths 3, 6, 9, 12 and 18 months. Reactivity feedbacks and S/D margins were estimated at the beginning of each fuel cycle and results were compared with on-power refuelling case. It was observed that batch refuelling for a cycle length of 3 months can be adopted without any changes in the cluster design.

A scheme was worked out to irradiate (Th-LEU) MOX fuel in the 19 element PHWR fuel cluster mode. LEU has been assumed to be consisting of



Schematic and Photograph of Bottom Flooding Test Facility

15% of ^{233}U and 85% of ^{238}U in (Th-LEU) MOX. Uranium content in MOX is considered to be 28.7% so that ^{235}U content is 4.3% of heavy metal. Study showed that loading of 3 of each Thorium and Th-LEU MOX bundles in peripheral channels A-08 and A-13 is a workable option for irradiating the AHWR-LEU fuel bundles in PHWRs without affecting the operational and safety parameters in attaining a maximum burn-up of 25 GWd/T for AHWR-LEU bundle.

In AHWR, a core catcher is provided to contain the core melt down. The design of core catcher has been experimentally validated in a test facility with 40 kg of simulant melt at 1200°C poured into the test section and heated by radiative heater to simulate decay heat. Cooling water was injected from bottom through the riser tubes to cool the melt. It was observed that the melt got quenched in a short duration and has reduced into a porous mass.



Tail pipe & ECCS nozzles on end fitting

An innovative pull-out technology was developed for making the Tail Pipe Nozzle and Emergency Core Cool System (ECCS) Nozzle as an integral part of the end fitting. The technology, including the hardware and procedure has been optimised after a number of qualification trials.



Rolled joint detachment tool



Induction heating of pressure tube



Pressure tube as it comes out of end fitting

The major design philosophy of AHWR coolant channel is the easiness in replacement of the pressure tube, which has a limited operating life. Technology based on induction heating of the rolled joint area followed by its cooling by liquid nitrogen and application of controlled axial load has been developed for detachment of the pressure tube from the end fitting. The existing pressure tube along with the bottom end fitting is taken out through the bore of top end fitting and replaced with a new assembly.

The innovative seal plug has been designed that uses metallic seal element to meet contradictory requirement of strength and flexibility. The prototype seal plug has been manufactured and shop tested for the first time. Metallic seal element has been developed and qualified at simulated pressure and temperature conditions for about 500 hrs. The leak rate observed (0.3 cc/hr) from seal element was significantly less than the acceptable (100 cc/hr) value.

For AHWR-LEU based fuel development, laboratory scale production and characterization of ThO_2-13%UO_2 (nat. U) and ThO_2-30%UO_2 (nat. U) were carried out. Addition of Nb_2O_5 was observed to



Radial Sealing Plug



Seal Element



Prototype SRDM with Test Console on full-scale test facility

increase the sinterability of the powders. Pellets up to 94% Theoretical Density have been fabricated with < 15 wt% reject recycling. Prototype Shut-off Rod Drive Mechanism (SRDM) for AHWR has been designed, developed, manufactured and function tested on full-scale test facility at BARC for more than 1000 test-drops.

THORIUM FUEL CYCLE

Th-U metallic alloys with various compositions were produced using in-house produced Uranium and Thorium metals, and their thermal conductivity as well as thermal expansion coefficients were evaluated as a function of uranium content. While Th-52%U alloy exhibited lowest thermal conductivity, Thermal expansion coefficient has a little effect with uranium addition up to 30 wt%.

KAlpakkam MINI (KAMINI) Reactor

KAMINI reactor was operated upto a maximum power of 30kW for neutron radiography of 960 pyro components for Vikram Sarabhai Space Centre, and irradiation of sphere-pac fuel pins, a MOX reference fuel pin, one carbide fuel pin as well as samples for activation analysis. During the year, the reactor was operated 97 times till November.

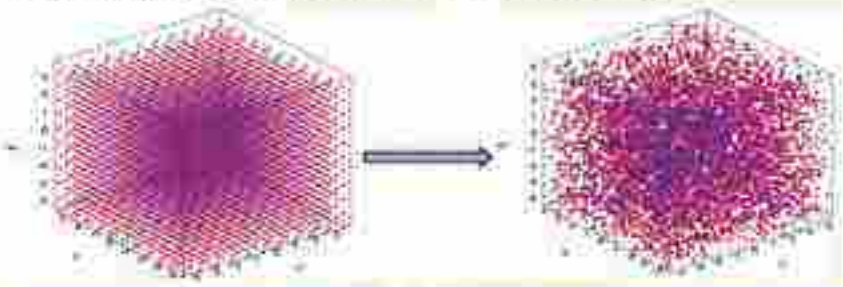
A special chamber with heaters was installed in the reactor pool after safety clearances for testing of PFBR High Temperature Fission Counters. One

prototype detector was tested upto a temperature of 845 K and 21 detectors (Boron coated, gama-compensated ion chamber type) were also tested. Periodic Safety Review document for KAMINI was submitted to safety authorities.

OTHER THORIUM REACTOR SYSTEMS

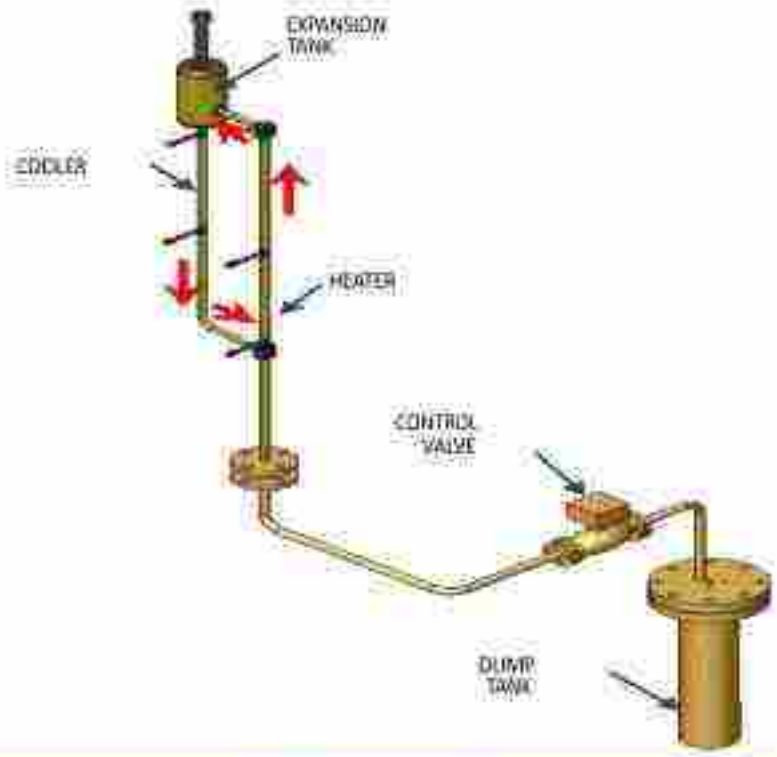
Integral and differential reactivity worth of control rods, Primary Shutoff Rods (PSRs), Secondary Shutdown System (SDS-2) and individual rods have been computed in hot operating condition of 55% HEU fueled Compact High Temperature Reactor (CHTR) with thicker PSRs and B4C particle based SDS-2. Worth of shutdown systems as a function of axial positions was estimated in hot operating condition to find out the maximum removal speed of these devices in operating as well as approach to criticality of this core.

Transient analysis (Loss of Regulation Accident-LORA) of CHTR with adiabatic fuel temperature feedback in 3D space-time analysis has been carried out using the code ARCH-IQS.



Stochastic distribution of TRISO from FCC lattice using RFCCL algorithm

The Innovative High Temperature Reactor (IHTR)-10MWth reactor is designed as a technology demonstrator of IHTR-600MWth pebble bed reactor for the commercial hydrogen production. To estimate the self-shielding effect in TRISO particles in Pebble Bed HTR, a fast Monte Carlo algorithm called Randomisation of Face Centred Cubic Lattice (RFCCL) has been developed. The Dancoff factor is computed by tracking resonance neutrons in stochastically distributed TRIstructural ISOtropic (TRISO) particles embedded in graphite matrix. This distribution has been used to compute Dancoff factor from 2% to 60% packing fraction of TRISO particles.

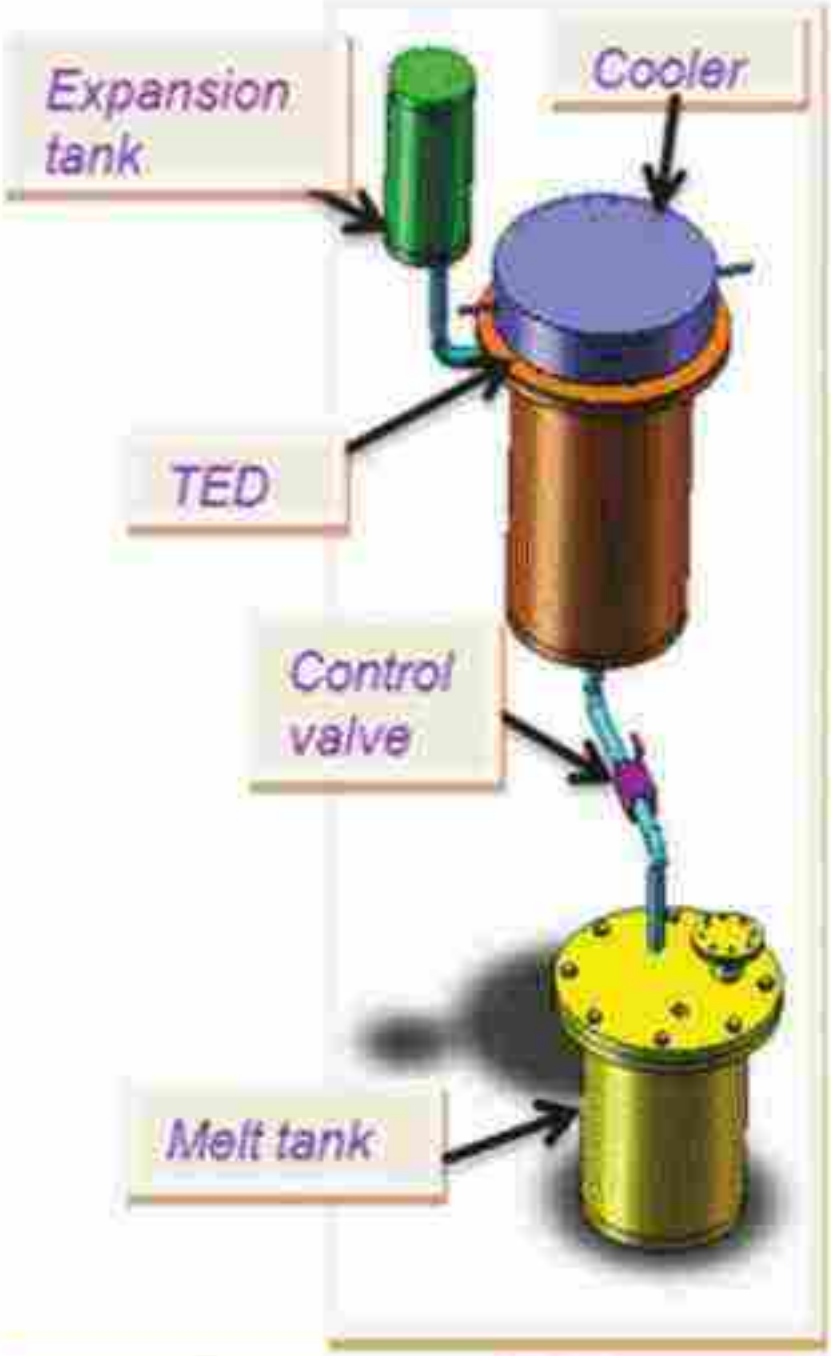


Isometric view of KTL

For studying the thermal hydraulic and material compatibility of Nb-1%Zr-0.1%C alloy at operating temperature of CHTR, the Kilo Temperature Loop (KTL) has been built and commissioned in collaboration with NFC, Hyderabad. KTL is a rectangular loop and comprises of five parts viz. heater section, cooler, melt tank, expansion tank and main loop piping. The loop consists of high temperature components such as Main loop and expansion tank and low temperature components consisting of the dump tank, isolation valve and associated piping. Material of construction for low temperature componerits is SS 316 and high temperature components are fabricated with Nb-alloy having composition, Nb-1%Zr-0.1%C. BARC has developed the Nb-alloy used for construction of the loop. The alloy material in the form of plates and pipes required for the construction of the loop including its fabrication has been accomplished by NFC, Hyderabad.

Lead Bismuth Eutectic (LBE) is used as the working fluid of the loop. However, operation of KTL was challenging since the Nb alloy gets easily oxidized at temperature greater than 400°C in the ambient atmosphere. In view of this, the loop was installed inside a leak tight enclosure filled with argon gas. A closed argon gas circulation system for the enclosure, with an oxygen-scavenging unit is developed to bring down the oxygen level in the enclosure to 10 ppm. Steady state natural circulation

experiments and various transient experiments were carried out at different power levels. The experimental data are being used to validate in house developed computer codes like LeBENC and commercial CFD codes.

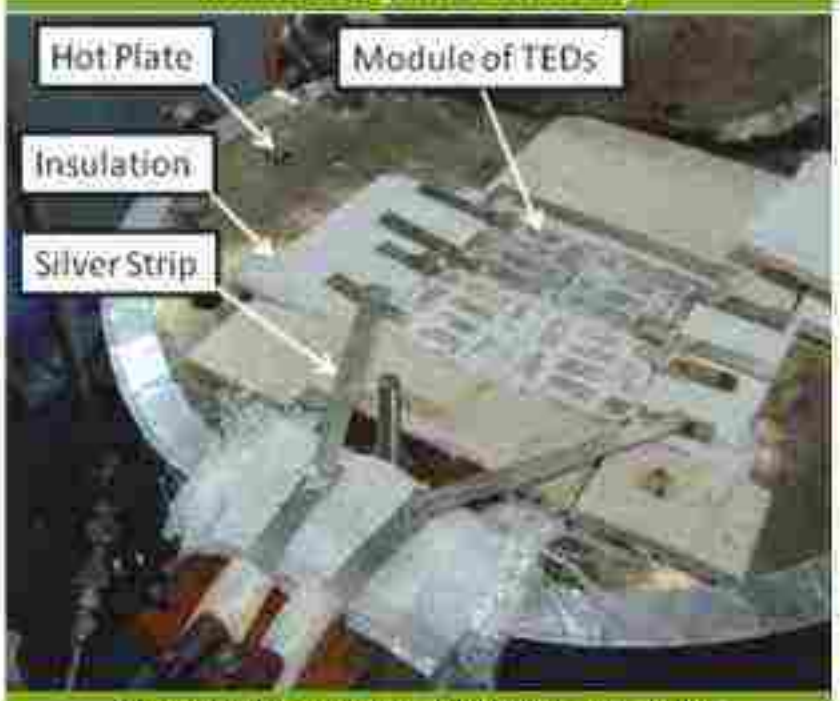


Thermoelectric power generation is reliable, noise-free, long life and maintenance-free due to absence of moving parts and can be used on receiver surface for electricity generation and from main heat transport system of nuclear reactors. Instrument control signals, alarms, feedback signals etc. can be powered by these devices made from semiconductor alloys like PbTe (Lead Telluride) and p-type TAGS-85(AgSbTe2)0.15(GeTe)0.85. A test facility has been built to test these thermoelectric devices up to 500 °C using electrically heated molten salt and water cooled cold junction at 40°C. Experiments were conducted to study the performance and for optimising the designs.

Physics simulations were carried out for the Pool-type conceptual design of the 850 MW(e) pool type Indian Molten Salt Breeder Reactor (IMSBR) using LiF–ThF$_4$–^{233}UF$_4$ with natural circulation by considering all the geometry details of the pool. The effect of B_4C liners as well as thermalisation effect of helium bubbling to remove fission gases was estimated. Design parameters such as breeding ratio, inventory, excess reactivity, neutron spectrum delayed neutron effect etc. have been compared for both thermal and fast spectrum.

A new analytical method has been adopted to calculate effective delayed neutron fraction correction factor for circulating to static fuel conditions. Effect of recirculation on eight groups of delayed neutron precursor has been studied with various flow rates of fuel salt.

Thermoelectric generator Test Facility



Thermoelectric generators installed on a hot surface



UO$_2$ particles coated with SiC/C layers

CHAPTER-3

As a part of CHTR fuel development program, 1.2 Kg sintered UO_2 microspheres of 500 ± 50 µm size were prepared by sol gel method and sent for SiC coating processing.

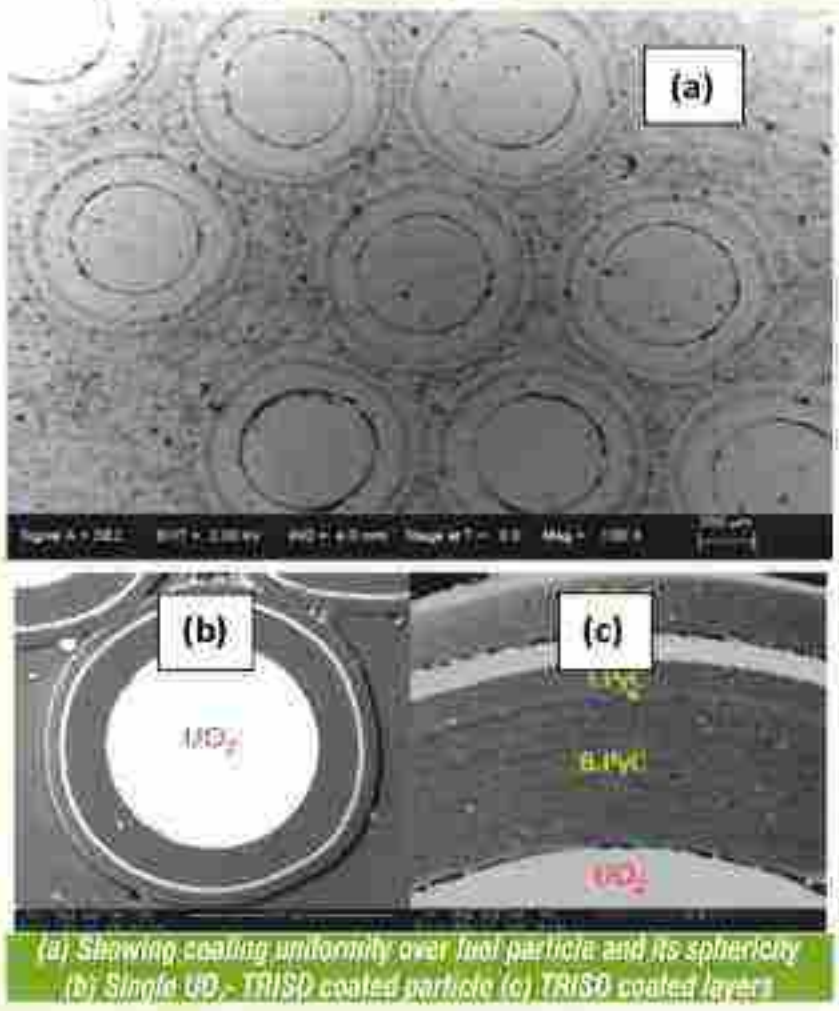
The Monte Carlo code M3C developed for criticality calculations using continuous energy cross section data is ready for release. The code has been benchmarked with several published results and used for simulation of PHWR, AHWR and CHTR infinite lattices. The in-house 3-D space-time core neutronics analysis code that is used for 'Analysis of Reactor Transients in Cartesian and Hexagonal Geometry' (ARCH) has been improved by including thermal feedbacks module. The diabatic fuel temperature feedback model has been developed and benchmarked in ARCH-IQS and used to analyze some anticipated transients in CHTR. The 3-D Space-Time analysis code ARCH has been modified to include an option to simulate moving fuel assemblies in addition to the movement of control devices. The complex issue of precursor density movement has also been factored in the calculations.

MATERIALS

The key properties of TRIstructural-ISOtropic (TRISO) coated layers were evaluated and preliminarily qualified for its safe use in upcoming High Temperature Reactors. Apart from 'Burn Leach Test' as the leak proof qualification criteria of SiC coated layer, various characterization studies such as Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Pycnometry, Raman spectroscopy, nano-indentation and Small Angle Neutron Scattering (SANS) were performed. About 750g of TRISO coated natural UO_2 kernel (for CHTR application) was prepared for coated layer characterization and other related R&D by following the earlier developed method.

Production of beryllium metal as well as beryllium oxide ceramic were continued for in-house use. Beryllium oxide shapes required for upcoming nuclear research facility have been fabricated following a route consisting of cold-isostatic pressing and sintering. A process has been developed for fabrication of beryllia coated magnesia crucibles (95 mm inner diameter, 200 mm long and 5 mm wall thickness) through cold-isostatic pressing and slurry coating technique.

An integrated solvent extraction process flow-sheet for the production of high purity (more than 99.9%) yttrium oxide from a crude concentrate employing Aliquat 336 as extractant in thiocyanate medium was developed and tested on bench scale operation.



(a) Showing coating uniformity over fuel particle and its sphericity (b) Single UO_2 - TRISO coated particle (c) TRISO coated layers



Berylium oxide ceramic block



BeO coated MgO crucible

In continuation of indigenous effort of preparing rare-earth magnets, the production of Samarium-cobalt alloy powders has been scaled up to few kilogram level batch. Magnets of different shapes have been fabricated using these powders and characterized at Defence Metallurgical Research Laboratory (DMRL). These magnets have been found to be at par with imported material.

Processing schemes for preparation of natural or enriched Boron Carbide (B_4C) and its composites (B_4C-ZrO_2 and B_4C-HfB_2) were developed. Discs of 60 to 200 mm diameter and 3 to 5 mm thick were fabricated using pressure assisted sintering approach and a near theoretical density (more than 99%) was achieved.

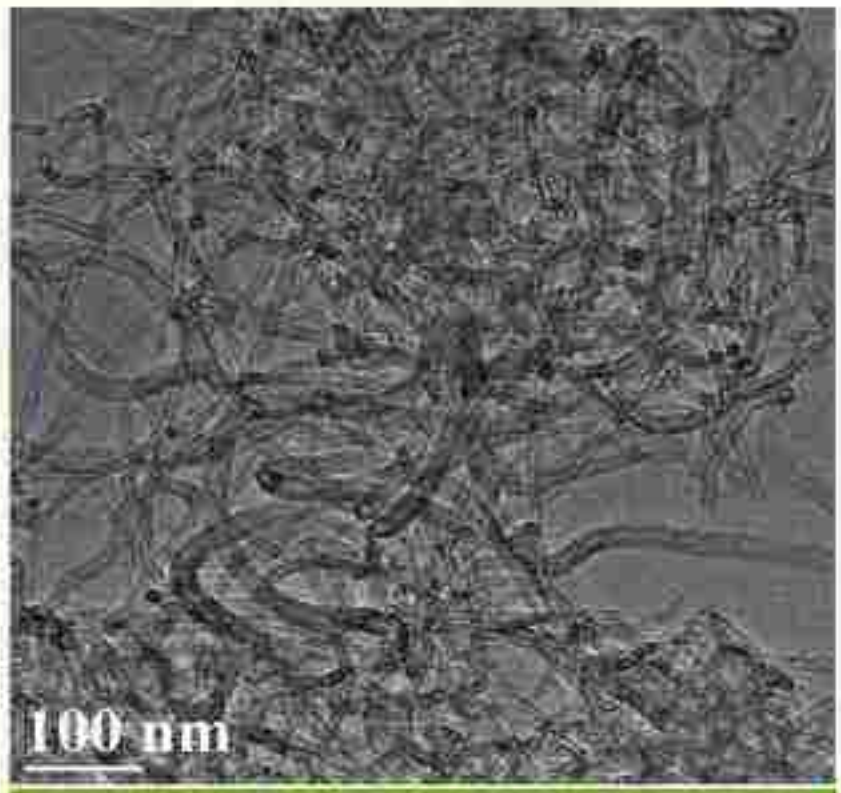
Process flow sheets for the synthesis and consolidation of various metal borides such as TiB_2, CrB_2, ZrB_2, HfB_2 and NbB_2 were established.



Boron carbide and Boron alloy products of various dimensions

Dissolution studies on fly ash showed dissolution of 60% of Lighter Rare Earth Elements (LREE) and 90% HREE in sulfuric acid media at ambient temperature.

Carbon Nanotubes (CNTs) having diameter in the range of 15-25 nm and length ~500 µm have been prepared in kilogram scale using fluidized bed chemical vapour deposition and incorporated in polymer matrix to develop beads and utilized for rare earth extraction from lean sources with four fold increase in rate and threefold increase in adsorption capacity with respect to conventional solvent extraction. Carbon nanotubes have been doped with N_2 for H_2 adsorption. Incorporation of N_2 has changed the microstructure of the nanotubes and resulted in



CNTs developed in fluidized bed



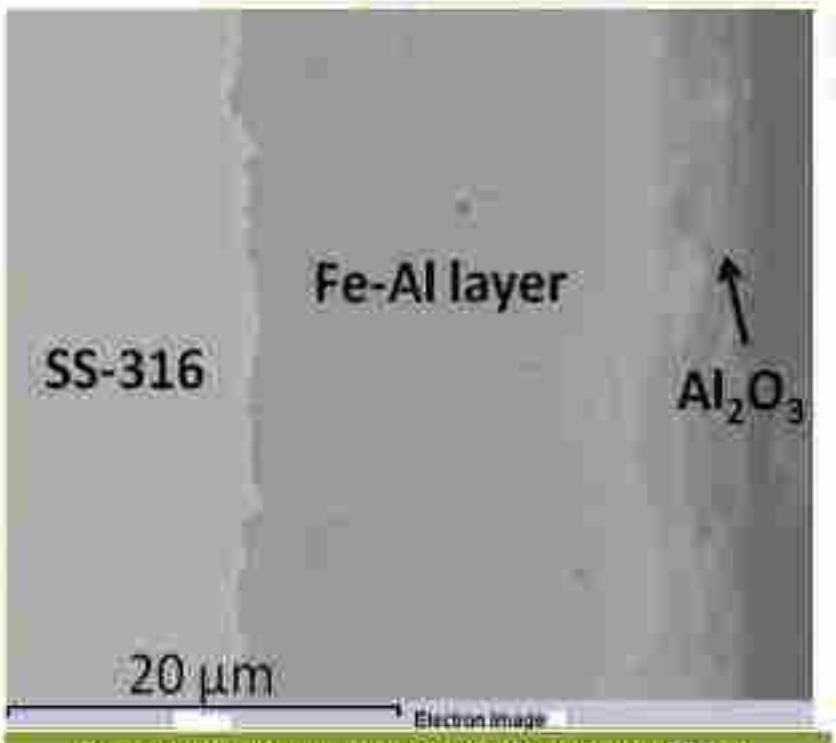
CNT-polymer composite beads



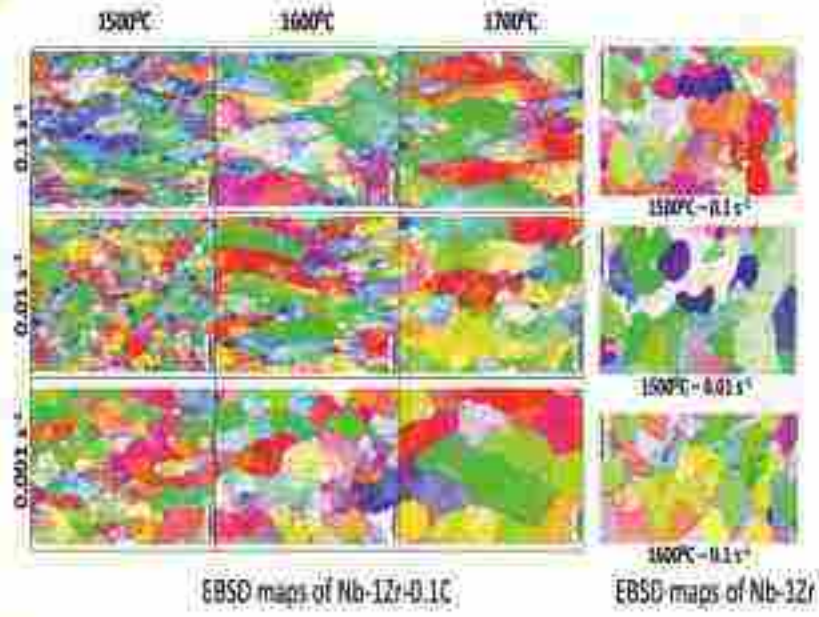
Nitrogen doped CNT

three fold increase in H_2 adsorption with respect to bare nanotubes. Transition metals and rare earth based intermetallics have been incorporated inside synthesized carbon nanotubes for development of magnetic nanoparticles.

Al_2O_3 / Fe-Al layer act as an effective barrier for hydrogen (and its isotopes) permeation through steels. A novel technique viz. halide activated pack cementation process has been utilized to form desired coating of few microns thickness. The capability to form coating in component level was demonstrated by coating the inner wall of the cylindrical storage steel vessels. The coating was qualified and found suitable for the permeation barrier application.



Cross-sectional Image of Alumina/Fe-Al coating on SS 316



EBSD maps of Nb-1Zr-0.1C EBSD maps of Nb-1Zr

A comprehensive programme to understand the hot deformation behaviour of Nb-alloys was taken up. Compression test was carried out on Nb, Nb-1Zr and Nb-1Zr-0.1C in the temperature range of 700 to 1700 °C and strain rate range of 10^{-2} to 10 s^{-1}. Micro structural characterization of deformed alloys using Electron Back-Scattered Diffraction (EBSD) was carried out in the high strain rate sensitivity regime. The EBSD (as given in map) showed that the final grain size increased with increasing temperature and decreasing strain rate. Dynamically Recrystallized (DRX) grains were seen to surround the original deformed grain in a typical necklace structure representative of DRX. For the same test conditions, Nb-1Zr showed larger grains and more complete DRX as compared to Nb-1Zr-0.1C. Carbon addition retarded dynamic recrystallization.

HYDROGEN ENERGY

Design, fabrication and installation of tubular membrane reactor set-up for H_2 production through Iodine-Sulphur (IS) thermo-chemical cycle was completed and trial runs were conducted. For HI concentration studies through Electro-Electrodialysis (EED) process, EED cell was fabricated and installed.



EED cell and HI decomposition setup for hydrogen production



High pressure SS reactive distillation setup



Six cell electrolyser module test skid

Preliminary experiments on HIX reactive distillation in SS system were carried out with water to establish high pressure operation feasibility and hydraulic performance. Compact alkaline water electrolyser plant for producing high purity O_2 and H_2 was rectified for reduction in impurity level at source itself and tested for cell performance. Model of compact, bipolar type alkaline water electrolyser for prediction of electrochemical characteristic has been developed.



Scaled-up three cell electrolyser module



Miniaturized tubular SOEC

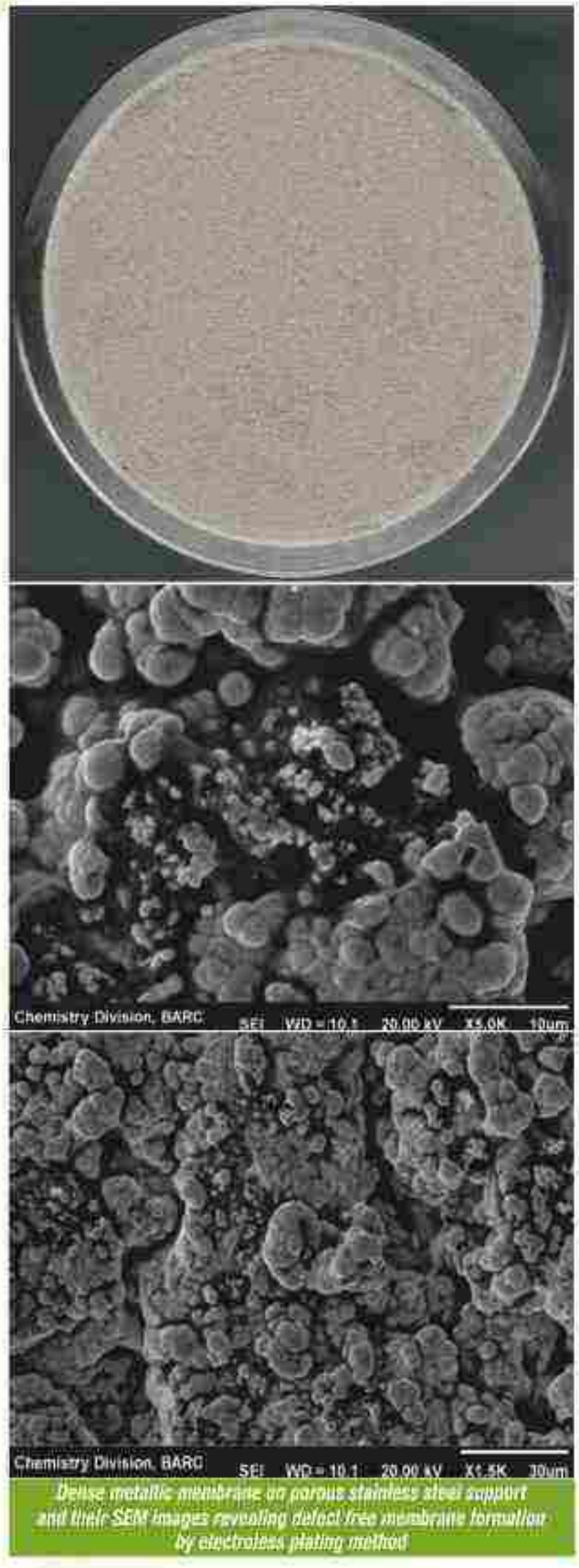
Several experiments have been carried out in improved single cell and scaled-up three cell compact electrolyser module for design performance evaluation. Various kinds of membranes/diaphragms have been tested in lab scale electrolyser set-ups to enable the selection of the membrane, cell configuration and the optimal operating conditions for obtaining high purity gases.

The performance of a miniaturized tubular Solid Oxide Eelectrolyser Cell (SOEC) was

demonstrated for generation of H_2 at the rate of 4.2 N Nml/min/cm^2 at operating voltage 1.4 V and 850°C temperature.

Dense palladium-silver metallic membrane of composition $Pd_{0.77}Ag_{0.23}$ and thickness about 25 µm on porous stainless support was developed by electroless plating method. Characterization of the membrane by SEM, EDS and XRD after high temperature annealing revealed uniform and defect free alloy formation on the substrate. Thermodynamic and kinetic studies of hydrogen and deuterium absorption-desorption revealed favorable conditions for its application in purification of H_2 isotopes.

Hydride forming zirconium alloys of the type Zr_2M (M=Fe, Co, Ni) type Zr alloys were studied for the storage of H_2 which are beneficial for safe long term storage of H_2 due to their much lower equilibrium pressure than that of ZrM type alloys. A comprehensive first principles study on the structural, electronic, mechanical and thermodynamic properties of Zr_2Fe and its hydride Zr_2FeH_4 has been carried out. The nature of chemical bonding and charge density distribution between the constituent atoms in Zr_2Fe and Zr_2FeH_4 were analyzed. The changes in mechanical properties due to hydrogenation of Zr_2Fe were investigated. Thermodynamic properties of Zr_2Fe and its hydride Zr_2FeH_4 were also studied which could be useful for planning experiment.



Dense metallic membrane on porous stainless steel support and their SEM images revealing defect free membrane formation by electroless plating method

MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

In the Indian concept of Lead Lithium Cooled Ceramic Breeder (LLCB) for ITER-TBM, liquid lead-lithium eutectic (Pb-17Li) will act as a coolant. To investigate the corrosion compatibility of the candidate structural material of Test Blanket Module (TBM) with Pb-17Li, an electromagnetic pump driven Pb-Li loop was designed, fabricated and installed by BARC. The materials for compatibility studies on Indian Reduced Activation Ferritic/Martensitic Steel (IN-RAFMS) and the surrogate material, modified 9Cr-1Mo (P91). The loop consists of all important components like electromagnetic pump, heat



Electromagnetic pump driven Pb-Li loop

exchanger, test section, and diagnostics like level sensors, electromagnetic flow meter, etc.

The test section carrying flat samples of RAFMS and P91, has been maintained at 500°C while the temperature reduces to 270°C at the liquid metal channel inside the electromagnetic pump. The loop has been commissioned successfully and has already logged 5000h of uninterrupted operation.

To study the compatibility of RAFMS and P91 materials in molten Pb-Li alloy, a rotating disc corrosion test facility was set up. Experiment was initiated with a six segmented sample of IN–RAFMS material in molten Pb-17Li. The set up with the above samples has completed 550°h of smooth operation at 550°C, while samples have been removed after every 2000h. The experiment will be continued up to 10,000h. It was observed that weight loss of RAFMS in Pb-17Li during the interval from 2000 to 4000h was double than the weight loss obtained for the first 2000h.

The mechanical and thermodynamic properties of tritium breeding material Li_2TiO_3 were studied. The mechanical properties of lithium titanate were measured using pulse eco-technique and its thermodynamic properties were calculated using PHONON code.

At IGCAR, detailed characterization was carried out to understand the role of Tungsten and Tantalum in influencing the phase and micro structural stability in the indigenous version of 9%Cr-based Reduced Activation Ferritic Martensitic (RAFM) steel having controlled amounts of Tungsten and Tantalum besides low carbon. The temperature-induced phase field evolution was investigated by dynamic calorimetry. The experimental data were augmented by thermodynamic simulations for an extended range composition covering higher Tungsten and Tantalum contents. The presence of Tungsten in RAFM steel resulted in retention of a small amount of austenite in the martensitic. Besides, Fe-rich $M_{23}C_6$ / M_6C carbides containing some dissolved Tungsten were also found.

The RAFM steel when subjected to long-term thermal annealing at 823K revealed a comparative reduction in the coarsening kinetics of $M_{23}C_6$ phase due to the presence of Tungsten. In addition, the presence of fine MX precipitates having Tantalum and Vanadium also contributed to the extended microstructural stability of the tempered martensitic phase against thermally-induced ageing. However, it was also found that the propensity for the formation of Fe-rich and Tungsten-rich Laves phase increases with addition of Tungsten and Tantalum.

The thermo-physical properties of RAFM steel such as specific heat, Young's and shear modulus, thermal diffusivity, Poisson ratio and linear thermal expansion were measured up to 1273K. The results obtained in the study offered a comprehensive design database on this indigenous version of RAFM steel.

CHAPTER-4

ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES AND THEIR APPLICATIONS



Magnets of Quadrupole focusing lenses & Dipole correctors



First of its kind 500 kg Six DOF Electro Hydraulic Servo Shake Table developed by BARC

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 which were immensely beneficial in 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

APSARA reactor is in partially decommissioned state with pool structure under protective cover. Remaining building space is utilized for experiments on modified APSARA & High Flux Research Reactor (HFRR).

After completion of necessary formalities, regulatory authorities cleared the construction of the upgraded 2 MW APSARA reactor. First phase of civil construction has already commenced. The reactor will augment facilities for beam tube research, radioisotope production, testing of detectors and materials. Safety review of design basis reports and Preliminary safety Analysis Report was completed.

The fabrication of fuel plates for modified core of APSARA with U_3Si_2 (LEU based) fuel dispersed in Al matrix and clad in Al-alloy was completed.

AHWR Critical Facility

AHWR Critical Facility was operated on 63 occasions. Experiments were carried out with a cluster assembly of 19-pins, each having 60 cm long ThO_2 stack sandwiched between 80 cm long natural uranium stacks (U-ThO_2-U) installed at six different pile locations. Fine structure flux inside the cluster was measured after irradiating activation foils. Level coefficient of reactivity at critical height of extended core was also measured. Critical Facility was used to test 23 nuclear detectors and irradiation of 8 large volume samples for Neutron Activation Analysis. Renewal of authorization to operate the facility for another ten years was obtained from regulatory authorities after Periodic Safety Review.

CIRUS

CIRUS reactor was permanently shut down since 31st December 2010 with de-fuelled core. 2.6 Tons of chloride laden degraded heavy water was purified using a mixed bed ion-exchanger. Reactor systems were maintained in preservation mode and services including ventilation were kept in operation in truncated mode. Recovery trials of useful material, settled on floor of spent fuel storage bays, for reprocessing & safe disposal are underway.

A graphite plug was removed from the thermal column of graphite reflector for estimation of pattern of stored Wigner energy, thermal conductivity and specific heat. Tools to collect samples of irradiated core structural materials were fabricated. Change in properties due to prolonged irradiation of aluminium and steel will be studied. The data will be shared with IAEA as a part of CRP on 'Ageing Data on Corrosion and Irradiation induced Degradation of In-core components of Research Reactor CIRUS'.

DHRUVA

DHRUVA is the only facility for radioisotope production and is the national facility for neutron beam research. DHRUVA operated with a high level of safety at 80 MW power till October 2014 and at the rated capacity of 100 MW since November end resulting in enhanced utilization and radio-isotope

production. Several measures to minimize stress on fuel and reduced activity enabled smooth operation at this power level with 76% availability factor and the highest ever capacity factor of 53%. Several researchers from across the country utilized the reactor through UGC-DAE Consortium for Scientific Research. Comprehensive Periodic Safety Review of the facility was carried out and renewal of authorisation for operation of facility for another five years was obtained from BARC Safety Council (BSC).

During the year about 900 samples were irradiated for radioisotope production. AHWR Th–Pu MOX Assembly was irradiated upto the target burn-up of 20,000 MWD/Te. A new Th–LEU MOX assembly was installed in the core for irradiation.

It is proposed to irradiate a Project-B type fuel cluster at DHRUVA. The fuel cluster has 6 fuel pins (3 circular and 3 twisted with 3 lobes) and uses enriched UAl, dispersed in Al matrix. Fuel assembly power as a function of burn-up, peak linear heat rate and reactivity change were calculated. Safety evaluations were also carried out for post irradiation handling of the irradiated fuel assembly.

Required number of fuel assemblies, Al shields and SS plugs were fabricated and delivered to DHRUVA facilitating its operation at up to 100 MW power level. Two types of modified DHRUVA fuel clusters to increase the reactivity of the fuel facilitating higher power generation without fuel failure were fabricated and supplied to DHRUVA for irradiation testing. A technique was developed for



Motor test station



Control console

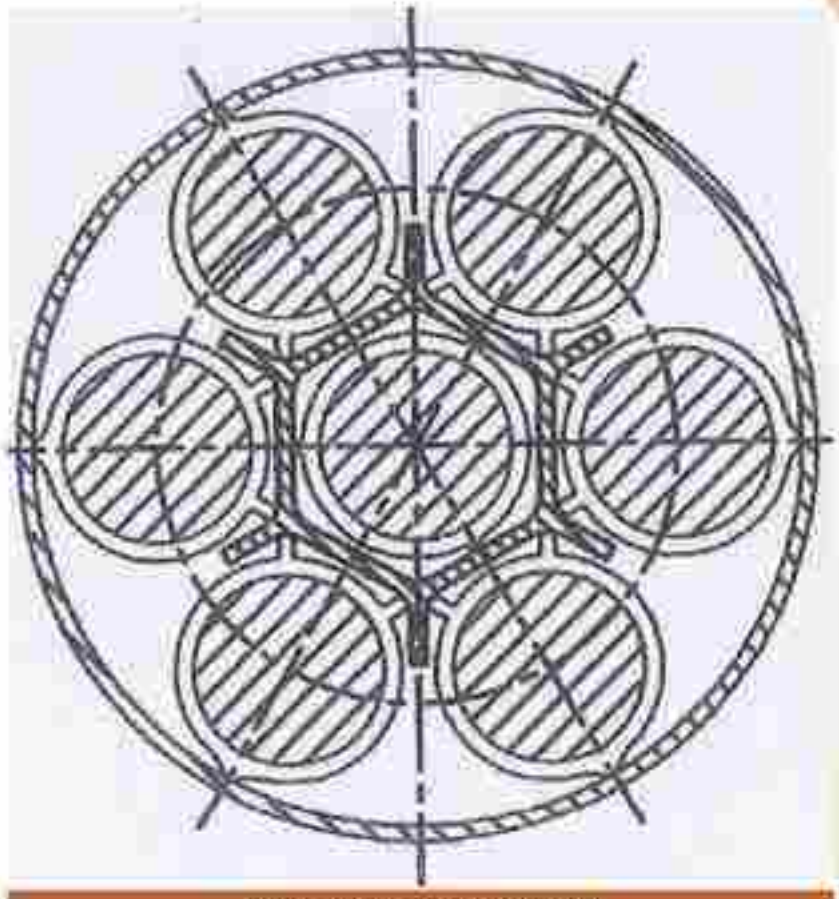
manufacturing of lobed-cum-twisted clad tubes and subsequent fabrication of fuel pins. A test cluster was fabricated and has been given to DHRUVA for flow testing and irradiation.

As part of en-masse replacement of existing arrangement of Fuel Failure Detection (FFD) system, all Radiation Elements (REs) were replaced by a modified arrangement consisting of mixing chambers surrounding the REs in view of its better discrimination for identifying failed fuel location. A facility for testing of LT motors on load as well on no load was set up to carry out qualification tests after repairs / overhauling of the motors.

A straightness checking gauge consisting of a semi-circular pipe section with rollers had been developed for handling of irradiated canned fuel to facilitate charging in dissolver of Pilot Plant (PP). A new grappler had been designed for retrieval of stuck irradiated fuel assembly inside the dissolver unit of PP. This grappler was designed with two fix jaws and an operating / movable jaw. Both the devices were commissioned and utilised for handling and processing of old canned assemblies.



Gauge for handling of irradiated canned fuel



Design of new core of DHRUVA

The performance of heavy water purification system was reviewed for improving decontamination factor by use of better ion exchange resin and filtration by use of 5 micron polypropylene filters. Premixed resin with higher cross linking (10%) lots, two each supplied by M/s Thermax Limited and Ion Exchange India Limited, were put in service for in-situ performance evaluation. The service conditions were also improved. The resins performed well with higher decontamination factor, service life and lower extent of leachable organics.

In order to reduce the chances of fuel failure and gain in reactivity, a new core divided into inner and outer zones, was designed. The fuel assemblies in the inner zone and outer zone would have different fuel mass, clad thickness and flow area.

Physics studies including reactivity gain with respect to reference core were carried out for the core loaded with the modified fuel assemblies. Flow coast down transient and Loss of Regulation Incident (LORI) were analyzed. Two such assemblies were fabricated and loaded in pile for test irradiation after getting regulatory clearance. Major advantages included flux flattening across the core by around 5%, about 5 mK gain in reactivity, 12% reduction in refueling operations and thereby reduced stress on fuel & better safety margins.

High Flux Research Reactor

Preliminary Design Basis Reports (DBRs) on major systems of High Flux Research Reactor (HFRR) had been completed. Construction of research reactors, nuclear fuel cycle facilities and allied facilities in the Vizag campus is in progress. Engineering details for all the facilities were worked out. Physics design of 125 MW Thermal Research Reactor (ThRR) using natural uranium fuel cluster with & without flow tube was completed. Consolidated report is being prepared for site clearance from MoEF.

ACCELERATORS

At BARC, piping installation for Radio Frequency Quadruple (RFQ) Vane channels, RFQ outer Channels, Drift Tube LINAC-1 (DTL-1) and DTL-2 cooling systems of Low Energy High Intensity Proton Accelerator (LEHIPA) at Common Facility Building was in progress.



Distribution Headers of RFQ Cooling Systems

For study of Irradiation Assisted Stress Corrosion Cracking (IASCC) under LWR conditions, design work of CLOE loop (Corrosion Loop Experiments) for installation in Jules Horowitz Reactor (JHR, France) as a part of Indian in-kind contribution is underway. Conceptual design of in-pile test section of Corrosion Loop was completed.

Fabrication of the 1st segment of Radio Frequency Quadrupole (RFQ) accelerator for 20 MeV, 30 mA Low Energy High Intensity Proton Accelerator (LEHIPA) was completed. The prototype



RFQ Cooling System Pumps

DTL tanks were fabricated and characterized. The measured parameters are in good agreement with simulations.

Vacuum Control Interlock and Information System (VCIIS) built-around TPLC-32 PLC platform to establish and maintain vacuum in LEHIPA were developed and dispatched to LEHIPA site. A high power coaxial coupler for 350 MHz operation developed in collaboration with CEERI-Pilani was tested upto 50 kW with low duty cycle. Two such couplers were developed for beam acceleration experiments on RFQ.

A 325 MHz RF amplifier was developed and tested for 7.5 kW power with an overall efficiency of 66 % and power gain of 92 dB on par with international developments. The performance was approved by Fermi Lab (USA). A 3 kW Solid State RF Amplifier was delivered to Fermi Lab as a part of IIFC.

Design of a 1 GeV, 30 mA Linear accelerator of overall length 297 m with superconducting cavities (Half wave resonator, Spoke and Elliptical cavity) with 16 MV/m accelerating gradient has been completed.



1st segment of 3 MeV RFQ



600 mm long DTL prototype



A 50 kW Coaxial Coupler with water cooling



Vacuum Control System of LEHIPA



Magnets of Quadrupole focusing lenses & Dipole correctors

The transmission was calculated to be around 96% and beam loss of 2 % is at low energy (i.e. less than 2 MeV).

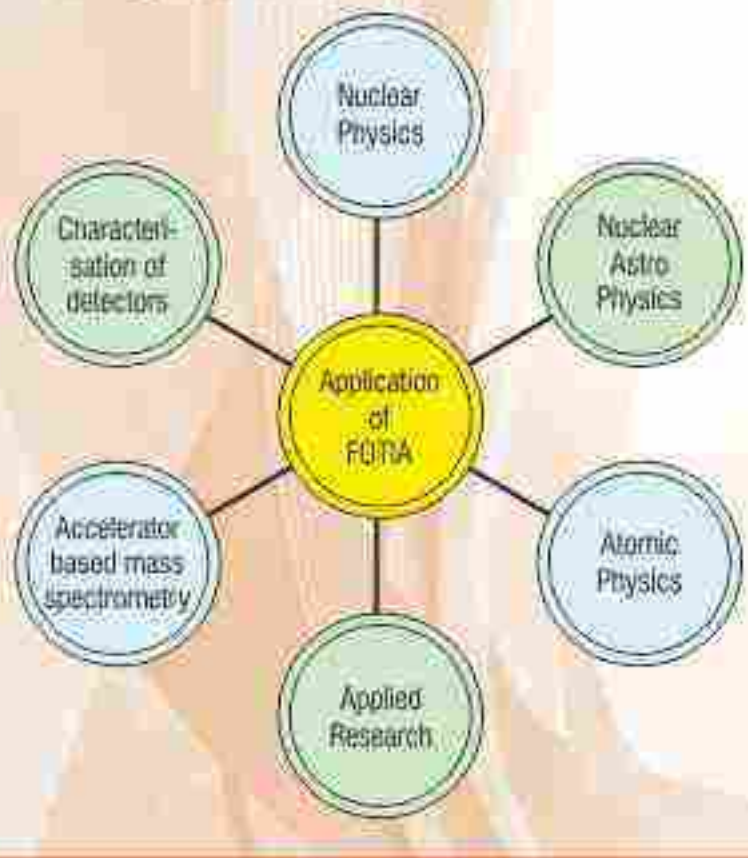


7 kW RF amplifier



Scheme for the 1GeV high intensity super conducting proton accelerator

A system has been developed and commissioned at BARC to take the ion beams out in air for Biology and Material Science experiments. The 6 MV FOTIA accelerator provided ion beams to users from BARC and Universities for a variety of Biological, Material Science, Environmental and Archaeological studies.



Applications of FOTIA

Experimental station for Small and wide angle x-ray scattering beam-line of INDUS-II was set up. Macromolecules of metals and polymers at room temperature and above are studied to get structural information. It consists of Sample Holder Assembly and the Beam Stop Assembly. Kapton Foil Holder Assembly is mounted for vacuum isolation, which in turn permits mounting of CCD camera in normal



Argumentation of FOTIA

ambient. The bellow assembly, supported over a frame structure, provides the scattered beam a collapsible high vacuum environment in which the beam travels till it is detected by the camera. It provides adjustments in X, Y and Z direction and tilting along the beam direction.



Experimental Station for SWAXS Beam-Line for INDUS-II



Water cooled compact slit assembly for ARPES/PEEM Beam Line Facility of INDUS-II

Water Cooled Ultra High Vacuum X-Ray Beam Slit Assembly has been upgraded in terms of the size of X-ray Beam for Angle Resolved Photo Electron Spectroscopy (ARPES)/Photo Emission Electron Microscopy (PEEM) Beam line facility INDUS-II at RRCAT. The total range is 40 mm x 25 mm. The resolution of slit movements is 10 microns.

A Double Wedge Tuner (DWT) was developed under a MoU between DAE and the Fermi Lab for compensation of Lorentz force detuning and microphonics stabilization of the superconducting cavities. Device has been delivered to Fermi Lab, USA for functional test. For the Medium Energy Beam Transport (MEBT) lattice of Proton Improvement Plan (PIP-1) under Indian Institute Fermi lab Collaboration (IIFC), "Electromagnetic Quadrupole focusing lenses and Dipole correctors" were developed. These magnets were qualified for their magnetic performance parameters.



Double Wedge Tuner Installed on AES-012 at Fermi Lab, USA

Development of 476 MHz Pulsed RF system for Free Electron Laser

A pulsed 476 MHz, 10 kW RF power amplifier was to feed the Sub-harmonic Pre Buncher (SHPB) RF cavity of Free Electron Laser (FEL) being developed at RRCAT. A Graphics User Interface (GUI) was also developed for operation of the RF system and measurement of various parameters. This RF amplifier was tested satisfactorily at full power of 10kW with 50 micro second RF pulse width at repetition rate of 50 Hz.



476 MHz Pulsed RF system

Deployment of digital low level RF control system for Indus-2

Digital Low Level RF (DLLRF) system were developed and installed for two RF stations of Indus-2 i.e. station-1 and station-3 of Indus-2 RF system providing phase and amplitude stability better then ± 0.5° and ± 0 .5% respectively.



Digital LLRF Systems installed with RF station-1 and RF station-3 in Indus-2 RF area

Development of 16 kW 32-Way RF Power Combiner and 1 kW RF Power Divider at 650 MHz

High power solid state RF amplifiers were developed for Indus-2 and proton accelerators. To increase the density of amplifier modules, a 32-way low loss RF power combining structure with coaxial output and 32 N-type inputs connectors operating at 650 MHz was successfully designed and developed. This will be used in making compact solid state RF amplifiers for Indus-2 and high intensity superconducting proton accelerators under the Indian Institutions Fermilab collaboration.



16 kW 32-way low-loss RF power combining structure

Development of single-cell 650 MHz SCRF cavity

The first 650 MHz single-cell SCRF cavity developed at RRCAT was successfully tested at Fermilab at 2K during VTS testing at Fermilab under Indian Institutions and Fermilab collaboration. The cavity performance has exceeded the rated specification of acceleration gradient (Eacc) of 17 MV/m with quality factor Q0 > 2.0 x 10^{10} at 2K.



650 MHz cavity on VTS insert

Development of 1.3 GHz 5-cell SCRF cavity

An important milestone has been reached on the path of development of Superconducting Radio Frequency (SCRF) cavities under the aegis of Indian Institutions Fermilab Collaborations (IIFC) by successful testing of the first 5-cell, 1.3 GHz SCRF niobium cavity on October 2014. The cavity was characterized and pre-qualified at 77 K at RRCAT. It was sent to Fermilab for further processing and testing during September - October 2014. The cavity



5-cell 1.3 GHz cavity on VTS insert

showed E_{acc} of 20.3 MV/m at 2 K and 42 MV/m at 1.5-1.7 K with Q0 of 2 x 10^{10}.

Development and Testing of a Blade Tuner for SCRF Cavity

A blade tuner has been designed and fabricated to study the issues related to the slow and fast tuning mechanism required for SCRF cavity.



Blade tuner integrated with 1.3 GHz prototype dressed cavity

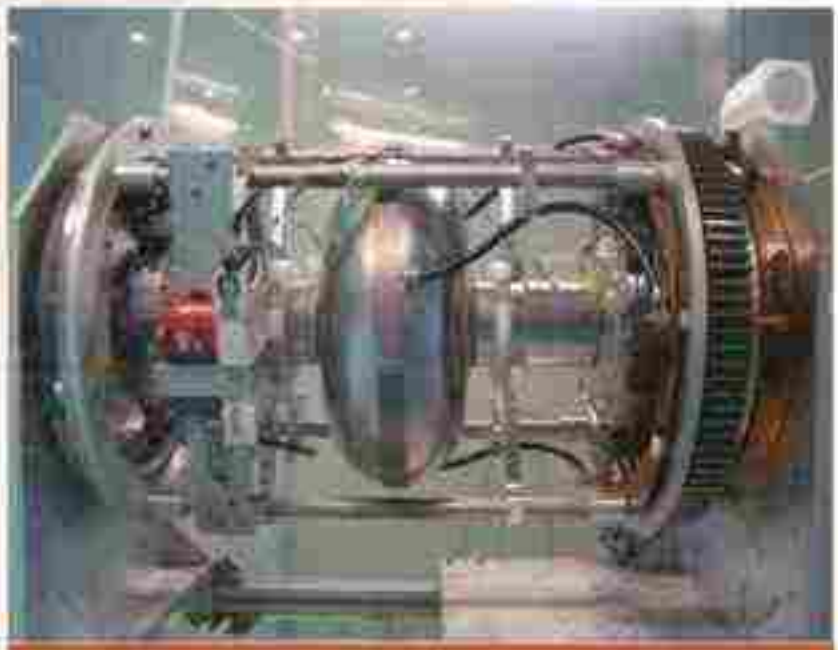
Tuner for SCRF cavity helps in tuning the RF resonance frequency. It also controls the RF frequency instabilities of cavities during operation. A prototype nine-cell 1.3 GHz normal conducting, dressed copper cavity was fabricated and integrated with tuner for testing the sensitivity, stiffness, hysteresis, resolution and precise control of the tuner. A tuning sensitivity of 320 kHz/mm and hysteresis of 35 µm were measured during room temperature testing, which matches closely to the design parameters. The tuner was also tested with piezo actuators, which are required for fast tuning control of the cavity frequency.

Development of polishing facility for 650 MHz SCRF cavity

A horizontal electro-polishing setup was developed for electro-polishing of five-cell 650 MHz SCRF cavities. The cavity is held in a horizontal position during electro- polishing. The cavity serves as the anode whereas an aluminum tube which delivers electrolyte to the cavity, serves as cathode. The setup can move the cavity from horizontal to vertical position for mounting of cathode, draining of electrolyte and rinsing of cavity



Semiautomatic cavity tuning machine developed for 1.3 GHz SCRF cavities



Electro-polishing of single- cell 650 MHz cavity



High pressure rinsing of single-cell 650 MHz cavity

after the process. A set up was also developed for High Pressure Rinsing (HPR) of 650 MHz SCRF cavities. The rinsing process removes chemical residue from the interior of cavity surface which may cause field emission and limit the performance of SCRF cavity during VTS testing. The HPR is installed in a specially designed class 100 clean enclosure.

Laser welding of Niobium based superconducting radiofrequency cavity

Japanese Patent Office has granted patent No 5632924 on October, 2014 to the innovative process based on laser welding technique of niobium based superconducting radio-frequency cavity. This technique is conceptualized and developed at RRCAT for the first time in the world. The application bears the title, "Niobium based superconducting radio-frequency (SCRF) cavities comprising niobium components joined by laser welding".



The world's first laser-welded 1.3 GHz niobium SCRF cavity

Development of a new vacuum brazing approach for joining niobium to type 316L stainless steel for application in superconducting radiofrequency cavities

A new vacuum brazing approach has been developed for fabrication of niobium-316L stainless steel transition joints. The resultant brazed assembly (Fig.42) not only displayed required hermeticity (helium leak rate <1.1 x 10^{-10} mbar.l/s) for service in ultra-high vacuum but also met other necessary qualifying tests, including ten-hour degassing heat treatment at 600oC and ten thermal cycles between room temperature and liquid nitrogen temperature without exhibiting any noticeable degradation in hermeticity. A noteworthy aspect of the transition joint was its ductile fracture mode in shear test which is a significant improvement over existing global practice.



Vacuum brazed niobium-type 316L stainless steel assembly

Development of magnets for the 700 MeV Booster Synchrotron

Prototype laminated dipole and quadrupole magnets were developed with improved fabrication techniques, magnetically characterized and they have achieved the desired magnetic field quality for improving the performance of the existing 700 MeV Booster Synchrotron.



Series dipole magnet cores (left) and an assembled dipole magnet (right)



Series quadrupole magnets

Development of fast corrector magnets for fast orbit feedback system of Indus-2

Combined function fast corrector magnets have been developed to correct the electron beam positions for the range of perturbations typically up to 100 Hz for Indus-2. In the first phase, five such correctors were placed in the ring for local beam orbit correction.



Fast corrector magnet assemblies



Magnet installed in Indus2 ring

New Eddy current thin septum magnet

New eddy current septum magnet with free thin septa was developed with improved field homogeneity near the injection. This new magnet will replace the existing thin septum magnet which will improve injection electron efficiency into 2.5 GeV Storage ring.



Eddy current septum in measurement bench

Development of long pulse high duty cycle solid state modulators for SNS applications

An IGBT based long pulse modulator capable of delivering 33 kV, 20 A at 5 Hz repetition rate was designed and developed. In this design,



Solid state converter modulator setup

pulses of 1.6 ms pulse width, 80 µs rise time and 70 µs fall time were achieved at the modulator output. A drop of ± 0.6 % and very low fault energy of 3.5 J was obtained.

Up-gradation of RF system for Vertical Test Stand

1.3 GHz solid state RF system capable of feeding upto 500 W CW power was designed and developed for testing the Superconducting RF cavities in the Vertical Test Stand (VTS). This RF system has been further augmented to include a 650 MHz low level RF control system with indigenous design and development efforts. Further, the software of the RF system was upgraded to include automatic identification of optimum phase of operation.


650MHz, 5KW solid state power amplifier developed for vertical test stand RF system

Design and development of 6 MW peak power S Band microwave system for 10 MeV travelling wave electron Linac

A high power klystron based microwave system of peak power of 6 MW and 10 µs pulse width has been indigenously developed to energize 10MeV Travelling wave electron linear accelerator for agricultural radiation processing facility. A fully solid state 50 kV electron gun modulator also has been developed and coupled with the electron gun of the linac. Beam power of 500 W at 10 MeV beam energy has been obtained using the above system.

Deepti: Software to visualize x-ray fluorescence spectra

The microprobe XRF examination of a specimen for spatial distribution of elements, Energy Dispersive X-ray Fluorescence (EDXRF) analysis and Total Reflection X-ray Fluorescence (TXRF) characterization of materials at ppb (parts per billion) levels required a lot of XRF data analysis and data visualization tools. A software application "Deepti" has been developed to help the user to detect and analyze multiple-peaks in the data and analyze the fluorescence peak intensities of different elements present in the sample.

Factor of ten enhancement in intensity of Radioactive Ion Beam (RIB) of ^{111}In (Indium-111) for user experiments

The isotope ^{111}In has a half-life of 2.8 days and is widely used radioactive probe. With the optimized plasma sputtering technique a factor of ten enhancement in intensity compared to last year was achieved at VECC. First, the radioactive isotope of Indium was produced by bombarding natural silver target with alpha-particle beams from the K130 cyclotron. The chemically separated radioactive sample was thereafter subjected to plasma sputtering in the ECR ion-source of the isotope separator. Finally the pure beam of ^{111}In with an intensity of twenty thousand particles per second was implanted in the sample being studied with a total dose of around 10^{17} atoms. The first user experiment was recently done using this beam. In this experiment the change in beta-decay rate, which is of fundamental importance in nuclear astrophysics, is

being examined for ^{111}In by implanting it in different environment such as gold and silicon matrix.

Broad ion beam based, mask less, low cost and fast nano-patterning for electronic, magnetic, optical and mechanical devices

VECC, has recently demonstrated a method that allows patterning of isolated nano arrays by broad ion beam implantation without any mask and/or lithography. The key feature of this method is that the projectile atoms are inserted and restricted at specific sites without any mask. This method has potential applications in mask less, low cost and fast nano-patterning for fabrication of electronic, magnetic, optical and mechanical nano-devices. This method can produce striped as well as regular isolated conductive or magnetic dot patterns using suitable prefabricated structures. This ion beam based technique is highly flexible and controllable with respect to the implanted species, implantation depth and concentration. Further, the present method of synthesis does not require any protective layer deposition as the desired atomic species is implanted at the subsurface layers and protected from the external environment and contamination. Further, with this process large area nano-patterns can be potentially realized eliminating the need for multistep ion-beam processes used currently.

Role of electron momentum re-distribution in Fe-based superconductors

This study was aimed at examining the role of low momentum electrons in the superconductivity of iron based superconductor $Ba(Fe_{0.943}Co_{0.057})_2As_2$ using the technique of positron annihilation spectroscopy. $Ba(Fe_{1-x}Co_x)_2As_2$ is superconducting with critical temperature Tc of 19.5 Kelvin whereas $BaFe_2As_2$ is non-superconducting. Single crystals of $Ba(Fe_{0.943}Co_{0.057})_2As_2$ and $BaFe_2As_2$ were examined by coincidence Doppler Broadening of Positron Annihilation Radiation Line-Shape (DBPARL) down to temperature of 14 Kelvin. This was the first reporting of positron probing of any Fe-based superconductor.

Observation of p-type conductivity in As doped ZnO

Zinc Oxide (ZnO) is a promising semiconductor material with potential applications, for example in optoelectronic devices, spintronics materials and hybrid solar cells. Synthesis of p-type ZnO and p–n junction are the key factors in practical device fabrication. The effect of nitrogen doping by implanting 1.4 MeV N^+ ion beam accelerated in the 3.4 meter long RFQ of the RIB facility was also examined. The results indicated a room temperature ferromagnetic ordering in N implanted ZnO sample with the conducting characteristics of n-type semiconductor. However, p-type conductivity in ZnO films grown on semi-insulating GaAs substrate were also seen. This was also supported by ab initio calculations indicating that spin polarized magnetization can be induced due to formation of AsO or, AsZn-2VZn defects. SQUID results also showed that room temperature ferromagnetism has been induced in the sample with a value of 0.83 emu/g. The XPS results indicated that AsZn-2VZn complex has been formed, whereas no signature of AsO was found in the spectra.

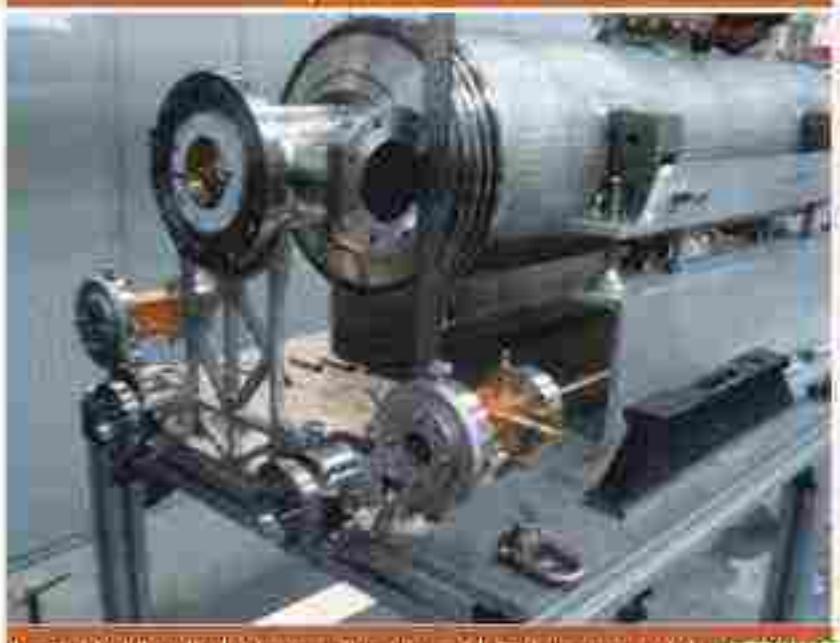
Indigenous technology development related to superconducting electron linear accelerator and room temperature radio-frequency accelerator cavities

VECC is developing a superconducting electron linear accelerator (e-Linac) based on 1.3 GHz SRF technology in collaboration with TRIUMF (TRI University Meson Factory) in Canada. In the first phase, a 10 MeV injector that comprises an electron source and two superconducting cryo modules - a Capture Cryo Module (CCM) consisting of two 1-cell niobium beta=1, 1.3 GHz niobium cavities and an Injector Cryo-Module (ICM) which will house one 9-cell, 1.3 GHz niobium cavity are being built. For the VECC machine, the electron source and the first CCM will be indigenously made in Indian industry whereas the ICM is being built at TRIUMF. A test area has been set-up at TRIUMF for testing the ICM. The physics and engineering design of the e-Linac as well as installation and tests of the injector and ICM at TRIUMF are being done jointly by VECC & TRIUMF physicists and engineers.

A test setup was designed and developed for evaluating the effectiveness of the conversion of the 4K LHe to 2K in the 4K-2K insert. The set up will be used for evaluation of the overall performance of the



VECC engineer participating in assembly of injector Cryo Module at TRIUMF



Assembled 9-cell niobium cavity string of injector cryo module at TRIUMF

cryogenic layout and thermo-syphon circuitries designed for the cryo-modules.

In the RIB facility heavy-ion beams will be accelerated beyond 1 MeV/A using superconducting heavy-ion linear accelerators. The linear accelerator will have QWRs (Quarter Wave Resonators) housed in a cryostat. While the QWRs will provide the required acceleration gradient there will also be transverse defocusing of the beam and to counteract this one has to place powerful solenoid magnet focusing lens within the cryostat. A compact superconducting solenoid has been designed for the purpose. The solenoid will have the required focusing strength of 9 Tesla; however the field should not extend much beyond the physical length of the solenoid to assure that the stray field on the surfaces of the adjacent superconducting RF cavities does not cross the critical value.

650 MHz, b=0.61, Superconducting RF linac cavity

Under Indian Institute Fermilab Collaboration (IIFC), R&D on the design and development of 650 MHz, b=0.61, Superconducting RF linac cavity is going on. A five cell 650 MHz, b=0.61, linac cavity was designed and its copper prototype fabrication was done. Ten elliptical shape, 4 mm. thick half cells of copper cavity, two 4 mm. thick, I.D. 96 mm. x 150 mm. long pipe and a 4 mm thick, I.D. 72.9 mm. x 250 mm. long pipe were fabricated. Deep drawing of copper sheet to form half-cell was done using hydraulic press.



Five-cell 650 MHz, b=0.61 elliptical shape prototype copper cavity

Using an automated bead pull system, RF electric field measurement has been carried out on the beam axis for 5-cell copper prototype cavity and five modes (from mode-4 to mode-0) have been measured at 651.395 MHz, 649.46 MHz, 647.055 MHz, 645.14 MHz and 643.61 MHz respectively. The desired accelerating mode, -mode or mode-4 was located at 651.395 MHz.

The niobium half-cells and beam pipe for the single cell SRF cavity was fabricated from the ultrapure niobium sheet with dimensions of 600 mm.

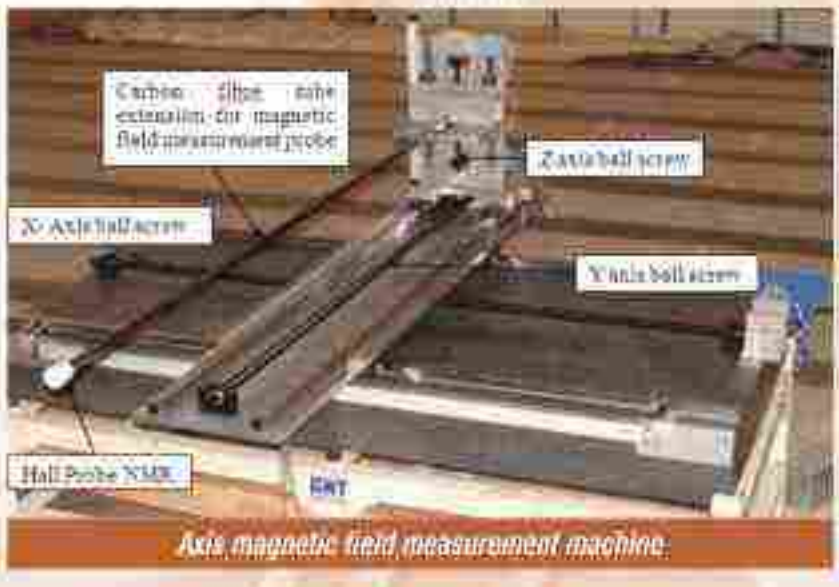


Fabricated niobium half cells and beam pipes for single-cell b=0.61, 650 MHz elliptical cavity

x 600 mm. x 4 mm. and RRR value greater than 300. These two niobium half-cells and beam pipes will be electron-beam welded soon to construct a single-cell b=0.61, 650 MHz elliptical SRF linac cavity.

Design and development of a 3 axis magnetic field measurement facility

As part ANURIB (Advance National facility for Unstable and Rare Isotope Beams) project to develop this expertise at VECC, a precise 3 axis drive system was designed and developed to move a magnetic field measuring probe (hall sensor/NMR) in a precise manner with accurate positioning in 3D space and measure the magnetic field. The drive of each axis is given by stepper motor and the position is measured by precision linear encoder system with resolution of 20 micron and accuracy of 50 micron. Each axis has linear guide and ball screw combination to achieve accurate drive. The drive system 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 or NMR in 3D is better 0.2 mm for the whole volume. This facility can be used for accurate magnetic field mapping of big dipole magnets, solenoids etc. The position of each drive was measured.



Axis magnetic field measurement machine.

LASERTECHNOLOGY

Continuous wave (CW) green beam generation intra-cavity frequency doubling of Nd:YAG laser

In a Z-shaped resonator ~104 W of CW green beam is generated by intra-cavity frequency doubling of Nd: YAG laser. The commercial pump head was designed in five-fold symmetric



100W continuous-wave diode-pumped solid state green laser

configuration for side pumping of 5 mm diameter Nd: YAG rod. The optical to optical conversion efficiency achieved was 11.3% whereas wall plug efficiency was estimated to be 5.5%. This is the highest CW green power obtained by intra-cavity frequency doubling of a diode side-pumped Nd:YAG laser.

Development of 12 W Yb-free Erbium-doped fiber laser in eye-safe region

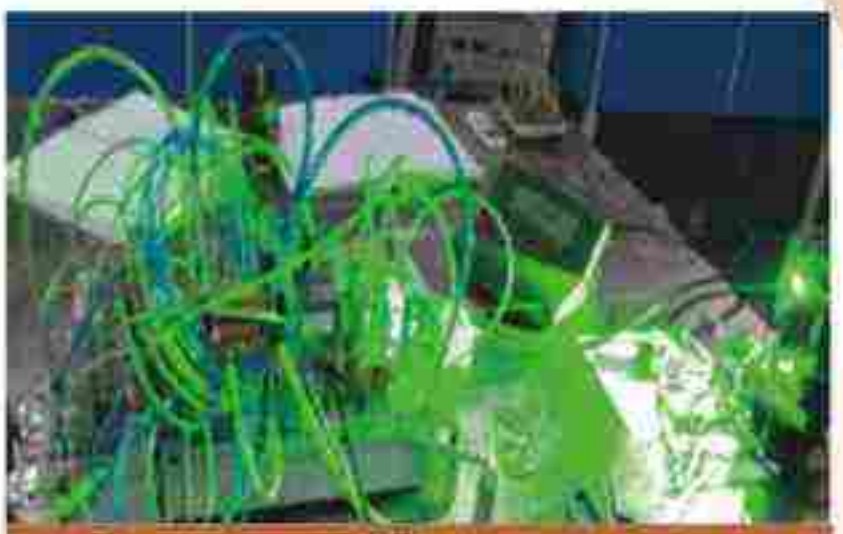
A fiber laser emitting 12 W of CW power at 1600 nm in eye-safe wavelength region was developed. This laser employs a large mode area of Yb-free erbium doped fibre which is pumped at 976 nm. The observed optical-to-optical slope efficiency was about 30%. This is the highest output power obtained in commercially available off-the-shelf Yb-free Er-doped fiber in laser oscillator configuration with 976 nm pumping.

Development of passively Q-switched Yb-doped fiber laser

A Cr^{4+}:YAG based passively Q-switched Yb-doped fiber laser providing an average output power of 41.6 W with stable Q-switching operation with pulse duration of 410 ns and a pulse repetition rate of 127 kHz has been developed. An optical-to-optical conversion efficiency of 52% was achieved.

Development and characterization of engineered version of a green laser system

A prototype model of a green laser system based on intra-cavity frequency doubled acousto-optically Q-switched Nd: YAG laser producing high average power (80 W) with short pulse duration has been developed. In CW operation, a maximum 198W of output power at 1064 nm with 29% of optical to optical conversion efficiency was obtained. Whereas,



The prototype model of 80W average power green laser

in Q-switching operation, 170 W of average output power at 22 kHz with 165 ns pulse duration (FWHM) was obtained. For intra-cavity green beam generation the system was restored with LBO crystal and output curved mirror. A maximum 100W of average green power with 68 ns at 25 kHz of repetition rate was obtained. The optical to optical conversion efficiency was measured to be 13.3%.

Diode Pumped Solid State (DPSS) green laser for dye laser pumping

The performance of the high average power (30W) green laser at 532nm with variable repetition rate (8-18 kHz) with pulse duration less than 100 ns for pumping of dye laser was evaluated. A maximum 47 W of average green power at 10 kHz of repetition rate with 65 ns pulse duration was measured. At higher repetition rate the pulse duration varies from about 75 ns at 12 kHz to about 120 ns at 20 kHz of repetition rate with 40W of average green power. The laser performance is being evaluated.



Dye laser (Rhodamine-6G) pumping by using in-house built DPSS green laser

Diverse output states from ultra-long Yb-doped mode locked fiber laser in figure-8 cavity configuration

In an ultra-long ring resonator (fiber length, 430m) configured into figure-8 shape, mode locking into Yb-doped fiber laser is achieved by the combined



Yb-doped mode locked fiber laser in burst mode of operation

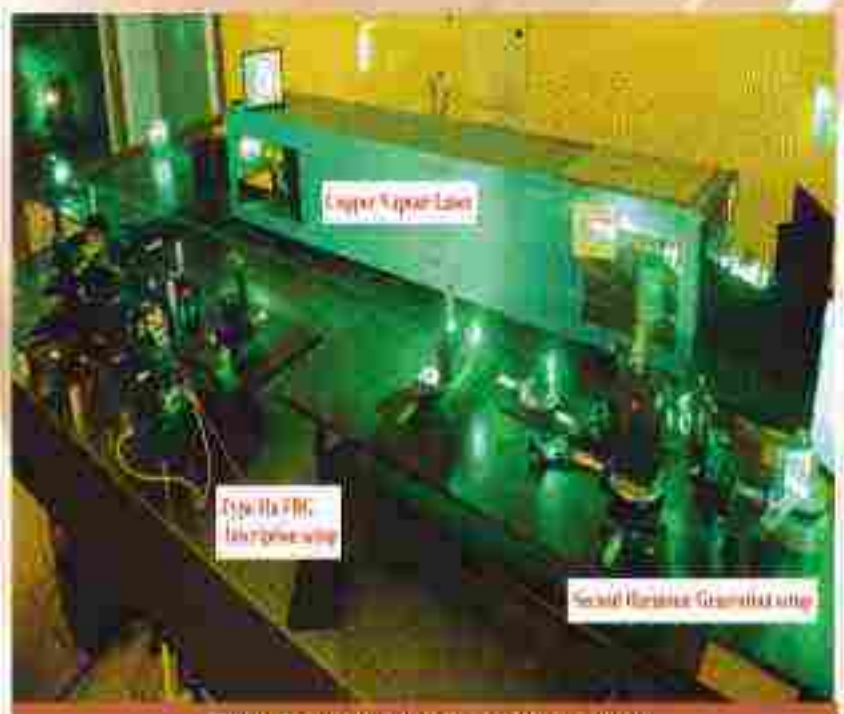
effect of Nonlinear Polarization Rotation (NPR) and Nonlinear Optical Loop Mirror (NOLM). Diverse mode-locking states are demonstrated from the laser by changing the biasing of polarization controllers producing different pulse profiles such as flat-top, step-like pulse with tunable pulse duration ranging from 3ns to 200ns.

R&D on development of semiconductor laser diode arrays

Semiconductor laser diode arrays structures were grown using the Metal Organic Vapor Phase Epitaxy (MOVPE) deposition techniques. Single layer of ZrO_2 (antireflection) and five pairs of ZrO_2/SiO_2 multilayer are used for facet coatings. The microscopic parameters of these multilayer structures are evaluated by using Indus-I and lab source experimental facilities. The laser diode arrays generated a total integrated output power of 11.5 W at the injection current of 11 A, pulse width 50 s and 1 kHz repetition rate. Subsequently, facet coated and die bonded laser diodes were also operated upto 745mW power in CW mode. One of such laser diode was also used as a pump source for exciting photoluminescence of InAsP/InP quantum well structure to study the electronic transitions.

Development of Fiber Bragg grating (FBG) based temperature sensor upto 800 °C

Fiber Bragg grating (FBG) sensor for monitoring temperature up to 800°C, is developed. It is based on FBG inscribed in single mode germanium doped optical fiber. FBG inscription is carried out using 255 nm UV radiation generated by second harmonic of high repetition rate (5.5 kHz) copper vapour laser. Long term UV exposure (of about 40 minutes) is required for the formation of FBG. Temperature stability of grating was studied by recording performance of the FBGs at various



Fiber Bragg grating inscription set up

temperatures upto 800°C using in-house developed test chamber. These FBGs will be very useful for the applications where high temperature is to be measured in presence of high Electromagnetic Interference (EMI).

Study of the effect of gain-length variation on laser pulse energy

Experiments were conducted to study the effect of variation of plasma column length on the energy of the argon x-ray laser. The output x-ray laser energy was measured for each plasma column length varying from 30 mm to 24 cm, 19 cm, 12 cm and 9 cm. The variation of the laser energy with plasma column length showed an exponential increase in the laser gain for plasma length below ~15 cm beyond which the gain increases linearly with length (saturation). In the exponential growth region, the gain coefficient of this laser was estimated to be 0.7 cm^{-1}, corresponding to a gain length product of 10.5 for a plasma column length of 15 cm.

Development of rep-rate Nd:phosphate glass regenerative amplifier

An Nd: phosphate glass based rep-rate regenerative amplifier was developed using diode pumping instead of flash lamp pumping. A laser pulse of 600 ps duration and 150 pJ energy, injected in this amplifier was amplified to pulse energy in excess of 2 mJ at a pulse repetition rate of 1 Hz with an overall gain of 10^7.



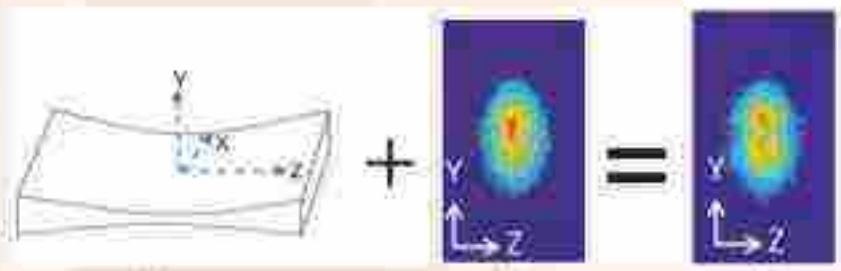
The Nd: phosphate glass based rep-rate regenerative amplifier

Negative ion acceleration in interaction of ultra-short laser pulse with transparent solids

For the first time, acceleration of negative hydrogen ions has been observed in the interaction of ultrahigh laser intensity (10^{19} W-cm^{-2}) laser with transparent solid matter. A negative hydrogen ion flux of $8x10^{11}$ H- ions/sr from PMMA target was recorded in a single laser shot using a Thomson parabola ion spectrograph.

Splitting a magnetically trapped cold atom cloud using a sheet type laser beam

The atom cloud obtained in an Ultra-High Vacuum Magneto-Optical Trap (UHV-MOT) of a double-MOT setup has been trapped in a quadrupole magnetic trap. The quadrupole trap was formed by using a current of 23 A in the coils in anti-Helmholtz configuration. The temperature of the atom cloud trapped in the quadrupole magnetic trap was estimated from the size of the cloud which is 250 μK. The dipole laser beam was shaped into a sheet form having width 21 μm and 2.3 mm along y- and x- axes respectively, using a cylindrical lens of focal length



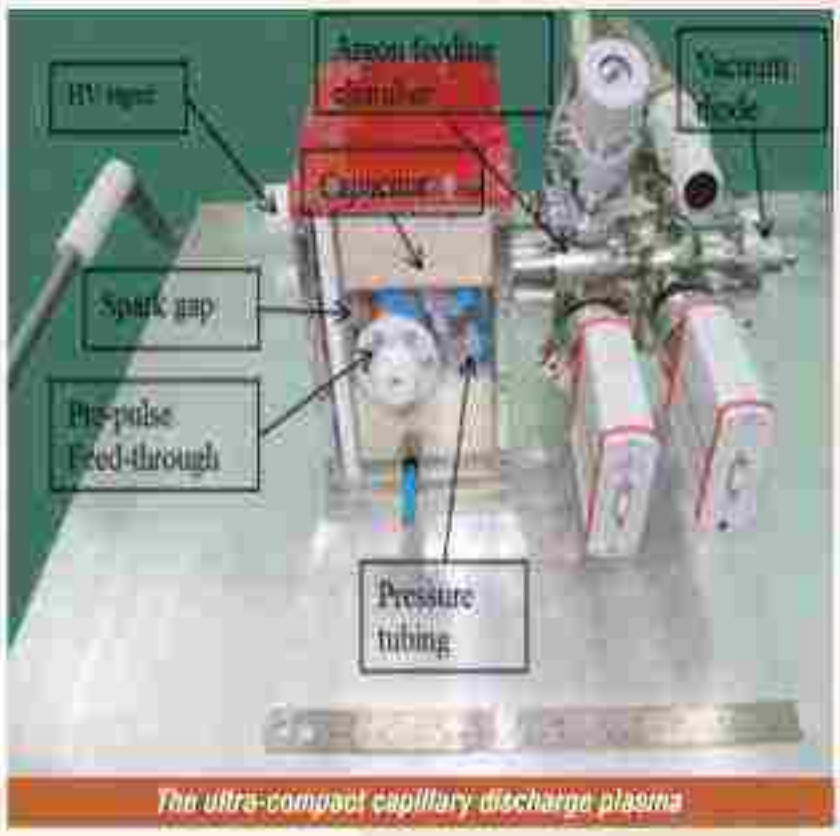
Schematic of the beam waist shape of the sheet laser beam at the magnetic trap centre

+200 mm and other beam shaping optics. The atoms trapped in the quadrupole trap interact with sheet beam potential, causing splitting of cloud. The fluorescence image of the atom cloud trapped in a quadrupole magnetic trap before (b) and after (c) interaction with the sheet laser beam.

Ultra-compact portable 50 kV capillary discharge setup

An ultra-compact 50 kV setup was designed for the capillary discharge soft x-ray laser at wavelength of 46.9 nm. The discharge system is based on capacitive energy storage method which delivers fast current through the 2.8 mm pre-ionized argon gas column in the capillary. The fast discharge circuit is made using an impulse capacitor of 20 nF, 50 kV which is isolated by a pressurized self-breaking spark gap with the 150 mm long capillary as a load. A Rogowski coil has been placed in the argon chamber which detects the capillary current. Testing of the system was done at 45 kV and the current generated around in the capillary is 12 kA.

At BARC, a time resolved Raman spectroscopy of the shocked material using pump-probe technique was set up employing a 2J/8ns Nd:YAG laser system for the studies relating to the shock velocity and particle velocity which are measured using streak camera and shadow-graphy/interferometric techniques respectively to construct equation of state of materials at high



The ultra-compact capillary discharge plasma



Laser energy : 2 J, Pulse duration: 8 ns
Wavelength : 532 nm/ 1064 nm
Focusable I_L : 8×10^{12} W/cm^2

A 2J/8ns Nd:YAG laser system



Experimental set-up for time resolved Raman spectroscopic studies on materials under shocks generated by laser materials interaction

pressure and for the spectroscopic method study which enables measurements of the material behaviour at molecular level. This laser is simultaneously used as a pump beam for shock generation (at wavelength-1064 nm) and as a probe beam at 532 nm for Raman excitation. A Raman spectrometer with 0.5 m focal length and 3 cm^{-1} wave number resolution coupled with an ICCD camera (gating time of 1.2 ns) is used for the Raman signal recording. A confinement geometry target scheme is employed to achieve enhancement of pressure by 8-10 times, keeping the laser intensity constant.

Laser Applications

In-situ cutting of triangular blocks of shock absorber assembly in RAPS-3 reactor

A remotely operable industrial Nd:YAG laser based cutting fixture, controller, and indigenous



Laser cutting of triangular blocks during mock-up (left) and laser cut triangular blocks in RAPS-3 reactor

technology has been developed and deployed successfully for in-situ cutting of apex portion of 19 mm thick triangular blocks made of SS410 in six coolant channels of RAPS-3 reactor for creating a creep margin of 19 mm. This has the operational life of these coolant channels for power generation of about 15 MWe/year up to a period of 9 years. Depending on requirement, this laser based technology for creation of creep margin will be deployed further in other coolant channels of RAPS-3 reactor also in near future. In absence of this technique, it would have been required to quarantine all the six coolant channels for fuelling and it would have reduced power generation of RAPS-3 reactor by 15MWe/year.

Gas assisted underwater laser cutting of coolant channel pressure tube stubs in high radiation field

Gas assisted underwater laser cutting process has been deployed successfully for cutting of pressure tube (PT) stubs from the rolled joint portion of pressure tube at the end of end fittings at KAPS-2, Kakrapar in a very high radiation field of 700 Rad/hr. KAPS-2 is the first reactor to use Zr-2.5% Nb pressure tubes. A total of six cuts of 118 mm length were performed by laser grooving method in underwater condition. The total time for cutting operation of PT stubs from one end fitting was 3 hours. Two such cutting operations were performed for both the end fittings. The job was carried out with minimum radiation dose of 480 mR and without any radiation hazard.



Laser cutting setup used at KAPS-2 reactor for cutting of pressure tube stubs

Development of 1 kW average power Nd: YAG laser with pulse profiling for deep cutting and welding

A prototype model of 1 kW average power Nd: YAG laser along with a fiber optic beam delivery has been developed. This laser can operate in cutting or welding mode with variable pulse duration in the range of 2-40 ms and variable pulse repetition rate from 1-100 Hz. Using this laser cutting of up to 35 mm thick SS and welding depth of up to 6 mm in SS has been demonstrated.



Laser cutting of 35 mm thick SS304 plate (left) Laser cut surface of 35 mm thick SS304 plate (right)

Micro-machining process of copper sheet using in house-built Diode Pumped Solid State green laser

In house built Diode Pumped Solid State (DPSS) green laser (Pavg >100W at 25 kHz; Pulse



Processing of copper sheet using DPSS green laser

duration: 70 ns) was used for micro-machining of 0.25 mm copper sheet. Four process parameters namely, laser peak power, repetition rate, assisted gas pressure, exposure time were chosen and varied at four different levels. The influence of each individual parameter on piercing performance was studied.

Laser shock peening for reducing the stress corrosion cracking in stainless steel

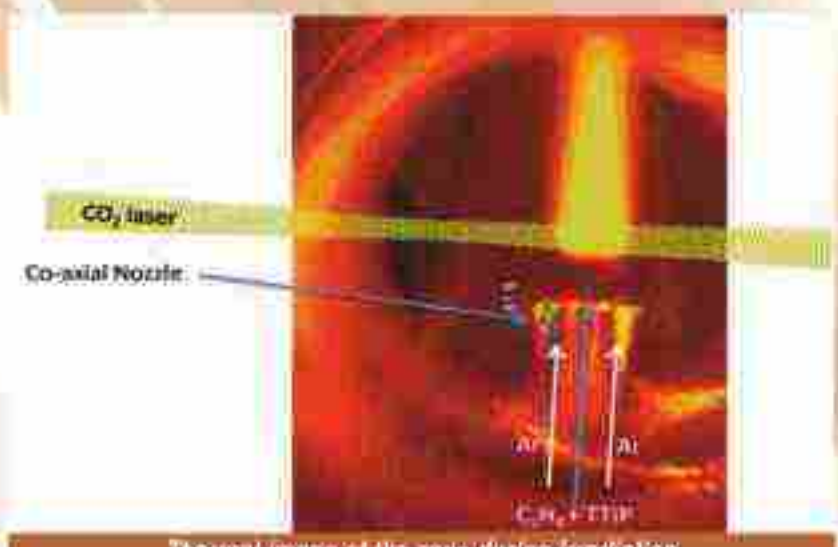
Laser peening has been carried out on austenitic stainless steel components to reduce the stress corrosion cracking which is one of the major causes of failures of the components in nuclear power reactors. Ten hour long accelerated tests showed that there is a significant reduction in the stress corrosion cracking in laser peened components.

Gas phase synthesis of TiO_2 nanoparticles

A laser based pyrolysis setup was used for gas phase synthesis of nanoparticles using CW CO_2 laser. This method uses ethylene gas as the sensitizer and Titanium Tetra Isopropoxide (TTIP) as titanium precursor for generation of TiO_2 nanoparticles. The synthesized TiO_2 nanoparticles have been characterized by Transmission Electron Microscope (TEM), Grazing Incidence X-Ray Diffraction (GIXRD), UV-visible reflectance spectra and Fourier Transform Infra-Red (FTIR) spectroscopy. Nanoparticles are formed near the nozzle just after crossing the laser beam. Temperature as high as 500°C, was measured 15 mm above the coaxial nozzle. No visible flame was observed in the interaction zone. Nanoparticles



CW CO_2 laser and gas-phase nanoparticle

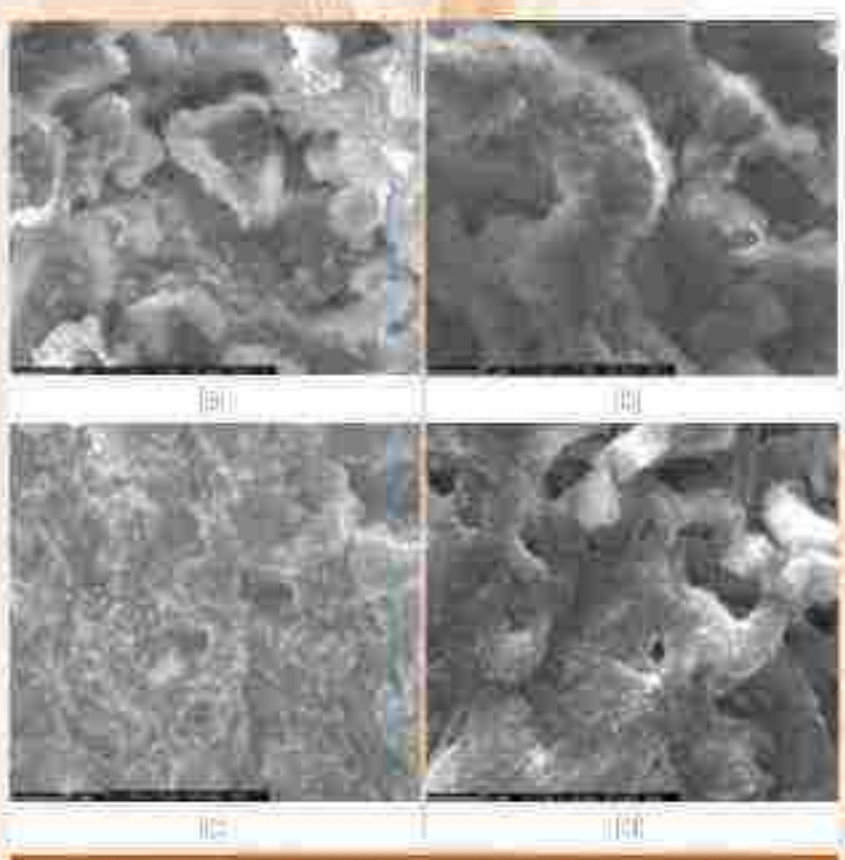


Thermal image of the zone during irradiation of C_2H_4 + TTIP crossing the CO_2 laser

formed were collected on the filter paper or suitable substrates like silicon/glass/ZnSe etc. kept in the collection channel. The first indication of formation of TiO_2 nanoparticles was obtained by FTIR absorption analysis.

SPECIAL MATERIALS

A rotary reactor of 12 kg/hr capacity was designed, fabricated, installed and commissioned for the synthesis of solid breeder materials viz., lithium titanate and lithium orthosilicate by solid state reaction process. About 2.0 kg lithium orthosilicate powder was synthesized by Solid State Reaction Process (SSRP) and pebbles of 1.0 mm size were



Microstructures of lithium orthosilicate with excess Li: (a) 5 % excess Li (b) 10 % excess Li, (c) 15 % excess Li



Electron back scattered diffraction images of (a) as-solidified, (b) deformed and (c) annealed samples of Nb-4Mo-1Zr-0.1C alloy.

fabricated and sintered. About 1.5 kg of lithium orthosilicate synthesized by SSRP using silicon dioxide and taking lithium carbonate 5%, 10%, 15% and 20% in excess of stoichiometric proportion. Pebbles of size 1.0 mm fabricated are undergoing characterization studies.

For high temperature applications, Nb-1Zr-0.1C alloy was developed and Mo was added to improve the high temperature properties of the alloy. The Nb-4Mo-1Zr-0.1C alloy was prepared by electron beam melting technique. The electron back scattered image of the as-solidified alloy showed the presence of large grains (0.5-1mm). In order to make this alloy suitable for application low temperature (800-1000 oC), the deformation behaviour of the as-solidified alloy was studied.

It was established that, the alloy can be warm worked at 900°C without cracking and oxidation. Mechanical properties of the annealed samples have shown that the Nb-4Mo-1Zr-0.1C alloy is 100% improved in the strength as compare to Nb-1Zr-0.1C alloy.

ADVANCEDTECHNOLOGIES

First of its kind 500 kg Six Degree Of Freedom (DOF) Electro Hydraulic Servo Shake Table (EHSST) was developed indigenously at BARC. Six DOF Electro Hydraulic Servo Shake Table (EHSST) is used for seismic qualification of nuclear and other components and structures in the country. High performance servo hydraulic actuators, indigenous servo controller and control & data acquisition software for 500 kg EHSST were also developed in-house and integrated to build the 500 kg six DOF shake table. In its first phase the shake table was commissioned in three degrees of freedom (X, Y and Yaw). Random input acceleration time history was faithfully followed by the shake table during the (without load) test.

A prototype Seismic Switch based on 3-Axis MEMS accelerometer has been developed and demonstrated. Seismic switches are used to generate Trip signal to scram Nuclear Power Plants (NPP) in case of a seismic event. This can sense acceleration (settable from 0.005 g to 1.7 g) and activates a relay or an LED on the board.

Solar Thermal Facility (20kW$_{th}$) has been commissioned for development of technology for



Prototype Seismic Switch



Indigenously developed 500 Kg Six DOF EHSST



Roof Top Solar Thermal Test Facility

power generation using concentrated solar power with six heliostats. Heat is collected by a natural circulation molten salt loop. Steam at 60 bar and 480°C can be generated in this facility which is condensed in an air cooled condenser. A 50 kWe solar plant has also been designed for Gamma Garden site with the experience gained. Technologies for solar energy storage and retrieval will be studied and demonstrated in this facility. Design of a 5 MWth solar steam generating plant for HWB Manuguru and a 2 MWe solar plant for IIT Jodhpur were under progress.

Tooling and fixtures were developed for the machining of zirconium hemispheres for the neutron detectors. Machined zirconium hemispheres are shown in the figure.



Zirconium Hemispheres machined at AFD

Thermal Ionization Mass Spectrometer (TIMS) for precise isotope ratio measurement of Li and Gd, TIMS for precise isotopic ratio measurements of Uranium and an Inductively Coupled Plasma Mass Spectrometer (ICPMS) for trace and ultra-trace impurity analysis of strategic materials were commissioned at user sites. One Quadrupole Mass Spectrometer is under final testing as part of a Resonance Ionization Mass Spectrometer setup in BARC. A mass spectrometer for Deuterium/Hydrogen isotopic ratio measurement has been developed for use at RRCAT, Indore. The technology of Quadrupole Mass Spectrometers (QMS) was transferred to M/S ECIL, Hyderabad.



Thermal Ionization mass spectrometer for analysis of Li and Gd

A position sensitive Multi-wire Cathode Strip gas Detector (MCSD) has been developed at BARC for the detection of fission fragments. A Time of Flight (TOF) set-up was developed to study the timing characteristics for fission fragments, using start signals from a BaF_2 (triggered by gamma rays) and stop signal from the MCSD (triggered by fission fragments after a flight path of 90 cm).

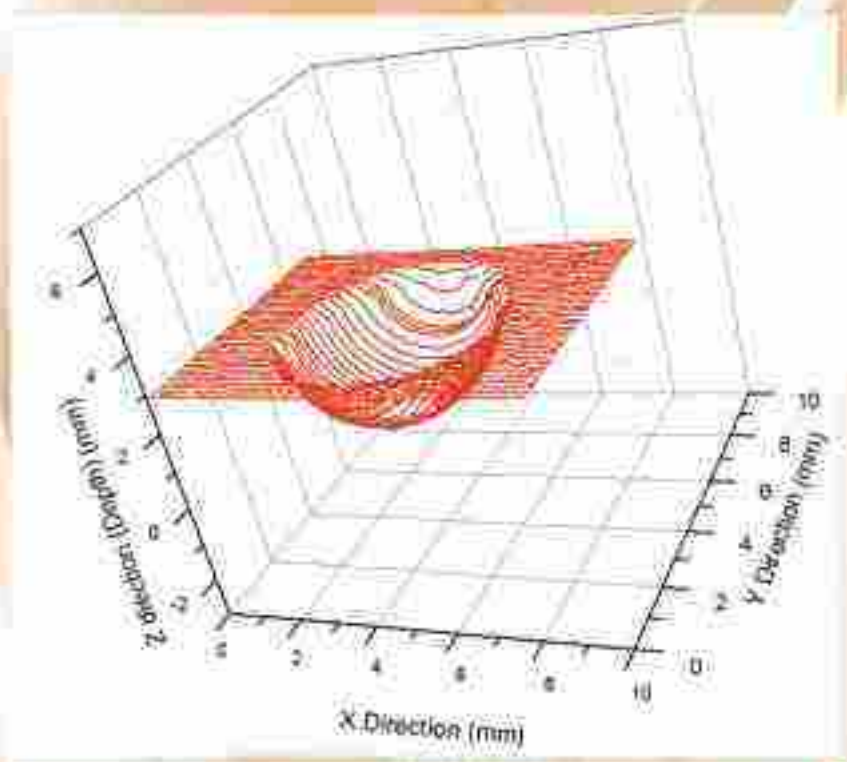
A technique for characterizing deeply curved precision machined metallic surfaces has been developed using the in-house built Time Domain Optical Coherence Tomography (TD-OCT) setup. The technique is useful for measuring radius of curvatures and shape errors on regular surfaces such as spheres, aspheric surfaces, splines, prisms and free forms generally useful in high speed



Test sample with deeply curved surface



OCT image of test sample over a line



Re constructed 3-D

applications in engineering domains. The technique has the capability of retrieving three-dimensional shape information within 0.015 mm accuracy and has several advantages over conventional laser interferometric techniques.

Position Sensitive neutron Detectors (PSD) was developed for the detector bank of the upcoming Time of Flight (TOF) spectrometer at DHRUVA. It will cover a detection area of 2.5 m^2 with 2.5 m arc length (70°), 1 m height (28°), consisting of an array of vertically arranged 50 PSDs. 25 PSDs are based on BF_3 gas with charcoal coated cathode and other 25 PSDs are based on ^3He gas.



Neutron PSD for multi PSD array

A compact neutron generator which can be mounted on a trolley and can be installed at the site has been developed. This generator will operate in both DC and pulsed mode and produce neutrons up to a yield of 10^8 n/s in D-T mode and 10^7 n/s in D-D mode and uses compact rack mounted power supply and RF ion source and replaceable target geometry.

This generator is intended for two major applications one for the detection of explosive/narcotic using neutron tagging technique and second it can be pulsed up to kHz rate with variable pulse width and can be used for fissile material detection using differential die away technique.



Trolley mounted Generator



Tagged Neutron Setup for Explosive detection



Table-Top Neutron Generator



Screenshot of 3 cameras for Secured Video Surveillance system



Hardware In-Loop Simulation (HILS) testing of Seeker at RCI

ECR series switch routers developed jointly by IIT-B, ECIL and BARC was integrated for providing a solution for dependable, secure video surveillance network. BARC has developed the stabilization system of the Active Radar Seeker which is being integrated by ECIL for DRDO. This has been validated in the Hardware-in-the Loop Simulation (HILS) setup at RCI Hyderabad. Mono-pulse target tracking was validated through an indoor setup. At HILS, the Seeker was mounted on a three axis Flight Motion Simulator (FMS) and the radiating target was mounted on a two axis Target Motion Simulator (TMS). Missile motions in yaw, pitch and roll were simulated through MMS and target motions using TMS.

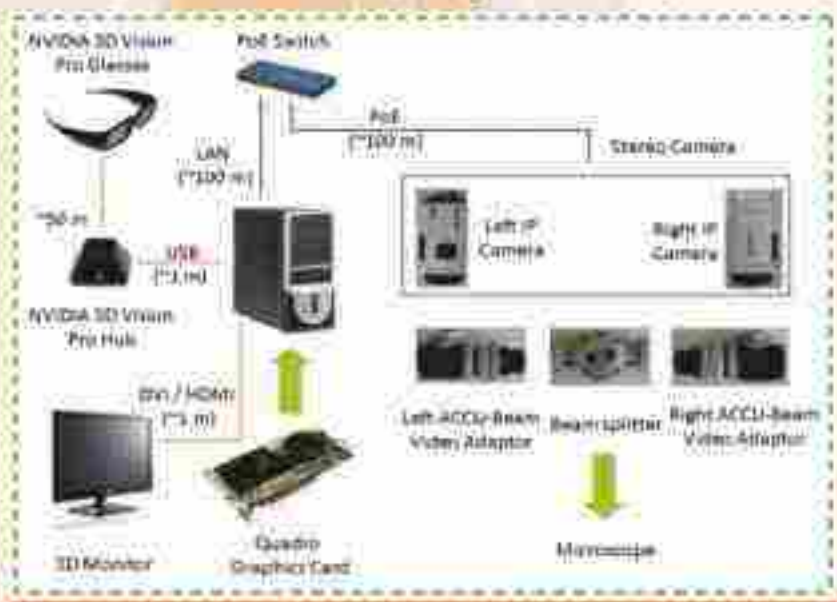
Development and integration of Servo controllers with the 2-axis gimbal mechanisms for the 0.73 M SATCOM terminal to be deployed in RUSTOM UAV and 0.45 M SATCOM terminal to be deployed in indigenous AEWCS were completed. These airborne SATCOM terminals are capable of



Airborne SATCOM Terminals for UAVs and AEWCS

continuously pointing at a geostationary satellite even in the presence of aircraft movements. This technology extends range of reconnaissance and weapon delivery platform beyond UHF/VHF range (line-of-sight).

Stereoscopic Visualization System of microscopy for Neurosurgery training and education has been designed, developed and deployed at AIIMS, New Delhi. This, indigenous HD (1280x720)



System Architecture of Stereoscopic Visualization System of microscopy



Focusing lens integrated with J Band Klystron tube



Scene showing external façade of a premise

real-time stereo rendering system is a cost-effective replacement for the existing proprietary system. It also records synchronized HD stereo image stream.

Solenoid focusing lens for J-band klystron has been developed for use in RF Seekers. The permanent magnets based lens produces desired axial magnetic field in the RF section. It was integrated with J-Band klystron tube at CEERI and tested for its RF performance. Peak RF output power of 130 watts was extracted with 80% beam transmission at 6 kV.

Walkthrough software has been developed which provides a virtual 3D tour of the premise including external façade, internal details e.g. staircases, corridors & realistic 360° panoramic view of each room. It is useful for training security and response forces.

Superconducting Magnetic Energy Storage (SMES)

VECC has undertaken the development of SMES system based Dynamic Voltage Restorer (DVR) to address the power quality problem of voltage sag, transients and harmonics that adversely affects industrial processes and critical facilities. DVR is one of the most effective and efficient compensating type power electronic controller used in the distribution network to get rid of or to mitigate the most severe power quality problem caused by voltage sags, especially for sensitive loads. Its major components, designed and developed at VECC included the following:

- SMES Coil: The cryostable superconducting magnet was constructed using NbTi based superconductor and vapour cooled current leads to carry DC current of 800A (max), thus storing 0.6MJ of energy. The coil assembly was being housed inside a Standard Magnet Dewar (SMD) with all related instrumentations and coil protection system comprising of a quench detection circuit and dump resistor placed externally.

- 2-Quadrant DC-DC Chopper: A high current IGBT based DC-DC chopper was designed and developed for charging the superconducting coil to its constant current of 400A (max) for energy storage and to discharge the stored energy to a constant DC-link capacitor voltage of 80 V as required by the VSI. A novel topology of "Hysteresis Band Controller" was adopted for proper functioning of the chopper in two-quadrant in order to match the power flow demand of the DVR system.

- 3-f Voltage Source Inverter (VSI) with DSP based control: A 10kVA 3-f VSI was designed and developed that compensates for the voltage sag in the utility mains so as to keep the load voltage constant, deriving power from the chopper controlled constant DC bus. A 12-bit multi-channel 12.5 MSPS ADC and 3-f PT based instrumentation samples the input mains and feeds to a DSP based controller that ultimately generates the



SMES coil (left), DC-DC chopper (centre) and Voltage Source Inverter (right)

switching signals to the IGBT bridge of the VSI, employing pre-sag compensation technique.

Integration and Functionality test of SMES based DVR

Following integration of the four sub-systems, the demonstration to check for its functionality was carried out on a 3-f load. The superconducting coil with 800 kg of cold mass and inductance 1.86H underwent rigorous cryogenic tests and thereafter cooled down to approximately 4.2K by liquid Helium with pool boiling mode of heat transfer.

A programmable power source was utilized to function as the utility input mains. The source was started with normal mains that was automatically sensed by the DSP based controller thus initiating the system to charging mode and energized the SMES coil. Several simulated voltage sags were generated by the programmable source and the results were recorded. Each time during sag the controller switched the system to discharging mode, locked the mains phase and compensated the load voltage both in phase and magnitude. The recovery of the mains was also sensed when the system reverted back to the charging mode.



Test set-up for SMES based DVR

Cryogenics

An integrated closed loop testing facility for cryogenic turboexpanders of sizes ranging from 6.5mm to 45mm has been developed by BARC for studying detailed thermal and rotor dynamic behaviour of new turboexpanders before final assembly in actual cryogenic plant. The facility includes simple closed loop speed and vibration testing stands to cold box with heat exchanger for experiments with impellers at low temperatures.



Integrated turboexpander test facility including room temperature test stand (left) and low temperature test facility with turboexpander mounted in a cold box (right)

Elaborate instrumentation in the form of pressure transducers, temperature sensors, flow meters, vibration measurement (accelerometers, rotor displacement) sensors along with front end software have been provided.

A full fledged closed loop cryogenic heat exchanger test facility has been developed to characterize the performance of high effectiveness cryogenic heat exchangers of various types (up to 4 streams) and a range of sizes (height up to 1.5m) at different pressure, temperature and flow conditions. The test facility uses helium as process gas. Liquid nitrogen (LN_2) is used for cooling of helium stream.



Closed loop heat exchanger test facility complete with data acquisition system (left); inside the cold box showing the test heat exchanger with temperature sensors mounted (right)

An experimental He refrigerator/liquefier was designed, developed and fabricated by BARC. After steady state cycle simulation studies, some major modifications were incorporated to achieve the target of 200W refrigeration capacity at around 4.7K. Most significant modification was changing the basic thermodynamic cycle from Collins to a modified Claude cycle which is more suited to turboexpanders. The multi-stream heat exchanger catering to the new process was designed and developed.



He refrigerator/liquefier (left) Multi stream heat exchanger specially developed for new process cycle (right)

Innovative Conditioning of Storage Vessel at VECC during commissioning to obviate helium gas scarcity

Inventory of helium gas needs to be maintained for continuous operation of the cryogenic system of Superconducting Cyclotron (SCC) at VECC, for which liquid helium (LHe) hold up in the system is around 1500 litres, equivalent to 1125 Nm^3 helium gas. A new buffer tank (BT-4) of 60 m^3 W.C. at 25 bar(g) maximum operating pressure was installed and commissioned, to maintain sufficient inventory. As there was scarcity of helium gas during commissioning of the new buffer tank, dry nitrogen was used for moisture removal as well as pneumatic pressure test. The BT-4 tank was fitted with two nos. Safety Relief Valves (SRV) and one rupture disc with marked burst pressure 28 bar(g) at 30° C. During the process of initial pressure test, the rupture disc burst at 26.156 bar(g) at 28.8° C, because the operating pressure exceeded 90% of the burst pressure limit.



Newly commissioned Liquid Nitrogen vessels of 15 Kl. Capacity (left) Newly commissioned buffer tank of 60 M 3 water capacity with maximum operation pressure 25 bar(g)

A special permission was obtained from Chief Controller of Explosives, PESO, Nagpur for permanent blanking of Rupture Disc port and keeping both the SRVs in service. The helium leak test of vessel was performed as per ASME Sec V and individual leak rate of each joints for vessel, nozzles, valves & interconnecting piping was found less than 1×10^{-8} mbar l/s. After this moisture content of the gas was found to be 35 ppm.

The above method of conditioning the helium vessel was done without any loss of helium gas, which is very costly and scarce now. Also, because of permanent blanking of rupture disc periodical pressure testing of the vessel can be done with the stored helium gas itself.

Moisture measurement in helium in ppm level

An optical setup was developed by direct absorption technique to measure moisture in different gases. Laser source emanates monochromatic light at different wavelengths from 1874.5 nm to 1877.8 nm by varying drive current and operating temperature. The laser source output wavelength was varied from 1876.24 nm to 1877.24 nm by varying current from 60 to 100 A at 32 °C using ramped modulating signal input to the laser driver generated by detector electronics. At atmospheric condition with temperature 23 °C and relative humidity 60% (volumetric ratio of moisture being 0.014), light is splitted into two, one transmitted through atmosphere (reference signal) and other (absorbed signal) through an absorption cell (optical length 500 mm) containing sample gas with 202 ppmv moisture content in helium. Transmitted light intensity is measured for both the cases using Hamamatsu make extended InGaAs PIN photodiode 8372-01 with peak sensitivity of 1.2 A/W and indigenously developed transimpedance amplifier



Optical Setup with different optoelectronic components to measure the moisture content in process helium gas

based on FET-input Op-amp OPA656. A transmittance level of 0.7, ratio of measured data and baseline data was observed. It was validated by hitran 2008 databases.

Robotics

A compact four wheeled robotic vehicle along with a remotely controlled telescopic assembly carrying a sensor capable of measuring 1000mR/hr at a max. height of 5.0m has been specifically developed by BARC for remotely mapping the radiation levels of HEPA (High Efficiency Particulate Attenuator) filter banks at radiological labs. Both the mobile robot and telescopic assembly are Tele-operated using RF signals from a self-contained control desk. The system records the radiation data.



Robot with Telefector carrying Radiation Sensor



Control Desk (for Robot control & Data acquisition)

A customized suspendable servo manipulator has been developed for remotely picking of active small size glass pieces from the floors of the waste management process cell. Suspendable Servo Manipulator is a novel design consisting of a slave and the master arm, connected to a controller through electric cables. It has five degrees of freedom and gripper, all controlled by electric motors. Major joints of the slave arm are mechanically balanced to reduce the swing of the arm, during motion. Remote operations are viewed through in-cell cameras and additional cameras mounted on the slave arm. This design provides extended reach for remote operations in the radiological labs, in which wall mounted remote tools cannot reach.

Autonomous Navigation of Mobile Robots in Indoor Environment

The research towards development of capabilities for autonomous navigation of mobile robots in indoor environments was continued at VECC. In continuation of a method developed earlier for building line segment-based maps of indoor environments by merging line segments extracted from registered laser range scans, a method for localization on such maps based on the Monte Carlo framework was developed. The method employs a novel scheme for computation of the importance weights to achieve efficient, accurate and robust localization.



Suspendable Servo Manipulator (SSM)



Master Arm of SSM in Control Room



Active Glass Pieces Picked-Up by SSM

Special Programmes

Integrity and leak testing of Tri Chloro Silane (TCS) distillation system, commissioning and testing of control system for the plant were completed at BARC.

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.

At BARC, a novel polymer composite of Ammonium Molybdophosphate and Polyethersulfone was awarded with a US patent. The composite can selectively pick up Cesium from Nuclear Waste and can be converted into source pellets. This could open up a new way to make Cesium Source Pencils for various Radiation Processing Applications and make nuclear waste handling safer.

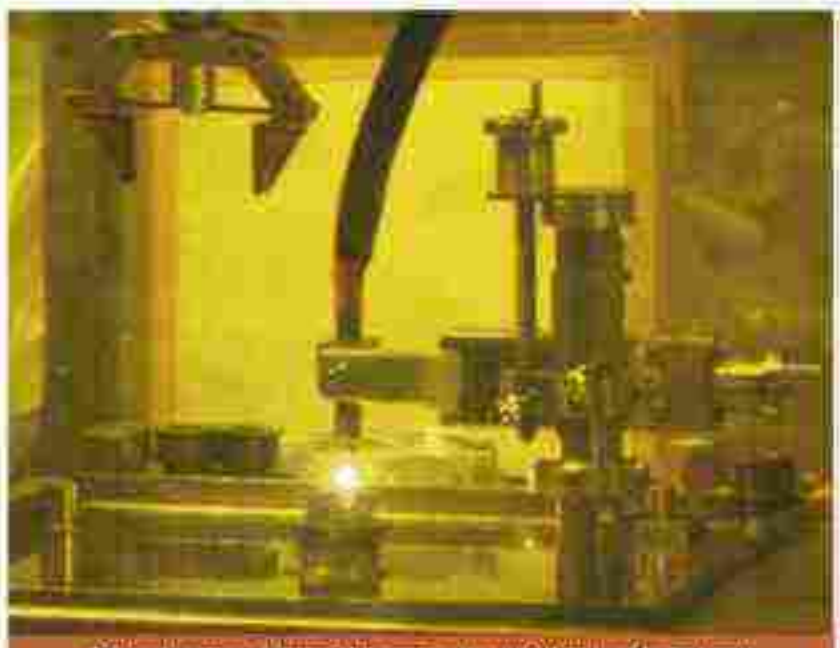
Around, 742 laboratory reference sources of beta, gamma, conversion electron, X-ray and positron sources of activity 1 MBq were supplied to users. Six ^{60}Co sources of activity 3.7 GBq were fabricated for the radiometric assay of nuclear fuel



Spherical polymer composite bead and its inside structure

rods. Five ^{63}Ni deposited on the inner surface of the copper annular ring sources of activity 3.7 GBq used as ion sources in ion mobility spectrometry were prepared.

At the Regional Centre RAPPKOFF, Kota of BRIT total activity of ^{60}Co which was processed during the year was about 63.52PBq (1717 KCi). Safe handling, transportation of adjuster rods from



Sealed source fabrication using tig welding inside hot cell



Cobalt sub-assemblies in storage pool

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. Twenty shipments of ^{60}Co with total activity of 54.67 PBq (1478 KCi) were transported. 74 Customized W-91 pencils with total activity of 2.23 PBq (60.35 KCi) were also fabricated and transported. The centre was also involved in the source loading operations of 60 kCi of ^{60}Co to Ethiopia and Cobalt Teletherapy Source to Cancer Hospital, Lusaka, Zambia.

AGRICULTURE

Crop Improvement

A high yielding Fusarium wilt resistant pigeonpea variety Trombay Akola Red Arhar (PKV-TARA) was released for commercial cultivation in Maharashtra state. Black gram selection TU-18 and Mungbean selection TMB-45 was promoted from IVT to AVT-I in All India Coordinated Research Project on Mungbean, Urudbean, Lentil, Lathyrus, Rajmash and Pea (MULLaRP). Cowpea genotype (TC 901 for summer) was promoted from IVT to AVT-I of All India Coordinated Research Project of Indian Council of Agricultural Research (ICAR).

The F_1 harvested seeds of cross between bruchid susceptible TMB-37 and resistant Thokalwadi wild screened in laboratory for bruchid reaction were found resistant to bruchids without any damage and adult emergence. Fifty three new selections evaluated for seed size, seed yield per plant and Yellow Mosaic Disease (YMD) reaction in the field conditions showed resistance to YMD along with large seed size and high yield.

Breeder seed multiplication of released varieties TU94-2, TU-40, TAU-1, TAU-2, and TPU-4 was carried out. F_2 population involving the cross between TAU-1 X KU96-3 was grown and individual plants were harvested as single plant selections and scored for Yellow Mosaic Virus (YMV) resistance / susceptibility.

The cowpea selections TC 1-26-E and TC 1-6-10-1 with resistance to leaf crinkle and cowpea

mosaic virus were multiplied and included in ICAR trials. Nine F9 lines of the crosses C-16 x TCM13-3 and TC 99-1 x EC 394758 were found to have combined resistance against leaf crinkle and cowpea mosaic virus diseases. The high yielding cowpea selection TC 601 was irradiated with electron beam and gamma rays (200 to 500 Gy) and the M1 populations were grown in the field and harvested.

F, from Crosses made using wild germplasm, drought tolerant/susceptible accessions and popular varieties were raised. Seeds of popular variety-Vijay were irradiated with 200, 300, 400 and 500 Gy gamma rays and electron beam. M, plant to row progenies was raised

During the year, eighty promising lines from different inter-varietal crosses were evaluated at IARI RS, Wellington, ARS, Niphad and Dr. Punjabrao Deshmukh Krishi Vidyapeeth Akola for improvement for rust resistance and quality.

For improvement of a variety HD2189, Sr24/Lr24 and GluD1d gene was incorporated by using molecular markers MABB (Marker Assisted Backcross Breeding). Using SCAR markers in BC4F4, 17 lines were identified to carry both the genes. Research to understand the molecular mechanism of stem rust resistance genes in wheat was taken up using transcriptomics and proteomics tools. Microarray analysis of stem rust resistance gene Sr24 was carried out.

By using RT-PCR and SYBR green dye, a technique was developed that does not require post-PCR agarose gel electrophoresis and can save time and money in marker assisted selection in a large population.

Two rice selections, BARCKKV10 and 11, were found superior in western Maharashtra in Advanced Variety Trial (AVT) quality of Maharashtra State Rice Coordinated Trials, 2014 which had shown more than 13.6% yield advantage over the state check Palghar in Kharif 2013.

Trombay groundnut varieties, TG 37A, TG 38, TPG 41, TLG 45 and TG 51 were registered as extant varieties with Protection of Plant Varieties & Farmers' Rights Authority, Government of India, New Delhi. New Trombay groundnut entries, TG 72, TG 73, TG 74 and TG 75 were evaluated in ICAR trials for all over the country. TG 60, TG 68, TG 70, TG 73, TG 74 and TG 75 were evaluated at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

About, 538 quintals breeder seed of Trombay groundnut varieties, TAG 24, TG 37A, TG 38, TDG 39, TG 47 and TG 51 were multiplied at BARC Farm, Gauribidanur, RMP, Mysore and under contract farming at Kehal, Parbhani and Pattanakodoli, Kolhapur and distributed to 20 seed growing agencies like National Seed Corporations, State Seed Corporations, State Agricultural Universities, agricultural department, seed companies and farmers.



Breeder seed multiplication of Trombay groundnut variety TG 37A at Kehal, Maharashtra

A high yielding widely adapted groundnut variety, TG 37A was field demonstrated at neighbouring villages of Kakrapar Atomic Power Station in Gujarat and Open Air Jail Campus at Sivagangai, Palayamkottai and Madurai in Tamil Nadu.

Six Trombay Mustard genotypes namely TM143 and TM108-1 in IVT timely sown, TM266 and TM188 in IVT late sown, TM209 in IVT rainfed and TM196 in IVT saline/alkaline are tested for yield evaluation. TM genotypes were evaluated for seed yield potential at State Agricultural University (SAU) to identify high yielding genotypes for release of variety.

Tissue culture multiplication of banana was transferred to KCE Society's JalaSri Watershed Surveillance & Research Institute, Jalgaon, Maharashtra through BARC's AKRUTI program.

Technical guidance was provided for establishment of tissue culture laboratory at their site and four personnel were trained in banana tissue culture in our laboratory.

Investigations into the roles played by different cell death related genes in the progression of Fusarium wilt infection caused by fungus Fusarium oxysporum f. sp. Cubense(Foc) on host banana plants were carried out on three genes namely MusaDAD1, MusaBAG1 and MusaBI1.

A rapid molecular method for detection of gliotoxin producing Trichoderma strains has been developed. A PCR-based method has been developed for detection of mating types in Trichoderma spp. A novel and purely organic seed dressing formulation based on a radiation-induced mutant strain of Trichoderma virens has been developed and evaluated in field trials.

Role of proteins in nanoparticles synthesis have been elucidated. Nonspecific proteins at equivalent concentrations have been checked for nanoparticle formation ability.

A viable technology for production of the anticancer drug camptothecin was developed using plant tissue cultures of the indigenous medicinal plant Ophiorrhiza.

A variety of microorganisms with useful properties from the Predigestor of Nisargruna Biogas plant were screened for phosphate solubilisation and antifungal property. Initial screening has found that these bacteria possess very good ability to solubilize phosphate.

The total number of Nisargruna plants installed has now crossed 190. MOUs were signed with Municipal Corporation of Greater Mumbai, Chennai and Tuthikodi for installation of seven Nisargruna plants of different capacities.



Nisargruna Plant at RRCAT, Indore. Inauguration by Dr. R. K. Sinha Chairman AEC & Secretary DAE



NISARGRUNA PLANT AT Kurudampalayam, Coimbatore with Capacity 2MT/day

FOOD PROCESSING

At BARC, a combination process including radiation treatment was developed for hygienization and shelf life extension of shelled sweet corn kernels up to 30 days at 4°C, and evaluated at laboratory scale. Minimally processed Ready-To-Cook Indian vegetables with improved shelf life and quality developed. Ready to bake 'Chapattis' with shelf life of 1 month (at 8°C storage) were prepared using combination of heating (80°C for 15 minutes) and radiation processing at 1kGy. Shelf life extension up to 6 weeks at ambient temperature of 'Thalipith', an Indian ethnic product, was observed using combination of radiation processing at 5kGy and subsequent heating at 80°C for 20 minutes.

A process was standardized to prepare Ready-to-Eat (RTE) prawns using combination treatment of microwave cooking and irradiation. Methods were standardized for the preparation of shelf-stable puran poli, chicken litti and chicken paratha and the products were found to be acceptable even after one year of storage at room temperature.

Composite PVA-gelatin films containing tomato pulp were prepared. These films are impermeable to oxygen, showed antioxidant and

antimicrobial activity and enhanced the shelf life of the chicken meat during chilled storage. These films could be a potential replacement for synthetic non-biodegradable polymers. Biodegradable and edible film with functional properties comparable to commercial cling wrap films was developed and the technology transferred to industry. PVA films were prepared by adding copper nanoparticles for improved mechanical, permeability and antibacterial properties of film. Composite films of zein and gluten were incorporated with aqueous alcoholic extract of green tea. These films were hydrophobic with good mechanical properties and showed slow release of antioxidants in model system and prevented lipid peroxidation in chicken meat.

Health protective compounds contributing to antimutagenic property of Java Plum, Apple (cv. Granny Smith) and rose petal were identified. Feasibility of Solid Phase Micro Extraction-Gas Chromatography-Mass Spectrometry (SPME-GCMS) in combination with chemometrics as a nondestructive method for rapid assessment of microbial quality of minimally processed fruits demonstrated. Radiation processing of wheat flour at different doses up to 30 kGy showed improvement in starch properties like solubility and water absorption as well as apparent increase in amylose content. Different bacteria involved in spoilage of food (e.g. Bacillus) or affecting the crops (e.g. Xanthomonas) were found to undergo genetically regulated Programmed Cell Death (PCD) in different stress conditions including radiation stress. Natural existence of 2-ACBs, known earlier to be a Unique Radiolytic Product (URP) was further confirmed. Substrate specificity studies of enzymes of M20D peptidase family showed that the enzymes of the family are Met-X carboxydipeptidases.

The technology for FVDTM (Fruit Vegetable Dip Treatment Machine) for processing of Litchi and other fruits and vegetables was developed. Litchi processing technology was transferred to SCRIMAD, Madagascar. Dip treatment of pomegranate arils with aqueous guar gum solution containing grape pomace extract showed improved shelf life of 6 d when stored at 10°C. Radiation processed RTC cauliflower was developed with improved shelf life (21 d) with acceptable microbial and sensory quality.



Wheat and Kodou rice samples irradiated with electron beam at different doses

Wine from radiation processed grapes with improved organoleptic qualities was developed. Guar gum based active packaging film possessing antimicrobial properties was developed using grape pomace extract. Shelf-life extension of pomegranate arils up to 12 d at 10°C was achieved using the developed active packaging. GC/MS based method was developed for rapid and early detection of microbial spoilage in Ready-to-Eat (RTE) jackfruit.

An irradiation facility based on 10 MeV, 3 kW electron beam linac is working at RRCAT. A large number of samples were electron beam irradiated using electron beam from the linac at this facility for agricultural and materials research. The samples included different varieties of wheat, soy, kodou rice, kutki rice, maize seed & flour, and lauki seeds. Soy seeds were irradiated to study the effect of e-beam on Anti-Nutritional Factors (ANFs) and nutritional & oil quality of the seeds by Directorate of Soybean Research, Indian Council of Agricultural Research, Indore. Wheat samples were irradiated for Indian Agricultural Research Institute, Pusa, New Delhi. Kodou rice, kutki rice, maize seed & flour were irradiated for insect disinfestation and nutritional studies for research work being done by Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.

Radiation Processing Services

Radiation Processing Plant (RPP), Vashi

During the year, about 3900 Tons of spices and other products were processed. New type of products like nutraceuticals and colour pigments were added after sample irradiation and post irradiation analysis. 5000 numbers of sterile surgical drapes were supplied to BARC Hospital.

The QA activities at RPP included the plant commissioning dosimetry at Industrial Gamma Irradiator of Southern Tsetse Fly Eradication Project (STEP), Addis Ababa, Ethiopia which was completed in June 2014. 3mM Ceric–Cerous sulphate dosimeters (Dose range: 1.0-6.0kGy) manufactured by BRIT as per ISO/ASTM 51205 were used for the dosimetry experiments. The dosimetry was carried out to set the process parameter for irradiating diet blood for Tsetse flies in the Kaliti Tsetse Mass Rearing and Irradiation Centre, STEP, Ethiopia.

Plant re-commissioning dosimetry of Panoramic Batch Gamma Irradiation facility at Institute of Food and Research Biology, Savar, Dhaka was completed for sterilization of medical products in November 2014. Supply of 3, 5 and 15 Mm ceric-cerous sulphate dosimeters to SriLanka, Bangladesh and Ethiopia.

Revenue generation during the financial year 2014-15 was ₹ 3.3 Crores. Since its inception, the facility has processed 30550 tons of products. Revenue earned by the supply of dosimeters, dosimetry systems and other associated systems is expected to be approximately ₹ 40 Lakhs.

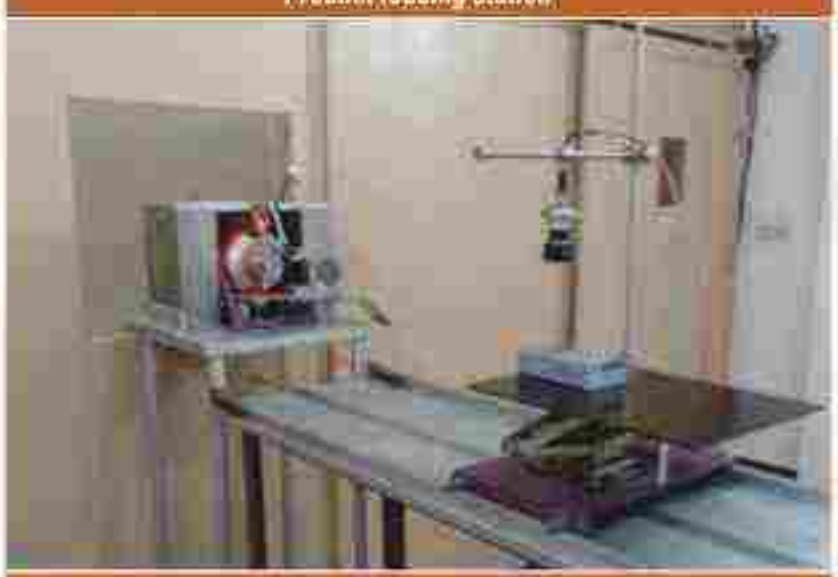
A facility has been set up for calibration of Nuclear Radiation Survey Meters at Vashi Complex. It will cater to calibration requirements of portable radiation monitoring instruments in the range of 0.5 mR/h to 5 R/h. The laboratory is approved by AERB and has started providing calibration services for in-house requirement.

New MoU for Radiation Processing Plants in Private Sector

BRIT has signed MoU with M/s Raghuvansh Agrofarms Ltd and M/s Archon Healthcare Pvt. Ltd, for setting up Radiation Processing plant at Indore and Bavla, Ahmedabad respectively. Two Radiation Processing plants, namely M/s Impartial Agro Tech (P) Ltd., and M/s Gujarat Agro Industries Corporation Ltd. were commissioned at Unnao, Lucknow and



Product loading station



Calibration laboratory for radiation monitors



Inauguration of M/s GAIL, Bavla, Gujarat by Chief Minister, Gujarat



M/s Impartial Agro Tech (P) Ltd., Unnao inaugurated by Secretary, MoFPI

Bavla, Ahmedabad respectively in 2014. With this, the total number of Radiation Processing Plants commissioned in the country under MoU with BRIT has gone up to twelve.

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 Radiopharmaceuticals Production (RPhP) to enhance production frequency, production volumes and regularize the production of new products introduced during previous years. Nearly 2.5-7 lakh patients (estimates calculated on very conservative basis) were benefitted from the radiopharmaceutical products supplied by BRIT.

Approximately, 670Ci of $Na^{131}I$ and over 22000 consignments was processed, formulated and supplied to various nuclear medicine hospitals all over India in the form of solution and capsules. These were used for diagnosis and therapy of thyroid disorders.



Hot cell for ^{131}I-NaI Capsules at RPhP, Vashi

Thyroid cancer treatment with large dose $Na^{131}I$ capsules is in one of the major challenges and towards this, milestone production of 3Ci per batch was achieved with large dose $Na^{131}I$ capsules. Denominations of 25mCi, 50mCi, 100mCi and 125mCi were produced and supplied for the thyroid cancer treatment. The revenue generated from the sale of $Na^{131}I$ based radiopharmaceuticals alone was of the tune of Rs. 10.3 Crores upto 31st December, 2014.

Total number of therapeutic treatments based on supplies was estimated to be 18960 patients. This included the therapeutic doses of $Na^{131}I$ for the treatment of thyroid cancer and hyperthyroidism.

About 2500 consignments containing nearly 22.5Ci 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



Indigenously developed semi-automatic production facility for ^{131}I- mIBG

all over India. Due to high demand from nuclear medicine doctors, the frequency of production and supply of ^{131}I-mIBG (both, diagnostic and therapeutic) used for neuroendocrine cancers and ^{153}Sm-EDTMP Injections used for bone pain palliation was increased. Sale of all other therapeutic radiopharmaceuticals has resulted in the revenue collection of ₹ 35 Lakhs.

Indigenously developed semi-automatic production facility for ^{131}I- mIBG therapeutic doses was updated for safe handling of 131I-mIBG production and supply.

As a part of upgradation facility, Compact NMR for the analysis of synthesized organic ligands and denatured solvents and a separate GMP compliant cold storage facility for in-vivo TCK cold kits at RPhP, BRIT are commissioned in 2014-2015.

During the year 2014-15, more than 73500 cold kits for formulation of ^{99m}Tc radiopharmaceuticals (15 Products; BRIT Code-TCK) were processed, lyophilized and supplied to various nuclear medicine hospitals all over India generating the revenue of ₹ 5.54 Crores.



GMP compliant Cold Room Facility

Nearly 195Ci of ^{99}Mo, in the form of Sodium Molybdate solution for solvent extraction generator and in the form of ^{99}Mo-^{99m}Tc Gel Generator was supplied. Approximately 400Ci of ^{99}Mo (1150 generators) in the form of Sodium Molybdate was processed and supplied as alumina column generator (New product-COLTECH) through which BRIT earned a revenue of ₹ 3.55 Crores.

During the year, COLTECH generator of 1Ci capacity was introduced, this is in addition to earlier 300mCi, 500mCi & 600mCi capacity generators.

More than 2,08,245 in-vivo diagnostic investigations were 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.

To observe safety and increase reliability, the generator production facility and all other production areas in the RPhP and QC laboratories were retrofitted with fire alarm system and smoke detectors.



Fire Alarm System and Smoke Detectors

The Medical Cyclotron Facility (MCF), Parel, supplied about 259 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 375Ci of



Indigenously fabricated module for preparing sterile injection grade ^{18}F-NaF

radioactivity and generating the revenue of ₹ 6.06 Crores during the year 2014-15. Around, 14,444 patients got benefitted with PET investigations in the reported year.

More than 200 patients were treated using ^{177}Lu-labeled DOTA-TATE supplied by BARC. About 129 ^{125}I-brachytherapy seeds were supplied to three oncology centers for treatment of eye cancer and 65 five ^{125}I-brachytherapy seeds (14 MBq) were supplied to Hinduja Hospital, Mumbai for treatment of prostate cancer. Preclinical evaluation of ^{131}I- Rituximab in lymphoma models was completed. RPC Clearance was obtained for collaborative studies with hospitals using ^{131}I- Rituximab. About 3.9 KCi of medical radioisotopes (^{131}I, ^{99}Mo, ^{153}Sm, ^{177}Lu, ^{166}Ho and ^{32}P) were supplied to BRIT for radiopharmaceutical formulations. About 280 freeze-dried HYNIC-TOC kits were supplied to BRIT and various hospitals and nuclear medicine centers in India for the preparation of ^{99m}Tc-HYNIC-TOC, an agent used for the diagnosis of various types of neuroendocrine cancers. Another 3 to 4 batches (110 kits) of HYNIC-TOC kits are scheduled to be prepared till March, 2015. Radioactive concentration of ^{131}I was enhanced to suit the requirement of high dose therapeutic capsule formulations.

Wet chemistry protocol for the preparation of ^{186}Re-HEDP for bone pain palliation and ^{177}Lu-labeled-Rituximab for radio-therapeutic treatment of non-Hodgkin's lymphoma have been optimized. Clinical evaluation of ^{169}Tm-EDTMP, potentially a cost-effective alternative of ^{89}SrCl$_2$ for bone pain palliation was initiated in collaboration with one of our clinical partners. Till date 7 patients have been administered with the formulation prepared using indigenous freeze-dried EDTMP kits.

Methodologies for indigenous synthesis of (HYNIC^0, Tyr3, Thr8) octreotide (HYNIC-TATE) and single vial kit formulation for preparation of ^{99m}Tc-HYNIC-TATE, for somatostatin receptor scintigraphy have been optimized. Preparation of freeze-dried mixed peptide (DOTA-TATE and DOTA-NOC) kits for radiolabelling with ^{68}Ga has been standardized to diagnose a wider range of neuroendocrine cancers.

Radiosynthesis and bio-evaluation of a ^{68}Ga-labeled porphyrin derivative, namely 5, 10, 15, 20-tetra (4-methylpyridyl) porphyrin have been studied for its possible application as a PET radiotracer for tumor imaging.

Radiation technology equipment

Bhabhatron machines

Four units of Cobalt Teletherapy Machines 'Bhabhatron' built indigenously at BARC were commissioned one each at Guwahati, Bathinda, Mungeli and Zambia taking the total number of operating units to 30.

Liquid Target Cavity using Niobium

Liquid Target Cavity for producing 16.5 MeV proton beam for Medical Cyclotron was developed as an alternative to silver target cavity, which needs frequent replacement. It is designed using Niobium with reduced activation cross section and high resistance to corrosion.



Liquid Target Cavity using Niobium

Research Irradiators & Blood Irradiators

Three units each of Gamma Chamber 5000 and Blood Irradiator 2000 were supplied to different universities for various applications in the country earning a revenue of ₹ 2.2 Crores. Decommissioning of GC 900 from University of Kolkata and MS University, Baroda was also undertaken.

Radiography Camera ROLI-2 & 3

Supply of 60 new indigenous radiography camera model ROLI-2 & model ROLI-3, and servicing and inspection of BRIT manufactured as well as imported ROLI cameras were the highlights during the reported year. Apart from the above,

production of 50 nos. each of ROLI-2 and ROLI-3 cameras were also carried out. Total revenue from the sales of radiography cameras and its services amounted to ₹ 3.6 Crores.

Radio Diagnostic & Treatment Services

About 5575 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits to serve about 5, 72,700 in-vitro investigations were supplied to various hospitals, research centres and immunoassay laboratories throughout India by BRIT. The revenue earned by BRIT from the sale of RIA and IRMA kits for the year 2014-15 is about Rs. 1.1 Crores.

RIA products and RIA Laboratory of RPhP, are certified for ISO 9001:2008 and ISO 13485:2008 from United Kingdom Accreditation Services (UKAS).

During the year, The Regional Centre for Radiopharmaceuticals (RCR), Bengaluru supplied 74 Ci of ready-to-use $^{99m}TcO_4^-$ (Pertechnetate) to user hospitals and 900 cold kits were sold through retail outlet for the preparation of ^{99m}Tc-radiopharmaceutical formulation. Door Delivery of Radiopharmaceutical and cold kit was started in the month of July 2014. They collected 258 consignments from BRIT Mumbai and distributed to different hospitals and diagnostic Centres in Bengaluru. Gamma Irradiation of 2277 blood bags was done and 592 consignments were collected from air cargo for the use at the Regional Centre. Radio analytical laboratory analysed 136 samples 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. The revenue earned by RCR, Bengaluru was around ₹ 26 Lakhs.

The Regional Centre for Radiopharmaceuticals, Delhi supplied 32Ci of clinical grade, ready to use ^{99m}Tc-radiopharmaceuticals injections in compliance with GMP & RPC for diagnostic nuclear medicine studies in Delhi & NCR Region. Retail Outlet supply of 2500 TCK cold kits was utilized by nuclear medicine hospitals in Delhi and NCR Delhi along with hospitals at Jaipur, Lucknow etc. More hospitals opted for BRIT's door-to-door delivery services and got benefitted by the customer friendly services of BRIT that reflected in increased demand in BRIT radiopharmaceuticals at Delhi. $Na^{131}I$ solution and capsules from BRIT, Mumbai was delivered to various hospitals in Delhi. RCR, Delhi earned a revenue of ₹ 11.5 lakhs from door-to-door delivery services. A renovated class 10,000 lab is nearly complete and will be used for production of radiopharmaceuticals and labeled compounds.

Technetium-99m is a well-known radioisotope for use in diagnostic nuclear medicine. $^{99}Mo/^{99m}Tc$-TCM-AUTOSOLEX is an automated computer operated closed cyclic module for separation, purification and recovery of ^{99m}Tc, using Methyl Ethyl Ketone (MEK) solvent extraction technique, from low specific activity (n,g)^{99}Mo obtained from BARC research reactor. The module has been indigenously developed and manufactured at Regional Centre, BRIT, Kolkata in collaboration with VECC with extended support and help obtained from BRIT, Mumbai and RMC, Parel, Mumbai. This generator is useful for centralised radiopharmacy at RRMC, VECC, Kolkata and RMC, Parel, and would be extended to other RCR's. About 215 TCK cold kits were sold this year 2014-15.

The TCM-AUTOSOLEX module can provide the most economic ^{99m}Tc-pertechnetate using indigenously produced ^{99}Mo. TCM-AUTOSOLEX Generator gives enhanced radiological and pharmaceutical safety as well as enhanced capacity to handle much larger quantity of



TCM-AUTOSOLEX Chemistry Module



The Electronic Control Unit

Mo-99. A TCM-AUTOSOLEX module has been installed at RRMC, VECC Thakurpukur. First human study at RRMC, VECC, Thakurpukur was carried out in October, 2013. The patients underwent nuclear imaging successfully using various radiopharmaceuticals tagged with Tc-99m extracted by the new TCM-AUTOSOLEX module. Five control units, each with a heater, a conductivity detector and associated cables were fabricated and shipped to BRIT, Mumbai for distribution to BRIT Regional Centres. Another unit was installed at RMC, BARC, Parel, Mumbai for evaluation and use at RMC.



Testing of the gas target chamber at 180°C

For evaluation study of new ^{68}Ge-^{68}Ga generator system and purification of ^{68}Ga elute from SnO_2 column, a new method of purification of the primary eluate of ^{68}Ga from the generator was standardized using a cation exchange resin. In the optimized method of purification the average yield of purified ^{68}Ga was around 80.7 8.5%.

Production of ^{22}Na by proton irradiation of natural neon gas target [^{nat}Ne(p, n)^{22}Na] was undertaken in VECC cyclotron. The radioisotope ^{22}Na finds application in many fields. It is widely used for



Components of the gas target chamber



Gas target chamber fitted with the beam line

calibration of dose calibrators, detectors and other nuclear instruments. It is a convenient source for calibration of PET cameras. ^{22}Na is also used in Positron Annihilation Lifetime Spectroscopy (PALS) to study voids and defects in solids.

The Regional Centre for Radiopharmaceuticals, Dibrugarh located at Assam Medical College & Hospital rendered Radioimmunoassay and Immunoradiometric diagnostic services for the patients of the entire North-Eastern region. The revenue collected from RCR, Kolakata and RCR, Dibrugarh combined is estimated at ₹ 11.85 Lakhs.

Under the IAEA Coordinate Research Project (CRP) on direct production of ^{99m}Tc in cyclotron, separation of technetium radionuclide from the irradiated Mo target by a new method was studied and the suitability of the quality was ascertained as compared to those produced by standard methods.

An automated computer controlled ^{99}Mo/^{99m}Tc generator based on Dowex-HNO$_3$ technique named as TCM-AUTODOWNA has been manufactured and used for evaluation of the system by the collaborative effort of BRIT, Kolkata and VECC. A computer controlled semi-automated ^{99m}Tc-TCM-AUTODOWNA module has been designed, developed and utilized for preparation of pharmaceutical grade ^{99m}Tc by anion exchange (Dowex-1) column and alumina column using nitric acid. It utilizes abundantly available ^{99}Mo produced by (n,g) reaction in BARC reactors. The module has been used for the separation of ^{99m}Tc from (n,g) ^{99}Mo. Separation efficiency was above 80%. The module is also suitable for recovery of 99mTc produced in cyclotron from enriched ^{100}Mo.



Chemical Process Unit Automation Electronics



Electronics Modules Front Panel

The various sub-modules of the ^{99m}Tc-TCM-AUTODOWNA

It provided the most economical ^{99m}Tc-pertechnetate using indigenously produced ^{99}Mo from research reactor. The separation did not incorporate any organic solvent. In case of cyclotron production, the recovery of the enriched target material was simple. Evaporation of nitric acid was performed under vacuum and trapped in NaOH solution.

Labelled Compounds and Diagnostic Kits

During 2014-15, Labelled Compounds Programme of BRIT supplied more than 59500 sources of Tritium Filled Self-luminous sources of various sizes and shapes to defence establishments along with the custom synthesis & supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products. The revenue earned during the year was around ₹ 3 Crores.

Jonaki, Labelled Biomolecules Laboratory at The Regional Centre, Hyderabad continued the production and supply of ^{32}P labelled nucleotides and



View of Renovated Labelled Compounds Laboratory at BRIT, Vashi Complex



TFS sources of various sizes & shapes



HPGe detector



LED Flourimeters

also a few molecular biology kits and enzymes for research in frontier areas of Molecular Biology, Biotechnology and Biomedical and drug discovery research of the country. It also markets ^{35}S labeled amino acids products produced at BRIT, Mumbai facility. Jonaki also supplies ^{99m}Tc-cold kits from BRIT, Mumbai to the nuclear medicine centers of Andhra Pradesh, through its retail outlet. Centralized radio pharmacy laboratory for supply of ^{99m}Tc as sodium pertechnetate was ready and functional. Regular supply will be made based on the requirements. Total revenue earned by The Regional Centre, Hyderabad was ₹ 1.4 Crores during the year 2014-15.

Radio Analysis

Radio Analytical Laboratory carried 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. Water samples were analysed 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 were measured and certified in environmental samples such as coal, fly ash, soil rock phosphate, gypsum etc. Steel samples were tested for the presence of ^{60}Co contamination. Steel survey at factory sites and warehouses was carried out to monitor the surface radiation dose. During 2014-15, RAL carried out more than 5500 tests on export/domestic commodities and 1100 tests on water samples (gross alpha, gross beta, ^{228}Ra & ^{226}Ra). Nearly 5300 water samples received from Punjab state were analysed for the certification of uranium content. Five steel surveys were conducted for certification of surface radiation dose and 40 food samples imported from Japan monitored for the presence of ^{137}Cs & ^{134}Cs were also analysed and certified. As part of the continuous improvement in quality of service offered to customers, the Radio Analytical Laboratory (Vashi) is in the process of obtaining NABL accreditation.

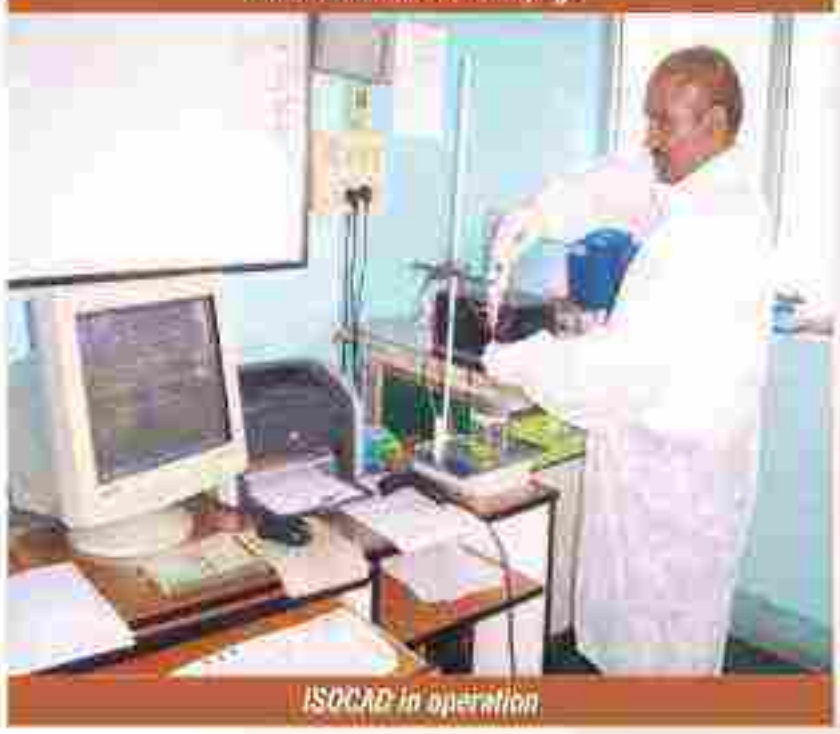
Radio Analytical Laboratory Services at Vashi Complex and RCR, Bengaluru together performed approximately 12,209 analyses of food and water samples for the presence of radioactivity and BRIT earned a revenue of ₹ 3.03 Crores.

Radiation Sterilization Plant for Medical Products (ISOMED)

ISOMED facility engaged in contract gamma radiation processing services for terminal sterilization of the medical products processed



ISOCAD Software main page


ISOCAD in operation

7758 m² of products earning a revenue of ₹ 3.18 Crores. It has acquired the OHSAS 180001: 2007, EMS 14001:2004 and WHO-GMP certifications during 2014. Integrated System of Computer Aided Dosimetry (ISOCAD), a unique bar-coded, GMP compliant software system for the dosimetry measurement was designed and test validated at ISOMED. It is now available as a commercial product from BRIT and being sold to several gamma irradiators operational in the country.

New Projects

DAE Medical Cyclotron Project: Radiopharmaceutical Facility

The civil construction work of the project was near completion. Work on HVAC, electrical work, LCW system etc. were completed. The cyclotron will be moved to medical cyclotron vault soon. It is expected that the installation of the Medical Cyclotron will start by June 2015.

Indigenous HDR Brachytherapy Equipment (IHDR)

Two High Dose Rate (HDR) treatment units of "KARKNIDON" were installed one each at TMH & ACTREC for cold evaluation. Five units have been cold evaluated at Vashi. Actual HDR source wire rope assembly fabricated at RLG with desired accuracy and production process was standardized. Trial runs were taken in treatment units. Data is being generated prior to hot production of ^{192}Ir miniature source for KARKNIDON. Modified SS Applicator & adopter assembly was developed.

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. After the site clearance by AERB, the design documents for the building were submitted to AERB. As per requirements of security and safety authorities, the work of construction of new RCC boundary wall for the complex, new security watch tower was over and installation of new security and surveillance equipment was in progress. The work on civil construction of laboratory building was nearing completion. The work on installation of facilities for waste management, electrical supply, water supply etc. was progressing. During the year, enhanced and revised sanction for the project was received from DAE. With enhanced sanction, a purchase order was released in favor of M/s INVAP, Argentina for design, fabrication, supply, installation and commissioning of facility. Work on design of LEU targets for irradiation in Dhruva was in progress.

Advanced Facilities for Radiopharmaceuticals Production

The project scope comprises of 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 . The present production capacity of radiopharmaceuticals and services from

RPL, Navi Mumbai and Jonaki Hyderabad would also be enhanced under this project. Fire alarm system in all labs/rooms in Radiopharmaceutical Laboratory and Labelled Compounds Laboratory was installed. High end instruments like HPGe detector with lead shielding, dose calibrators, Compact 60 MHz Proton NMR Spectrometer were commissioned and are being regularly used for checking quality compliance of raw materials and products. Effluent Treatment Plant is commissioned. GMP compliant 'Cold room' for storage of TCK cold kits has been commissioned and operational.

Integrated Facility for Radiation Technology (IFRT Control System)

Centralized control and display system was installed for IFRT facility. Redundancy has been provided in terms of PLC & Relay based logic. Radiation interlock has been provided for hot cell door & external transfer drawer opening. Sequential startup and stopping of air exhaust and supply blowers are provided for maintaining negative pressure in the facility. The control system facilitates centralized display and logging of radiation area monitors, fire alarm system and water pool management system and 24x7 surveillance of facility using CCTV monitoring. The project has been completed. A Hot cell has been constructed to handle 300 kCi Co-60 source.



Control Post & Radiation In-cell monitor for Hot cell door interlock

Technology Development for Radiation Technology Equipment

Specifications for I-125 seed manufacturing plant have been finalized. Tender for the civil construction has been raised.

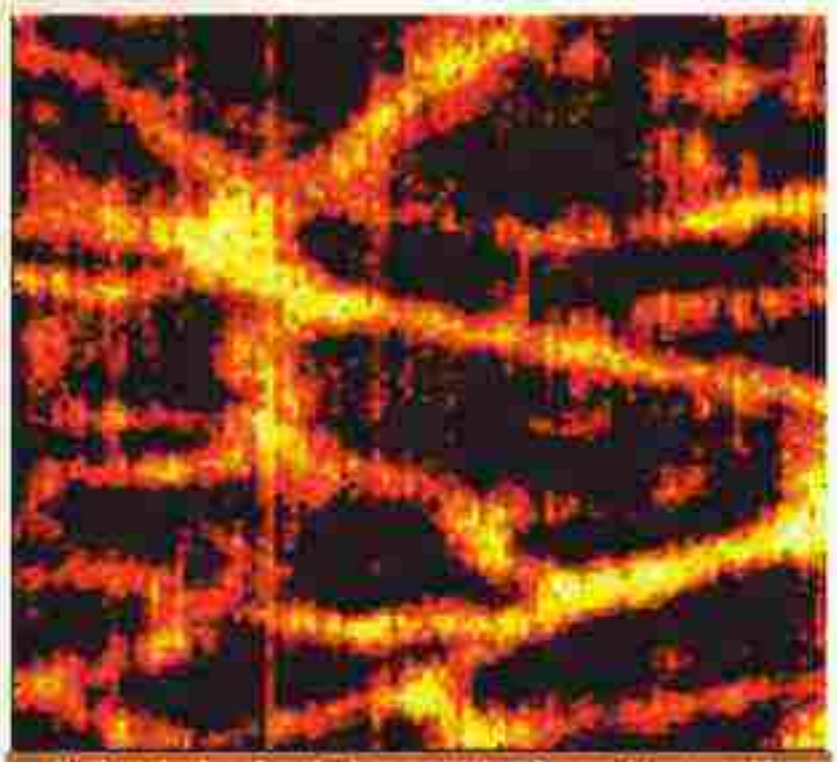
Biomedical Applications

Microvasculature Imaging using optical coherence tomography (OCT)

Three dimensional imaging of vasculature network in human forearm was carried out using swept source OCT system. The differences between the temporal fluctuation in OCT signal from the vascular regions and the surrounding tissue was used to perform 3D vasculature imaging. The



Control Panel for IFRT Facility



Noninvasive imaging of microvasculature image of forearm skin within the depth range of 300μm to 800 μm below the surface. Image size: 2x2 mm.

advantage with the use of OCT is that no exogenous contrast agent is required for imaging the vasculature. A total 600 B-scans were acquired for 100 different lateral location of the sample. At each location 6 B scans were acquired and the average of 5 cross-correlation map of these 6 images is used to obtain the flow contrast.

Polarized Raman spectroscopic studies on ordering of hemoglobin molecules inside red blood cells

The polarized Raman spectroscopy of optically trapped Red Blood Cells (RBC) was carried out to probe the hemoglobin ordering inside RBCs. Measurements were performed by varying the orientation of trapped RBC with respect to the polarization axis of Raman excitation beam. The heme bands in parallel polarized Raman spectra were observed to become maximum when the equatorial plane of RBC was parallel to the excitation beam polarization direction and minimum when the plane was normal to the polarization direction. Further, the magnitude of intensity modulation was found to be different for the bands belonging to different symmetry species. In contrast, no significant orientation dependence was seen in the perpendicularly polarized Raman spectra. To comprehend these results a theoretical modeling based on a hypothetical RBC packed with hemoglobin molecules such that the planes of all of the heme groups are oriented parallel to the RBCs' equatorial plane was developed. The theoretical predictions were found to be in good agreement with the experimental observations. These results suggested that hemoglobin molecules are ordered inside the RBCs with the plane of the heme groups oriented parallel to the equatorial plane of RBC.

Development of integrated micro fluidics tweezers platform for sorting of microscopic objects

An integrated platform for opto-fluidic sorting of microscopic particles has been developed. For this, PDMS based microfluidic chip having three inlet channels and three outlet channels joined by a straight section was fabricated. The sample suspension enters the chip from the central inlet channel and is squeezed by two side streams containing buffer. By controlling the flow-rates of central and side streams by syringe pumps, the width of the sample suspension stream could be adjusted. The chip was integrated with optical tweezers setup and an asymmetric line tweezers was created and positioned in the central stream. With this setup it was demonstrated that the tweezers could deflect high refractive index microscopic particles (polystyrene beads) to one of the side stream while the low refractive index microscopic particles (biological cells) remain in the central stream.

An Optical Coherence Tomography (OCT) probe for in-vivo imaging of oral cavity

A scanning OCT probe for use in in-vivo imaging of oral cavity has been designed and developed. The beam steering and scanning device that has been designed and fabricated is capable of an angular scan range of ± 6 deg. at 14 Hz frequency. The drive and the control circuitry suitable for integration with an OCT system has also been designed and developed. The developed probe is capable of an angular scan range of ± 6 deg. at 14 Hz frequency with a scan linearity of 0.5% or better.



Developed OCT probe

Alternative Applications of Heavy Water

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 such as Acetone-d6, Acetonitrile-d3, Chloroform-d, Dimethyl Sulfoxide-d6 were developed at HWP, Baroda in laboratory scale. Process optimization was also done to minimize the consumption of Heavy Water used for synthesizing these molecules. As a part of MoU signed between HWB & BRIT, BRIT has already started marketing these solvents to various reputed research institutes in the country. The synthesis route for deuterated NMR solvents like Di-chloro-methane-d2 and Benzene-d6 were also developed and process optimization was under progress.

Board has further taken actions to restart supply of Deuterium gas to Indian manufactures and two parties have come forward for manufacture of D2 based gas mixtures which will be used for curing optic fibers, calibration of analytical instruments and other R&D works. The diaphragm compressors available at HWP, Talcher, were used and the same was transported to HWP, Baroda overhauled and commissioned for generating Deuterium gas by electrolyzer. Cylinders filled up to 120 kg/cm^2 were kept ready for dispatch to Indian suppliers.

Realizing the potential requirements of ^{17}O having application in nuclear medicine and bio-chemical research, HWB has successfully accomplished technology development for enrichment of O^{17} at HWP, Tuticorin. The technology development for enrichment of O^{17} reached to an advanced stage of industrial deployment at HWP, Manuguru.

Cancer Diagnostics and Treatment Services

The Tata Memorial Centre (TMC) is a grant-in-aid institution under the administrative control of Dept. of Atomic Energy, Govt. of India. It functions through its three centres, 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. There are eleven Disease Management Groups (DMG) and approximately 200 patient visit each DMG every day for first consultation per follow-up.

During the year, new equipments such as X-Ray Machine C-arm, Portable DR System, Robotic Surgery, Digital Radiofluroscopy, Ultrasound system with Portable Colour Doppler etc. were commissioned. Turnkey work for MRI and Linear Accelerator Telecobalt machine was in progress. Installation of equipments such as Steam Sterilizer, Cryostat Microtome, Water Purification system and Blood Collection Monitor was carried out. Purchase order was released for the procurement of Tissue Homogenizer and Laryngoscope.

Medical Oncology Information System (MOIS) software has been implemented for Breast and GI Disease Management Groups. Introduction of smart card services for all services and all categories of patients has been done. Browser based Software has been implemented for Admission/Discharge/Transfer & Operation Theatre. Refinement has been carried out in Diagnostic Information System & Radiology Information System. Development of PF and Pension software by ECIL was in progress. PC's/Laptop's, printers, scanner, servers, Information kiosks software licenses, etc. were procured. Installation of 12 MBPS and 20 MBPS internet connectivity and routers, IBM 2U rack server, wireless networking (Phase-II), Windows server, Adobe design STD Photoshop, smart card system, Corel draw graphics, bar code readers, various system software licences, printers and IT related equipment was completed. PACS server has been upgraded.

Advanced imaging facility with Super-resolution imaging ready Laser Confocal Microscope, Spinning disk laser confocal microscope and Multi-photon ready high sensitivity spectral Confocal Microscope has been established. Procurement and installation of LC-MS-MS-DLS-Mass Spectrometry facility, In-vivo high resolution optical Animal Imaging System, Automated DNA Sequencer, Transmission Electron Microscope, High end inverted live cell imaging microscope, inverted motorized microscope, high speed refrigerated centrifuge, new refrigerated system for four cold rooms, inverted fluoresce microscope,

Deep freezers -86 C ultralow temperature, Tetrad microscope and hot air oven required for basic cancer research in new areas were completed,.

Cancer Registry at Vishakhapatnam has been established. Health check-up comprising of collection of information on household details and screening of population for Blood pressure, Random Blood Sugar, Oral Screening and Breast & Cervical Screening for the eligible females in the population in and around the nuclear installations of Tarapur, Kaiga, Kota, Kakkrapara, Kalpakkam, Ratnagiri, & Sindhudurg was continued. Fifty two, prevalent cancers were seen in Karwar Health checkup and fourteen prevalent cases & two new cancer cases were diagnosed in Rawatbhata health checkup. Cases confirmatory of cancer diagnosis were referred either to Tata Memorial Hospital or nearest cancer centre.

Global tenders for Heavy Ion Therapy equipment were released and technical bids were opened for National facility for Hadron Beam Therapy. For construction of the Women & Children Cancer Wing and Hadron Beam Therapy Facility, MoU has been entered with M/s. HLL Lifecare as EPC consultant. User mandate and drawings were finalised.

For establishing of cancer hospital in Andhra Pradesh, contract for construction was issued to DCSEM but the same was cancelled as the agency did not commence the work. Retender is being issued for finalising contractor for construction. OPD activities have commenced and approximately, 150 patients have been treated so far. Purchase order raised for procurement of Ultra sound & colour Doppler scanner, Digital Mammography, DR systems stationary, Telecobalt Machine, Tissue processor. Porta Cabins have been installed. Computers are being installed and network is being established. Software in existence in TMC are being replicated for connectivity and data transfer.

For cancer hospital in Chandigarh, procurement of high value equipments such as Telecobalt, Brachytherapy, X-ray C-Arm CT Simulator, Tissue Processor, Iseries Main Server, OT equipment i.e. OT light, Operation table etc for the Satellite Centre in Sangrur was in progress. Work order issued for supply, installation and commissioning of I.T. infrastructure, customisation and implementation of hospital management system application software to ECIL has been released. Cancer registry work was in progress. Work order was released for appointment of EPC consultant for construction of main hospital in Mullanpur.

Supporting research/ clinical trials, promoting the practice of Evidence Based Medicine (EBM) and imparting education to researchers and trial coordinators, is the main aim Clinical Research Secretariat (CRS) and DAE-CTC. The support is in the form of infrastructure, trained manpower, study design, statistical assistance, data management and analyses, data monitoring etc. During the year, 10 clinical trials were funded through DAE-CTC funds. It also supported statistical analysis for 102 studies and translated 49 Informed Consent documents. The 2014 Evidence Based Management meeting focused on Perioperative Care: Improving Outcomes after Surgery & Oncologic Imaging: A Multidisciplinary Perspective and was attended by 376 delegates. Two EBM books covering all cancer sites were published during the conference and are useful ready reference books for clinicians and registrars.

Assistance was provided for the organization of 8 conferences and meetings, and conducted "Research Methodology Course" and two workshops on "Good Clinical Practice" which were attended by 280 participants and 250 participants respectively.

^{60}Co Teletherapy Sources

Ten teletherapy sources with total activity of about 85.5 kCi in the range of 130 and 168 RMM were supplied by BRIT to various cancer hospitals in India. One of the ^{60}Co teletherapy source was exported to the Cancer Disease Hospital, Lusaka, Zambia. Seven 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 was ₹ 5.65 Crores.

Brachytherapy Applications

BRIT supplied 234mCi of Ir-192 and Pt wires as brachytherapy sources to various cancer hospitals.

Cancer Awareness & Prevention

Preventive oncology screening was done for 2160 people which included 1432 females and 728 males. Mobile urban community outreach program was conducted for prevention of cervix, breast & oral cancers. During the year, total 35 organisations /institutions conducted the cancer awareness programmes through which 6700 people were benefitted.

Intervention Arm Survey in Guhagar was continued. Health Awareness programme were carried in 18 villages and total 3200 population covered. 2600 population from 18 villages were screened for oral cancer. 2600 population from 18 villages were screened by Double Contrast Barium Swallow (DCBS) method. Total 85 persons were screened positive for oral cancer. Follow up was conducted for 78 patients. Total 12 cases were referred of Double Contrast Barium Swallow.

Intervention Arm in Rajapur taluka was conducted in June 2014. Total 28 villages with a population of 13500 were covered under health awareness program. Oral screening was done for 3200. Seventy three cases tested positive for the oral cancer.

WATER

Water Purification, Desalination of water & Isotope Hydrology

Under 'National Mission for Clean Ganga', Department is actively participating in water analysis aspects along with other national laboratories as technology provider/ technical adviser as well as participate in awareness program.

Two technologies, solar energy driven portable domestic brackish water RO technology and stand-alone solar PV battery-less UF units for water purification were transferred to private parties for wider deployment in rural and remote areas in a



Hon'ble Prime Minister during his Visit to BARC, Bicycle Mounted Water Purification (RO/UF) Unit



Bicycle mounted RO & UF Units driven by hybrid power system

commercially viable manner. "Bicycle Mounted Water Purification (RO/UF) Unit Driven by Hybrid Power System" technology has been released for technology transfer. It can convert contaminated raw water with salinity up to 1000 mg/lit in to safe & clean drinking water @ 10-20 lit/hr capacity. It is an off-grid, stand-alone unit capable of handling the situation of, 'no power, so no good water', mostly prevalent in remote/ rural areas. It can be adapted as an Ultra-Filtration (UF) unit too. Mobility of the unit enhances its utility.

An additional RO system (15 m^3/hr) was commissioned in the existing Seawater Reverse Osmosis (SWRO) plant of NDDP to cater the needs of boiler feed make up water of Madras Atomic Power Station (MAPS). The plant uses the product water from existing SWRO plant as feed and produces water quality suitable for high end application. The performance of the plant was checked for the feed water from 200-500 ppm Total Dissolved Solids (TDS) and the permeate TDS was found in the range of 3-13 ppm. The plant is in continuous operation and performing well. The major energy consuming equipment of SWRO section is High Pressure Pump (HPP) used for pressurizing sea water to the required pressure as feed to the RO membranes. This was



Second Stage RO Unit at NDDP, Kalpakkam

identified as one potential area of energy saving. A Variable Frequency Drive (VFD) was installed and commissioned to demonstrate the power saving.

For XII plan project on field application of indigenous desalination technologies, meetings were held with the consultant for Design Basis Report of sea water intake and reject disposal system for 5.0 MLD sea water desalination plant at OSOOM, Chatrapur. For 5.0 MLD RO Plant (Vizag) under Phase-II activities, conceptual Design Basis Report (DBR) and pre-project DPR has been prepared and submitted. For water treatment plant at Shiv Ganga (Deoghar), draft MoU to be signed between BARC and Dy. Commissioner (Deoghar) was prepared and duly approved by the competent authority.

Safety Assessment Report for Multi Effect Distillation-Thermal Vapor Compression (MED-TVC) and Low Temperature Evaporation (LTE) desalination plant coupled to AHWR were prepared as per AERB guidelines and submitted. The proposed nuclear desalination plant consists of three units of 800 m^3/d capacity MED-TVC plant using low pressure steam as energy source. A 250 m^3/d LTE desalination plant has also been proposed.

Indigenously developed membrane technology was tested at UCIL, Tumalapalle for treating wash liquor and mother liquor streams. Trial runs were conducted with ceramic coated SS tubular membrane skid for mother liquor and wash liquor streams. SDU thickener overflow and underflow streams were also treated in reject recirculation mode. Fine solids in the feed streams were removed. Based on trial runs, tender specifications for UF capillary membrane system (2 m^3/hr capacity) for treatment of wash liquor streams were prepared and sent to UCIL, Tumalapalle.

NF Membrane treatment for hardness removal from raw water was demonstrated. NF membranes allow low permeation of mono-valent salts such as sodium chloride and high rejection of bivalent salts and hardness causing constituents from feed water. A series of Thin Film Composite (TFC) charged Nanofiltration (NF) membranes



Characterization of NF charged membranes in Test Cell



Characterization of NF charged membranes in 2512 spiral configuration

bearing fixed negative charge (-SO_3^-,H^+) were developed using innovative chemical compositions through in-situ interfacial polymerization technique.

These membranes are prepared by continuous casting machine and subsequently rolled in spiral modules of dimensions 2512 (2.5 inch diameter x 12 inch long) and 4040 (4 inch diameter x 40 inch long). Innovativeness of this technology has been protected by filing the two patents: Charged thin film composite nanofiltration membranes & their use for water purification and effluent management & charged thin film composite nanofiltration membranes derived from disulfonic acid containing aromatic monomers. The know-how of 'Preparation of Thin Film Composite (TFC) Charged NF Membranes for Hardness Removal and Aqueous Effluent Treatment' was released for technology transfer.



Performance Demonstration of NF charged membranes in 4040 spiral configuration in UMP

A three dimensional, 3D CFD model of the spray drying process used for Zero Liquid Discharge desalination has been developed. Model involves tracking of evolution of each droplet inside the spray dryer along with simultaneously updating heating medium properties.



Nanocomposite Ultrafiltration Membrane Device

The technology of nanocomposite candle based domestic water purifier has been transferred to two entrepreneurs. It is a combo domestic water purification device which is made of polysulfone based nanocomposite ultrafiltration membrane in cylindrical configuration. This configuration/ device stand alone can be effective for removal of microbial contaminations, and decontamination of arsenic and iron through chemical addition without the need of any electricity and overhead water tank.

The process is suitable for treatment of ground/surface water in the states like West Bengal, Chhattisgarh, Bihar, Jharkhand etc. where water is severely contaminated with arsenic and iron. It also removes the microbial contamination to the desirable limits at domestic level without the need of electricity and overhead water tank and hence can be used in slums and rural areas of the country.

Electro-De-Ionisation (EDI) unit was operated & purified water was supplied to laboratories for high end applications. Nine compartment pilot scale EDI module was assembled with indigenously fabricated components which produced ultrapure water of resistivity 11-12 mega Ohm.cm water from feed water having conductivity 5-8 micro-S/cm. Membrane Distillation experiments were conducted using hydrophobic PTFE sheet membrane.

Isotope hydro chemical investigation for understanding the hydrology of Pilikula Lake, Mangalore, Karnataka concluded that the Pilikula Lake is receiving large amount of groundwater due to agricultural activities in its catchment which improved the groundwater recharge. Isotope hydrological investigation to assess the groundwater salinity in and around Kelwa and Mahim villages of Palghar

Taluka, Maharashtra concluded that majority of groundwater salinity is due to seawater intrusion; however, at few places salt pans also contribute to increased salinity in groundwater. Isotope technology for evaluating utility of tanks for enhanced groundwater recharge in hard rock zones of Nalgonda district, Telangana revealed rejuvenation of tanks could aid significantly in groundwater recharge.

INDUSTRIAL APPLICATIONS

Electron beam accelerator at Vashi, Navi Mumbai has been upgraded to 5 MeV energy and 15 kW power. Using this machine, it will be possible to irradiate thicker industrial materials to demonstrate and establish applications of radiation technology for wires and cables, food preservation, hygienisation and sterilization of medical products.



Electron beam processing of electrical cables

Results of the various experiments conducted demonstrated that radiation hygienisation of Dry sewage sludge is more practical, scalable, economical and could contribute to "Swacch Bharat Mission". The technology is under consideration by Nagpur Municipal Corporation for 100 tons/day facility.

A radiotracer investigation was carried out at M/s Gujrat Borosil Limited to measure Residence Time Distribution (RTD), Mean Residence Time (MRT) and homogenization time of molten glass in furnace and fore hearth sections of a glass production unit using ^{140}La radiotracer. Results of this study helped the plant engineers to control and optimize the production process and improve the quality of the glass.

A radiotracer investigation was carried out using ^{82}Br confirmed leakage in a high pressure heat-exchanger system consisting of six tube-shell type heat-exchangers connected in series in a hydrocarbon plant at M/s Indian Oil Corporation Limited, Panipat Refinery. Based on the results of the investigations, shutdown of the plants was planned for remedial action. In each investigation the downtime time of the plant was reduced by about 15 days leading to substantial benefits to the refinery.

A Residence Time Distribution (RTD) investigation was carried out in a pilot-scale wetland system using technitium-99m as a radiotracer designed and constructed by Centre for Environmental Science and Engineering of Indian Institute of Technology, Bombay. Based on the study, the performance of the pilot-scale wetland was evaluated and the results could be used for design and operation of a full-scale constructed wetland.

BARC, prepared and sent about 445 nos. of ^{60}Co Polymer film sources of activity 37 kBq to users for their use as Position Identification of Perforation (PIP) sources in offshore procedures of oil-well explorations.

Micro -turning lathe for micro-fluidic stamp fabrication

At RRCAT, a micro-turning lathe has been developed for fabrication of ultra-precision micro-components in non-ferrous metals. The machine is being used to generate flat blanks in aluminium, copper, and PMMA substrates of size up to diameter 50 mm towards fabrication of embossed moulds for micro-fluidic devices. A diffuser nozzle geometry for a micro-pump has been laser micro machined on aluminium flat blanks (fabricated using the micro-lathe) using laser direct writing at 1064 nm which serves as the master. The negative of the master is imprinted on PMMA using hot embossing technique.



The Micro-turning lathe for fabrication (left) Aluminium and OFHC copper flats of ultra-precision micro-components turned using the lathe (right)



Fabrication of T-700 hard surface on 17-4 PH steel sample using laser additive manufacturing



Components of 17-4 PH steel after laser additive manufacturing with T-700 alloy

Development of Cobalt-free hard surfaces for tribological applications

Cobalt based hard surfaces have been used to improve the hardness and wear resistance of some of the nuclear components. But, it is not a preferred choice due to induced radioactivity. The development of cobalt-free hard surfaces using materials, like- Ni-Mo-Cr-Si alloy (T-700 alloy), tungsten carbide in Ni matrices, was undertaken using laser additive manufacturing. The performance of these hard surfaces is comparable with conventional cobalt based hard surfaces.

Laser additive manufacturing of Ti-SS transition joints

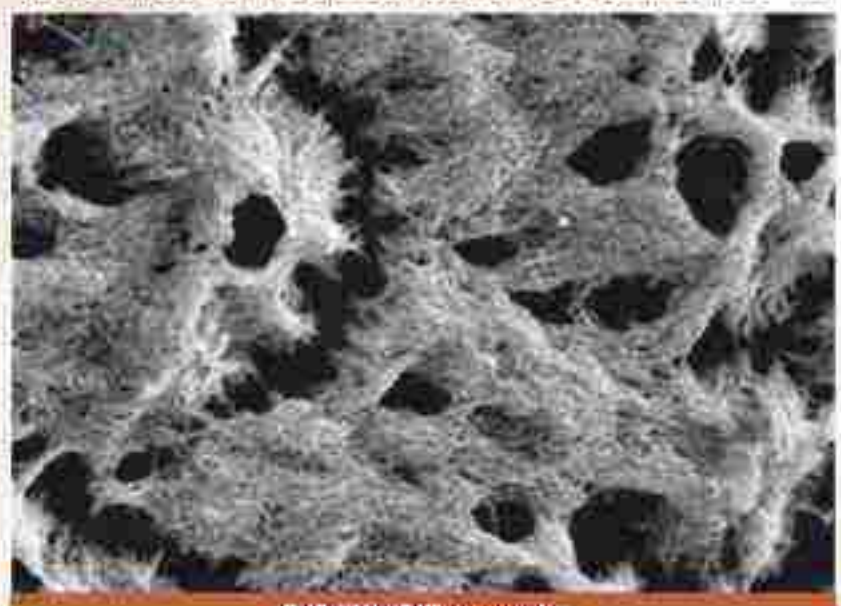
Laser additive manufacturing is an efficient fabrication process for the feature-based designed and manufactured components. A 2 kW fibre laser based additive manufacturing facility at RRCAT has been used to develop tubular transition joints of Ti-SS that has potential applications in the components of nuclear reactors and advanced accelerators.



Ti-SS transition joint fabricated by laser additive manufacturing

Growth of CdS nanowires using template assisted electro-chemical deposition method

Porous Alumina Templates (PAT) were grown by potentiostatic anodization of aluminium foil (purity 99.99%) in 0.23 M oxalic acid solution. Atom Force Microscopy (AFM) measurements confirms the pore formation having the diameter in the range 40-60 nm. Raman spectroscopy measurements performed on prepared samples established the



CdS NWs/PAT composite

formation of CdS. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analysis (EDXA) measurements of above treated sample confirmed the formation of CdS nanowires with diameter in the range 40- 60 nm and length 1-2 μm.

Gamma Scanning Simulator Column (GSSC)

A scale down model of Crude Distillation Units (CDU) as GSSC has been constructed at BRIT for demonstration and training of gamma scanning of CDU to detect anomalies such as flooding, weeping, missing tray, tray misalignment and light foam / heavy foam formation.



Gamma Scanning Simulator Column

Syringe Shield

BRIT is developing a syringe shield to be used as a protective gear in hospitals while administering $^{99m}TcO4^-$ or its products (or any radioactive injectables) to patients.



Syringe Shield

Radioisotope Sources supplied by BRIT

The various engineering products and services offered by BRIT included the supply of more than 2000 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 ₹ 41.26 Crores till December 2014.

Industrial Irradiator Sources

Irradiator sources with total activity of around 1259 kCi were supplied and exported in nine consignments to various processing plants within the country. Approximately 55 kCi and 60 kCi of Co-60 irradiator sources were supplied to IFRB, Bangladesh and Southern Testse Fly Eradication Project (STEP), Ethiopia respectively.



Southern Tsetse Fly Eradication Project (STEP), Ethiopia

Nearly 1000 kCi of Irradiator sources are planned to be supplied to various users by March 2015. Eight absorber rods were unloaded and transferred to RAPPCOF pool for the recovery of Co-60 source for fabrication of sources for irradiators and teletherapy machines. Total revenue earned from Co-60 Irradiator sources during the year was approximately ₹ 9.6 Crores.

Radiography Sources

Nearly 1233 radiography consignments of Ir-192 and Co-60 with total activity of approx. 52.8 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 ₹ 8.44 Crores. Custom Made Sources of Co-60, Cs-137 and Sc-46 were supplied on request for Nucleonic Gauges and other calibration uses. A total of 3.9 Ci of

radioactivity was supplied for reference and custom made sources for revenue of ~ 42.24 Lakhs. Contract with Los Alamos National Laboratory, USA, for identification of source to repatriate US origin sources was completed for the five institutes in India.

Isotope Application Services

Isotope Application Services Group of BRIT offered its valuable services to various industries. BRIT in collaboration with BPCL could troubleshoot Catalyst Cracking Unit (CCU) by combining Gamma Scanning with ^{60}Co and Radiotracer Technique. This service helped Bharat Petroleum Corporation Limited (BPCL) immensely to plan the shutdown and take necessary corrective actions and thereby saving several crores of rupees by minimising the downtime. Radiotracer technique was used for leakage Detection in Heat Exchangers at Bharat Oman Refineries Limited (BORL), wherein, high sulphur content in products was observed and indicated a leak in one or more than one heat exchangers. Leakage detection in Mumbai-Pune Pipeline of Hindustan Petroleum Corporation Limited (HPCL) was undertaken by BRIT. Radiotracer ^{99}Mo was used to successfully locate the leak location. The results helped HPCL to repair the leak and restore the pumping operations on immediate basis.



Radiotracer handling for gamma scanning



Arrangement of detector in collimator

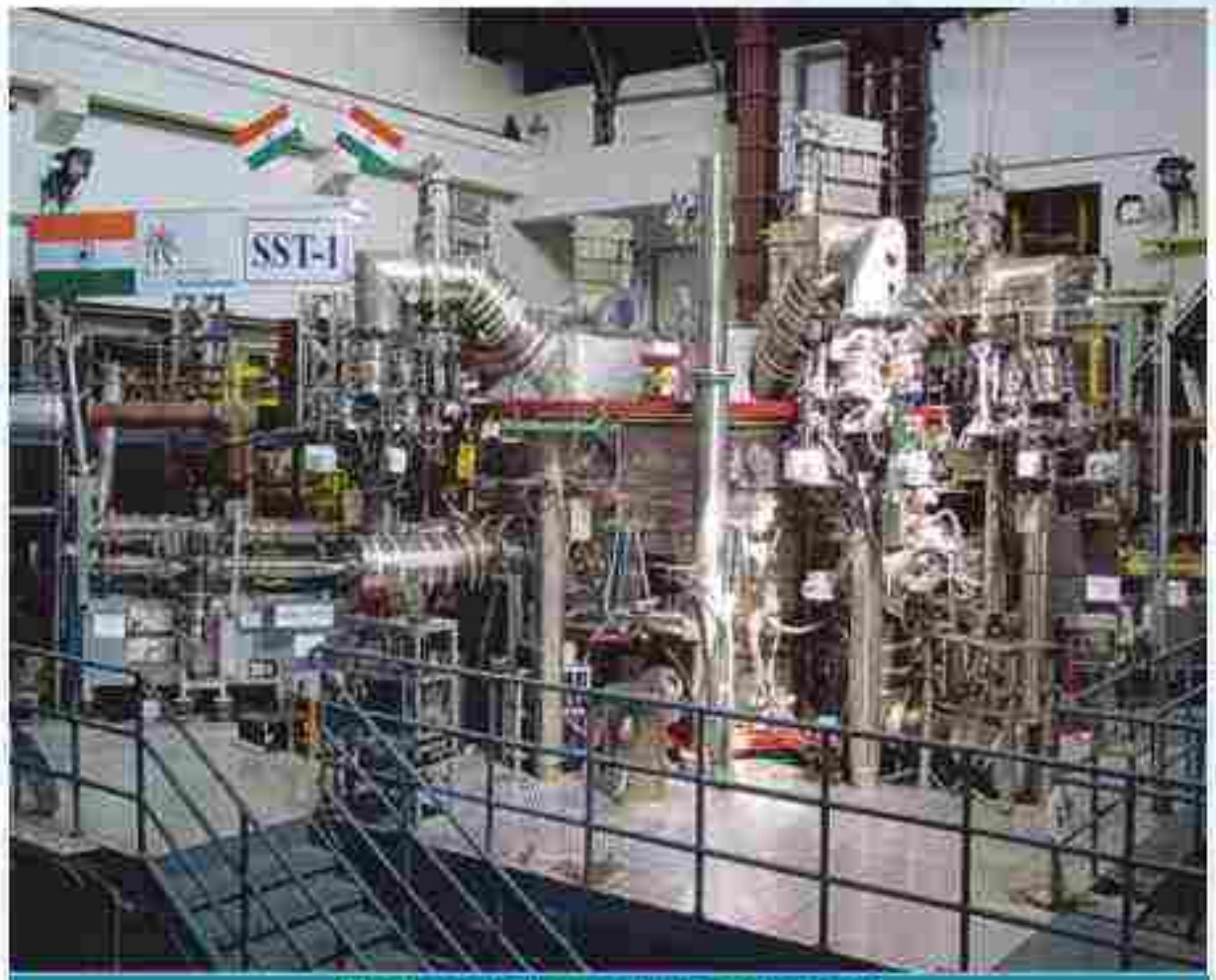
161Ci of ^{60}Co Sources from one gamma chamber were recovered and transferred to detachable Mobile Hot Cell (MHC) storage cask inside the cell in presence of AERB representative to demonstrate MHC operations to recover low activity sources. AERB has granted Type B(U) approval of ISOMED Cask Package and MHC cask was obtained.

Portable Research Irradiator (PRI) was redesigned to enable it to be used as Low Dose Irradiator, facilitating the research work targeted to study the gamma radiation effect at low dose rates. Safety Analysis Report (SAR) for Type B(U) certification prepared and certification obtained. SAR for Type A certification prepared. Type 'A' certification was obtained to house 10Ci of ^{60}Co source in PRI. The unit is ready for loading and operation.

Conceptual design for PANBIT irradiator: Dose Uniformity, Throughput and Shielding calculations of a conceptual Batch Irradiator being designed for 100 kCi of ^{60}Co was completed. ^{60}Co Source loading patterns were designed for nine spice irradiators situated at different locations in India.

CHAPTER-5

BASIC RESEARCH



Steady-state Superconducting Tokamak-1



The experimental setup for the Grazing Incidence XRR and XRF facility at RRCAT

BASIC RESEARCH

The Department of Atomic Energy has contributed significantly towards strengthening basic research in India. The Department pursues basic research in its R&D centres that ranges from mathematics to computers, physics to astronomy, chemistry to material science and biology to cancers. It also provides grants-in-aid to eight 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 BARC, a nodal domain theorem for non-separable quantum systems in two dimensions was proved. This presents novel connections between the theory of differential equations, partial differential equations and quantum ergodicity, a property of the quantization of classical mechanical systems that are chaotic. Non-equilibrium statistical mechanics has been extended to explain dynamic systems, viz. to study the motion of particles of a gas colliding with randomly placed polygonal scatters in a plane very much similar to Brownian motion or when systems approach equilibrium.

The School of Mathematics of TIFR made substantial progress in the context of GL(3) and GL(2)×GL(2) sub-convexity. In particular, sub-convexity was established in the twist aspect for generic GL(3) automorphic L-functions. This result is regarded as a major achievement in the subject after several decades. Studies on semilinear elliptic equations in the hyperbolic space were continued and new results on sign changing solutions were obtained. Existence of a maximizing function for a singular Moser-Trudinger inequality was established. Novel entropy conservative and kinetic energy consistent schemes for compressible Euler equations were constructed and their efficiency was established. Stability estimates on Levy driven stochastic conservation laws have been derived. Statistical properties of quantum random graphs at criticality were studied. Stability estimates for inverse boundary value problems, microlocal analysis in tomography and inversion of Radon transform were studied systematically. Phase plane analysis for a singular autonomous differential equation arising in number theory has been analyzed. Significant controllability results for fluid-solid coupling were obtained. Null controllability and stabilization results have been obtained for compressible Navier-Stokes system. A mathematical model for the epidemiology of tuberculosis in India has been proposed so as to study the differences in private and public sector treatments. At The School of Technology and Computer Science, work progressed in the area of hardness of approximation and improved construction of probabilistically checkable proofs. Using recent developments in coding theory, in particular the discovery of the short code, improved hardness of approximate colouring hyper-graphs and other related covering problems was shown. In the context of Probabilistically Checkable Proofs (PCPs), a new notion of soundness was introduced which led to new modular composition procedure leading to improved PCP constructions towards resolving the long-standing "Sliding Scale Conjecture".

At SINP, the spectrum of the SU(m) spin Sutherland model associated with the BN root system was computed including the exact degeneracy of all energy levels at SINP. Different realizations for the momentum sector of kappa-Poincare Hopf algebra which is associated with a curved momentumspace has been considered. The combined effect of a conical topological defect and a Coulomb charge impurity on the dynamics of Dirac fermions in gapped graphene has been studied.

In Quantum Fields on Lattice, the context of additive mass renormalization and chiral anomaly in Wilson lattice QCD it was shown that by appropriately averaging over suitably chosen branches one can reduce cut-off artifacts. Comparing the central branch with all other branches it was found that the central branch among all the avatars of the Wilson fermion is the most suitable candidate for exploring near conformal lattice field theories.

In Quantum Fields on Light-Front, in the area of polarized deep inelastic scattering, it was pointed out that the identifications of transverse boost and rotation operators in light-front theory are incorrect and the simple parton interpretation claimed was in fact for the transverse boost operator.

CHAPTER-5

The Harish-Chandra Research Institute (HRI) made significant achievements during the year. In the area of harmonic analysis, research was mainly concerned with 'Hardy-Sobolev' inequality for the twisted Laplacian. These results naturally extend the usual Laplacian results. Spectral theory of the twisted Laplacian was used for the purpose. In differential geometry, the main focus was on 'Constant Mean Curvature (CMC) surfaces'. Work on interpolation of two real analytic curves by piecewise minimal surfaces was completed. Work on questions like 'when CMC surfaces are algebraic curves?' is in progress. Work is in progress on vector bundles over real algebraic varieties and generalizations of 'Atiyah-Weil' criterion for the existence of holomorphic or algebraic connections in vector bundles.

In Algebra, a conjecture relating finite commutative semigroups was formulated. This generalizes the standard finite abelian groups. The conjecture has also been verified for some interesting classes of finite abelian semigroups. Work proceeded in finding some particular type of modules for Lie torus with finite dimensional weight spaces w.r.t its Cartan sub algebra.

In Number Theory, the number of representations of a positive integer by certain quadratic forms uses convolution sums of the famous divisor function. This sum was evaluated. A question of S. Bocherer concerning differential operators on Jacobi forms was answered positively. Based on classical work, a coherent picture of all tame extensions of a local field was obtained along with its various compatibilities. Schanuel's conjecture has shown to be true for an uncountable set of 'Liouville numbers'. Special functions like Hurwitz-Lerch zeta-functions, gamma and related functions, Epstein zeta-functions, Bessel functions etc. play important roles in many branches of science. An intermediate modular relation between various zeta-functions has been proven which gives rise to many arithmetical Fourier series as a consequence of its functional equation. Work was in progress in studying these functions in greater depth. Work was also carried out on multiple zeta functions.

The Institute of Mathematical Sciences (IMSc) remained involved in the various projects with



Indo-UK workshop on Computational Complexity Theory

national and international institutes on Mathematical Sciences without Walls; Developing tools for dynamical modelling of C elegans neuronal network activity; INO Project; Algebraic Problems; Provably Efficient Re-processing Algorithms; Potential Theory on Infinite Networks and Trees; DST-IMPECS Project on "Exact Geometric Computation for Non-Linear Problems"; DST-SERB Project on "National Network for Mathematical and Computational Biology"; Mechanisms of active intra-cellular transport: connecting theory and experiment and Non-Commutative geometry of quantum homogeneous spaces, the local index formula & associated invariants. The Institute conducted various Conferences and workshops which included topics such as Winter school on modular functions in one and several variables; Lecture Series on (easy) Quantum Groups by Moritz Weber at IMSc; Master-Class in Modular Theory of von Neumann algebras; Research in Science 2014; CMSC 2014 Creative Mathematical Sciences Communication at IMSc; Fracture: From Micro-Scale Processes to Macro-Scale Response, IMSc; Indian Strings Meeting 2014-15; Indo-UK workshop on Computational Complexity Theory and International Workshop on Mock-modular Forms and Physics.

The School of Mathematical Sciences, NISER strives to become a citadel for mathematics and allied subjects in terms of teaching and research. During the year, NISER continued its teaching and research activities. The courses for the second and third year have been designed to provide an understanding of foundational level mathematics in the areas of logic, number theory, algebra, analysis, geometry, discrete mathematics and informatics. Provision has also been made for pursuing studies in

special areas and writing an innovative project leading to a dissertation. Research students were encouraged to talk in the research seminars in the school and to attend national/international conferences as well as regional meetings which were supported by NISER. In addition to formal courses and research, seminars were conducted regularly. In the seminars, outstanding mathematicians from throughout the world presented their latest research findings in various fields of mathematics. State-of-the-art computing facility and a high performance computing cluster for theoretical calculation were provided as part of facilities for research and teaching.

PHYSICS

The national facility for neutron beam research was utilised very effectively by Scientists from BARC, other DAE units, universities and national laboratories through collaborative research projects. Number of instruments were upgraded by installing focussing devices, velocity selector, in-situ low and high temperature sample environment facility etc.

A study of the nucleus ^{186}Pt using the Indian National Gamma Array (INGA) spectrometer at the BARC-TIFR Pelletron Linac Facility has revealed the unusual coexistence of both shape and high-K isomeric states. The shape evolution with spin in this nucleus has been inferred from both data and theoretical calculations. The lowest positive parity band appears to evolve from a near-prolate deformed shape through triaxial at intermediate excitation and eventually to oblate at the highest spins. This interesting discovery has opened up an excellent opportunity to further study the interplay between axially symmetric and triaxial shapes.



Indian National Gamma Array (INGA) facility at Pelletron-LINAC laboratory, TIFR

Investigations on the structural stability of a Transparent Conducting Oxides (TCO) viz. CuLaO$_2$ at high pressures using in-situ Raman spectroscopy, electrical resistance and x-ray diffraction techniques showed an irreversible phase transition accompanied by a change in band gap at moderate pressures which will be useful to applications like touch panel and sensors.

High pressure FTIR, Raman and quasi four probe resistivity experiments carried out on (p-chloroanilinium), $CuCl_2$ ($C_6H_7Cl_2CuN_2$) in the family of organic-inorganic layered hybrid compounds indicate weakening of Jahn Teller distortion and consequent removal of puckering of $CuCl_4^{2-}$ octahedral within the layer. These effects trigger insulator to semiconductor phase transition along with change in the sample color from yellow to dark red.

High-pressure Raman spectroscopic investigations on Imidazole ($C_3H_4N_2$) combined with ab initio calculations on crystalline Imidazole suggest that C–H---X (X = N,) and the strong N–H---N intermolecular hydrogen bonding interactions inhibit polymeric transformations at high pressures.

The Yb fibre based laser heating facility was employed to synthesize GaN at high pressure and high temperature of 9 GPa and 1925 K respectively by direct reaction of gallium metal with N_2 in a Diamond Anvil Cell (DAC). The synthesis was confirmed by carrying out Raman and Angle Dispersive X-ray Diffraction (ADXRD) measurements of the retrieved sample.

Low temperature high pressure transport measurements carried out on superconducting pyrochlore $Cd_2Re_2O_7$ showed pressure-induced enhancement of superconducting transition temperature up to 10 GPa. At higher pressures (>15 GPa), a Mott type metal-insulator transition was observed associated with a structural modification. Pressure induced Electronic Topological Transition (ETT) was observed by application of moderate

amount of pressure (1.5-2 GPa) on a highly insulating Sb_2S_3 compound.

On the theoretical front, electronic, structural, vibrational and elastic properties of PaN were studied at ambient and high pressures using first principles methods. Generalized Gradient Approximation (GGA) reproduced the ground state properties satisfactorily.

The surrogate reaction method has been used to determine neutron-induced fission cross sections of the short-lived minor actinides ^{237m}Np and ^{240m}Np. The (n, f) cross-section for ^{231}Pa was measured using the hybrid surrogate ratio method. The average neutron multiplicity from a spontaneous fission of a super-heavy composite system has been extracted.

The fusion cross-sections of ^{7}Li and ^{12}C with ^{198}Pt at extreme sub-barrier energies were measured to unravel the role of entrance channel in the occurrence of fusion hindrance for very asymmetric systems. Onset of fusion hindrance was clearly observed in ^{12}C+^{198}Pt system but not in ^{7}Li+^{198}Pt system. The results were interpreted employing a recent model that considers a gradual transition from a sudden to adiabatic regime at low energies. A consistent description for all the excitation functions was achieved using a fission barrier of 21.8 MeV. However, the measured average numbers of neutrons emitted before fission in heavy-ion fusion-fission even at low excitation energies (50 MeV) was substantially under predict. This implied that a large fraction of measured neutrons are not emitted statistically in competition with the fission before reaching the saddle point. The observation will have implication on the study of fission time scale/ nuclear viscosity using neutron emission as a probe.

The Pelletron-Linac facility had an uptime of 83 % up to July, 2014. Comprehensive conditioning of the accelerating tube & column structure was carried out. Varieties of beams were delivered through Pelletron and superoonducting linac booster for users, including those for the INGA campaign. The SF_n (n=1-6) negative ions were unambiguously identified using Accelerator Mass Spectrometry technique at the Pelletron-Linac facility. An improved version of the prototype room temperature heavy ion Radio Frequency Quadrupole (RFQ) operating at 75 MHz was designed and fabricated.

Design of 50 kiloton Iron Calorimeter electromagnet and 1/8 scaled engineering prototype module of 2.2 kton for India based Neutrino Observatory has been completed. Physics studies of the sensitivity of ICAL together with additional plastic detectors on the walls of the underground cavern for the decay of weakly interacting dark matter have been made.

For MACE telescope, various sub-assemblies including Compound Parabolic Concentrator (CPC) Housing Sub-assembly, Main Frame Sub-assembly, PMT Housing sub-assembly and Drawer cage Sub-assembly were designed and manufactured.



MACE Camera



Camera Integrated

The trial assembly of the 21m diameter MACE gamma-ray telescope was completed at Hyderabad. After the detailed testing, the installation work at Hanle was started and it is expected to be completed by November 2015. The prototyping of the high-speed signal processing modules required for the telescope was completed and work on the bulk



The installation of the 27m diameter track and the first layer of the alidade structure along with 6 wheel bases at Hanle



Trial assembly of the HAGE telescope at ECIL, Hyderabad.

production of the modules was started. A Bonner Sphere based cosmic-ray neutron monitoring system was set up at HARL, Gulmarg. With this system the neutron energy spectrum up to 1GeV energy can be determined. The TACTIC telescope at Mt. Abu was deployed for TeV (10^{12} eV) gamma-ray observations of extragalactic objects. About 400 h of observation data was collected from Mrk421, Mrk501, 1ES1218+304, IC310, 3C279 and the Crab Nebula. No measurable gamma-ray flux was detected from the extragalactic objects.

Theoretical studies carried out in TIFR included the studies of the columnar order and Ashkin-Teller criticality in mixtures of hard-squares and dimers, large N Chern-Simons theory and strongly coupled anisotropic fluid, ADS(3)/CFT(2), Bianchi attractor in supergravity, heavy hadrons and glueballs, quarkonia and quark number susceptibility at finite temperature and neutrino parameters at INO.

In Astronomy and Astrophysics, a regular stratospheric balloon manufactured and flown with 7 kg payload from TIFR Balloon Facility, Hyderabad reached a record altitude of 51.83 km and penetrated through Mesosphere for the first time. World record manned balloon flight was made using balloons fabricated at TIFR Balloon Facility. Of the three instruments (LAXPC, SXT and CZTI), being fabricated for ASTROSAT satellite, SXT and LAXPC were handed over for integration tests. TIFR Near Infrared (1-2.5 microns) Imager and Spectrometer (TIRSPEC) for 2-meter HCT at Hanle (Ladakh) was upgraded with larger short slits and modifications made to make observations more efficient. TIRSPEC has been thrown open to general astronomical community from May 2014. Laboratory model of Infrared Spectroscopic Imaging Survey (IRSIS) payload for an Indian Satellite was fabricated and being assembled. A wide variety of problems related to solar physics, seismology, high energy astrophysics, black holes and other compact objects such as neutron star, 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 studied.

Discovery of a few new and interesting pulsars from follow up observations of the Fermi-LAT sources was made. Detection of synchronous switching of radio and x-ray emission in the pulsar PSR B0943+10, indicating rapid, global changes to the conditions in the magnetosphere was done. One of the youngest known supernova remnants in our Galaxy was discovered. Deep observations of neutral hydrogen (H I; at 21 cm) have established that a good fraction of atomic gas in our Galaxy is at temperatures forbidden by "Classical two-phase model". For the Ooty Radio Telescope, FPGA based custom acquisition control & module control systems were developed and computation facility was enhanced by procurement and operationalization of a 32 node (10 Tera Flop) IBM cluster which enabled

faster searches for pulsars from GMRT data & other studies. With the aim of providing seamless frequency coverage of the GMRT, new wide-band radio frequency feeds and receiver systems were developed. The design and fabrication of new 130-260 MHz & 250-500 MHz receivers were completed. About 10 antennas of GMRT were upgraded with broadband fiber optic link. A prototype of GPU based hybrid back-end system was developed.

In Condensed Matter Physics, single crystals of strongly correlated electrons systems have been grown by employing various crystal growth techniques. A new optical floating zone furnace to be used to grow oxide single crystals and other intermetallic compounds is expected to be installed in February 2015. Superconducting quantum bits and parametric amplifiers were successfully fabricated in the TIFR cleanroom and measured in the new Quantum Measurement and Control Laboratory at a temperature of 10 mK. A method to determine the change in chemical composition using intensity variation of a HAADF-STEM image at any point within a wedge shape sample of multilayer thin films containing two elements intermixed within the layers was developed. Electro-hydrodynamically driven turbulent flows at low Reynolds numbers in a two-fluid emulsion consisting of micron-scale droplets were studied.

In High Energy Physics, the CMS-T2 grid computing centre at TIFR consistently contributed to the computing efforts of the international collaboration as well as the Indian participants. Observations of pulsars, supernova remnants, binary sources and Blazars were continued with HAGAR. Work on characterisation of G-APD progressed. The principle of relativity, Newton's law of motion (relativistic form) and the equivalence principle were derived from cosmic gravity with implications for experiments with cold-atom clocks and interferometers.

The Nuclear and Atomic Physics studies observed the coexistence of magnetic and anti-magnetic rotation in ^{107}Cd and ^{111}In through lifetime measurement. Studies of high spin states in nuclei near closed shell to test the shell model prediction were carried. First microscopic demonstration of size induced 4f localization in CePd, was carried out. The effect of methyl group on negative ion resonance state in carbonyl group was studied by observing the dynamics of dissociative electron attachment to acetone and acetaldehyde. TIFR developed and utilized intense 5 fs-long optical pulses, whose carrier envelope phase could be precisely controlled, to experimentally probe how control can be exercised on electron wave packets in atoms and molecules on attosecond timescales. Ultrafast laser pulses were used to write optical devices like splitters and waveguides inside glass. External tuning of random lasers has been experimentally achieved. Absolute double differential e-emission distribution for coronene molecules by fast (few MeV/u) bare oxygen ions with PAH molecules, aimed to explore the collective excitation were measured.

At SINP, in Condensed Matter Physics including Surface Physics and NanoScience major capital equipments like cryogen free room temperature bore 9T for grain oriented, magnetocaloric effect studies, custom built UHV versatile thin film deposition set-up to fabricate high performance magnetic/nonmagnetic hybrid nano-structure, SQUID VSM for magnetic properties, thermal expansion, thermal transport experimental systems were installed. The possible Spin Glass like transition for the AFM nano particles in the limit of spin correlation length have been studied. New intermettalic full Heusler alloys with valence electron count 24 was synthesized to study the occurrence of possible large ZT. Large volume collapse has been observed in polymorphic antiperovskite compounds under annealing. Soft magnetic materials with high Curie temperature (400K) were synthesized and investigated. New compounds of 2-1-3 type of intermetallic were also synthesized for studying possible geometrically frustrated magnetism. Thermoelectric effects in strongly correlated systems and effect of strong correlations in band insulators are being studied. Research activities in Surface Physics encompass the physical and chemical methods of growing low-dimensional structures with tunable morphology and mechanical / electrical / magnetic / optical properties, epitaxial growth of semiconductor quantum structures and their applications in micro-nano technology. Scientists have been involved in the growth of magnetic and photonic structures through nano-manipulation and

self-assembly, development of polymer-based photovoltaics and other molecular electronic systems and study of their morphology-transport correlations. Light emission and ultraviolet photoconductivity characteristics of ZnO nanorods (NRs) fabricated using a facile, cost-effective, and catalyst-free thermal decomposition route under varying reaction temperatures have been studied. The accuracy of the photo-acoustic (PA) technique to assess blood oxygen saturation (SO2) using two laser beams was examined theoretically.

Research activities at SINP included experimental study of nuclear structures and nuclear reaction mechanisms using different accelerator centres in India and abroad. The High Energy Nuclear and Particle Physics division was involved in two major experiments at the Large Hadron Collider (LHC), CERN. The two experiments, ALICE and CMS collected data with a very high efficiency and members of SINP took active part 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.

The area of research in Theoretical and Astrophysical physics included topics such as Particle Physics Phenomenology, Gravity, Cosmology, Strings, Nuclear Theory and QCD at Finite Temperature and Density. In Plasma Physics, theoretical studies of electromagnetic wave propagation in magnetized plasma have been done. An exact non-stationary solution in parametric form of a fully nonlinear time dependent problem by using Lagrangian co-ordinates were presented. In the experimental front, in the existing device MaPLE (Magnetized Plasma Linear Experimental) study of the selective excitation of low frequency drift mode was done in detail.

VECC has proposed a new phenomenological model called the Critical Temperature included Fluctuation Model (CTFM). In order to probe the critical behaviour of Giant Dipole Resonance (GDR) in A 100 mass region, an extensive experiment was performed by bombarding ^{93}Nb target using ^{4}He beams at 28, 35, 42, 50 MeV from the K-130 Cyclotron and Large Modular BaF_2 detector array (LAMBDA), developed in-house. The group has taken up a program to study the neutron-rich nuclei around ^{132}Sn from fission fragment decay spectroscopy. The neutron-rich Iodine and Tellurium isotopes were produced by alpha-induced fission of ^{238}U. Alpha beam of 40 MeV was obtained from K-130 cyclotron and incident on a stack of ^{238}U electro-deposited targets separated by Aluminium catcher foils, in which fission products were collected. Radiochemical separation was carried out to separate Iodine. The radioactive solutions of fission products before and after the radiochemical separation were counted with High Purity Germanium (HPGe) detector to ensure the clean separation of respective isotopes. A γ-γ coincidence measurement was carried out using a setup consisting of four Clover HPGe detectors and two segmented planer Ge Low Energy Photon Spectrometer (LEPS)



Coincidence setup of four Clover HPGe and two LEPS of segmented Planer HPGe detectors.

detectors. For the coincidence measurement, 16 channel amplifiers and other standard NIM electronics were used to collect data in LIST mode with a VME based data acquisition system. Theoretical studies on nuclear astrophysics, fission dynamics, transport model calculations on cluster distributions in intermediate energy nuclear reactions, evaluations of transport coefficients of hot hadrons and calculations of triangular flow of thermal photons from quark gluon plasma were performed.

Institute of Physics (IoP), Bhubaneswar is engaged in research in the frontier areas of physics. During the year 2014-2015, Institute undertook research in various areas of theoretical and experimental physics. The major research activities included studies in experimental and theoretical aspects of condensed matter, high energy, nuclear and accelerator based physics. During the period, the Institute achieved many milestones in the research in accelerator based sciences, surface science, nano materials and low-dimensional systems. The 3 MV Pelletron Accelerator at the Institute was used for a variety of experimental research programmes involving ion-beam analysis and modification of materials. A number of external users from universities and other research institutions utilized beam times from this accelerator.

The high energy physics group of IoP remained actively 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, cross section processes of one loop, which are important for analysis of LHC data were studied.

In Condensed Matter Physics theory the research areas 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.

Research in Nuclear Physics remained focused on nuclear structure and nuclear reaction. Study of the mechanism for the formation of superheavy elements in astrophysical objects, nucleus-nucleus reaction and study of cluster decay properties were pursued. Newly discovered superheavy nuclei and a new mode of fission decay for neutron-rich heavy nuclei was also 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 were reported. Studies on quantum information were also continued.

In experimental physics, the major activities 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. Topics of current interest were ion beam-induced surface nanostructuring, pattern formation, epitaxial crystallization, and electronic structure



Dr. R.K. Sinha, Chairman, AEC & Secretary, DAE inaugurating the newly established Advanced Materials Processing Laboratory in IoP, Bhubaneswar

studies of multiferroics, manganites etc.

Newly established Advanced Materials Processing Laboratory in the Institute Campus was inaugurated by Dr. R.K. Sinha, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy on 27th June, 2014.

The research activities at HRI were carried out in five major areas of Physics and they were Astrophysics, High Energy Physics, String Theory, Condensed Matter Physics and Quantum Information. The astrophysics group has been

working on general relativity, high energy astrophysics (with specific emphasis on black hole astrophysics), astrophysics of galactic center, analogue gravity phenomena, dark matter problems and 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 from various colleges and universities were trained in basic astrophysics through short-term project works under the supervision of the members of the group.

In Condensed Matter Physics, the main focus areas were spin transport in nanoscale systems, strongly correlated fermionic or bosonic systems, electronic structure and morphology of nano systems, and topological quantum matter. HRI scientists working in the field of condensed matter made significant advances in the area of correlated quantum systems. Competition between antiferromagnetic insulating phases and charge density waves in the Holstein-Hubbard model and the issue of supersolidity of bosonic atoms in a mixture of heavy bosons and light fermions have been studied. Density matrix scattering theory for a two-component quantum liquid in a spin dependent quantum potential has been set up. Real space approach to correlated quantum systems has yielded tangible new results. Properties of silicene, which is graphene like but with a buckled sub-lattice structure were studied.

The High Energy Physics group at HRI mainly worked in two fields: neutrino and collider physics. Members of the neutrino physics group worked on models to explain some of the properties of neutrinos and studied their signals at various experiments. In particular, they were 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. Other important results include work on the fluxes of ultra-high energy neutrinos in the presence of physics beyond the Standard Model. 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 was centered on the experiments at the LHC in CERN, the biggest ever international experiment in the history of fundamental science. LHC data on Higgs boson can in principle accommodate another neutral scalar with mass in the vicinity of the Higgs mass. One possibility is a radion on whose mass and mixing with Higgs rigorous bounds have been set. Constraints have also been put from the available LHC data on the coupling of Higgs boson- gauge boson pairs. Non-minimal universal extra dimension framework has been used to study mixing of Kaluza-Klein top quark excited states. New production modes and decay channels for the KK top quark have been predicted and relevance for LHC explored. A new extension of the SU(2)L gauge symmetry in the standard model by a SU(2)R gauge symmetry has been proposed. This new mirror symmetry leads to the prediction of a new set of fermions whose existence can be tested in the LHC.

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. These correlations need to be carefully studied and quantified for an efficient transmission of classical information from one sender to several receivers individually. HRI scientists have managed to put upper bounds on the efficiency of such processes in a variety of situations. A new protocol for the weak measurement of any observable with pre and post selection was established. A relation between time energy uncertainty relation and multiparticle entanglement was found. It has been shown that the classical capacity of a quantum state follows an exclusion principle: If A has a quantum advantage in transferring classical information to B, then the former has no quantum advantage in transferring it to C.

Fundamental contributions were made by HRI physicists to string theory and quantum field theory in the past year. The string theory group explored various aspects of black hole physics, higher spin theories, string amplitudes, AdS/CFT, flux compactifications and cosmology. Duality

between higher spin theories in anti-de Sitter space in three dimensions and conformal field theory in two dimensions was studied with a view to embedding these dualities into string theory. A general strategy for calculating physical quantities in string theory and quantum field theories at intermediate values of the coupling constant was devised. Higher derivative corrections in string theories were extensively studied and efforts were made to connect string theories to particle physics and cosmology. In the process, a bound on the magnitude of the flux super potential was obtained.

The School of Physical Science, NISER continued to offer the five year integrated Master of Science (M.Sc.) programme in Physics which included courses 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. For carrying out research work leading to degree of Ph.D., the school offered programmes on High-energy physics (Theoretical)- String theory, Lattice Quantum Chromodynamics; High-energy physics (Experimental) - Experiments at Large Hadron Collider (LHC), Switzerland; Condensed-matter physics (Theoretical)- Electronic structure of matter, Colloids, Soft-condensed matter and statistical mechanics, density functional theory etc.; Condensed-matter physics (Experimental) – Magnetism, superconductivity, low-temperature physics, semi-conductors and nano-fabrication, spectroscopy; Ultra-cold atoms and Bose-Einstein condensation (Experimental) and Photonics – Nonlinear optics, Laser Physics, Nano-photonics. The various research & teaching facility provided included the 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 and facility of Magnetic nanostructures and multilayers.

CHEMISTRY

Low cost wound care product based on controlled release of nitric oxide was developed and transferred to M/s Cologen Healthcare Pvt Ltd, Salem, Tamilnadu. The dressing is very effective against a broad spectrum of infection-causing microbes including gram positive and gram negative bacteria and fungi and in chronic and non-healing wounds. The dressing eliminates wound biofilm due to antibacterial, antifungal and antipertozopan effect of nitric oxide. The active ingredient is a lipohilic gas which can effectively penetrate wound biofilm and kill bacerial cells. Since it is non-antibiotic based, there is less possibility of resistance development by the bacteria. Nitric oxide has powerful wound-healing properties and promotes angiogenesis and matrix deposition for quicker healing. Collagen present in the dressing also promotes wound healing. As the dressing is hydrogel based, it provides soothing comfort to wound bed. The dressing has long shelf-life and can be stored at ambient temperature and humidity for upto two years. The wound dressing will be marketed under the name 'BaNOCol' (Ba=BARC,



Hydrogel based non-antibiotic, low cost wound care product developed by BARC

NO=Nitric Oxide, Col=Cologen).

A technology for a point-of-use drinking water disinfection system is developed based on in-situ production of the powerful microbiocide, chlorine dioxide. The device uses a cartridge filled with a polymer that release chlorine dioxide upon contact with water. Water purification systems based on chlorine dioxide are currently not commercially available in the country. Considering the advantage of chlorine dioxide over chlorine (better biocidal efficiency and very low production of carcinogenic chlorination by-products), chlorine dioxide based system has tremendous potential. The technology will be made available for transfer to private entrepreneurs.

Turbovita, a novel Curcumin formulation based on the extract of turmeric containing all its active Curcuminioids has been developed as a part of incubation development project between BARC and Veena Industries, Nagpur. It is a unique phytonutrient formulation containing blend of highest quality of proteins, carbohydrates, fats, fibers, vitamins and minerals along with curcuminoids delivered in lipid delivery system to increase their solubility and increased bioavailability. A single



Turbovita, a novel Curcumin formulation developed by BARC

serving of Turbovita provides about 100 mg of available curcumin.

Palladium-platinum based catalyst supported on SS wire gauze has been developed for mitigation of H_2 which may be generated in nuclear reactors during loss of coolant accident conditions.



Catalyst bearing panels fitted in a PCRD box with thermocouple connections assembled for evaluation at HRTF, Tarapur



Zone refined high purity (~8N) germanium

The catalyst exhibited high performance up to 8.0 % of H_2 in the presence of 60 % v/v steam with t_{95} of 9–11 minutes with maximum temperature rise from 495–627°C for 5.0 to 8.0 % initial H_2 concentration. The catalyst panels are qualified for fabrication of Passive Catalytic Recombiner Devices (PCRD, totaling about 1000) for installation in all PHWRs in the country.

A convenient process for purification of germanium of purity 99.999999% (8N) has been developed and 2 kg of ultrapure material has been delivered for semiconductor detector development.

A portable and high sensitive sensor with electronic alarm working at ambient conditions is developed for detection of toxic H_2S gas (1 ppm level) based on the surface conductivity of hydrogenated diamond films. Diamond film based alpha radiation detector is developed for measuring plutonium and uranium-233 in the concentration range 1-1000 ppm



H_2S sensor



Alpha detector

in corrosive liquids. In biosensor research, an optical sensor is developed for detection of E. coli. The sensor films have been fabricated by incorporating pectin stabilized polyaniline nanoparticles in agarose gel to form free standing sensor films. The films when used for real time monitoring of bacterial growth exhibit a visible color change from blue to green. The sensor is generic in nature and has potential to gauge integrity and freshness of food items in real time.

Technology for plastic scintillators for making micro-survey radiation monitors and other detectors has been developed based on polymers like polystyrene / polyvinyl toluene along with organic fluorescence additives. A working model of portable hand-held radiation monitor utilizing the developed plastic scintillator has been made. The performance of the monitor is comparable to that of the imported ones.



Indigenously synthesized scintillator



Survey meter with indigenous plastic scintillator

Femtosecond laser induced breakdown spectroscopy was applied for the compositional analysis of simulated vitrified waste product. Its unique features are rapid analysis, minimal or no sample preparation step and simultaneous analysis for almost all elements across the periodic table and reduced heat affected zone making it an attractive and valuable tool for qualitative and quantitative analysis.

There is an enduring interest in cyclometalated palladium complexes due to their outstanding applications as catalyst in organic synthesis. Cyclopalladation of seleno and telluro ether ligands was investigated.

Thermal studies on compounds of interest in nuclear technology were carried out employing Differential Scanning Calorimeter (DSC), High Temperature X-ray Diffraction (HT-XRD) and Solid State Galvanic Cell. Electrospray Ionization-Mass Spectrometry (ESI-MS) technique based methodology was developed to determine trace levels of Pd in solution using benzoyl thiourea as a complexing agent.

A new methodology based on Energy Dispersive X-ray Fluorescence (EDXRF) was developed to detect level of elements using thin specimens of the sample deposited on thin scotch tape supports.

Partial Least Square Regression (PLSR) was carried out on the Laser Induced Breakdown Spectra (LIBS) recorded on ten low carbon steel samples. Studies were carried out to compare the effect of number of laser shots using multiple statistical parameters which indicated that 60 shots accumulation results in statistically the best analysis.

A new software acronymed "BhaPICA" developed for quick and easy analysis of high

resolution gamma spectrum of Pu required to determine the Pu isotopic composition and 241Am weight percent was developed and released for all the users of the Department.

A new pore-filled anion-exchange membrane has been developed for acid recovery from waste streams. The membranes were tested for recovery of nitric acid from simulated waste solutions without significant transport of metal ions.

Novel Polyethersulphone (PES) based polymeric beads containing Graphene Oxide (GO), prepared by phase inversion technique were evaluated for actinide ion (Am^{3+}, Pu^{4+}, Th^{4+}, UO_2^{2+} while Eu^{3+} was taken as a representative of trivalent lanthanide ions) uptake from acidic feed solutions. The results were highly encouraging as Am^{3+} uptake was very high at pH 5 suggesting that the GO beads can be used for the remediation of low acidic radioactive effluents containing Am^{3+} ions.

At TIFR, new NMR methods were developed for applications in both solution and solid state, especially for systems related to Malaria and Alzheimer's diseases. A new theoretical framework to describe charge transport across organic molecules was developed. New computational measures based on protein electrostatics to determine quality of protein structures was proposed. Zebrafish larval model was developed for manganese induced neuronal disorder. Spectroscopic techniques were developed which combine with NMR to derive structures of disease-causing, metastable proteins. Binding energy measurements of H-bonded complexes of H_2S with phenol derivatives were carried out using Birge-Sponer (B-S) extrapolation in conjunction with the ZEKE spectroscopy. Independently these were also determined using dissociative photo-fragmentation method. It was found that the B-S method is able to reproduce the binding energies within 15% of the actual value. Metabolomic studies were carried out to understand effects of malarial infection. Structural and dynamics investigations were carried out on functionally important folded and intrinsically disordered protein systems. Investigations on bacterial periplasmic binding proteins were completed and protein topology diagrams were used to explain the results. Insights were gained into the catalytic activity of nitridated fibrous silica nanocatalysts by DNP enhanced NMR. The morphology controlled synthesis of cobalt oxide nano-flowers by "thermal evolution" and facile and sustainable synthesis of various shaped iron oxide nanoparticles was also achieved.

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 embarks on teaching and research activity in the interface areas of Biology, Material Sciences and Medicine. The facilities provided during the year for the research and teaching included state-of-the-art NMR Spectrometer for 1D and 2D Experiments, GC Mass and ESI Mass Spectrometers and Time-Resolved Fluorescence Spectrometers.

BIOLOGY

A new fish facility was constructed at TIFR, Colaba campus. Geldanamycin, an anti-mitotic drug was tested and found to cure malaria in mice. A novel assay system to characterize motor proteins in vitro and in vivo was developed. Mitochondrial ros regulates cytoskeletal and mitochondrial remodeling to tune cell and tissue dynamics in a model for wound healing was found. The interplay between cyst cells and germline stem cells was investigated and found that EGFR activation in the somatic cyst cells attenuates germ cell mitosis in Drosophila testis and Actin dynamics regulates sperm release. The critical role for plasmodium p-proteins in nuclear division and in host invasion was elucidated. The neurocircuitry connecting each whisker to a distinct structure called "barrel" in the cerebral cortex of the mouse and the role of Lhx2 in specifying neuronal fates and morphogenesis was studied. The HDAC4 dependent differential response to fluoxetine in postnatal and adult mice affecting psychological stress was identified and the role of 5HT receptors in mediating emotional circuitry and molecular mechanisms was elucidated. The interplay between circadian inputs and DNA damage response in Chlamy was investigated. It was established that

DLC1 binding inhibits electron transport to the oxidation domain of nNOS. Microfluidic devices for imaging trafficking events in vivo using genetic model organisms was made. Master gene (Doublesex) for regulating wing patterns in butterflies, crucial for butterfly mimicry were studied. A stem cell population that forms muscles in the fruitfly was identified. Notable studies on learning and plasticity in stress, on mechanisms for associative learning and on human adaptation to throwing were carried out. Major common equipments commissioned included NMR and 2 clusters each of 1000 cores, one for NGS and another for general supercomputing.

At SINP, in the areas of chemical and structural biology, studies on the recognition of multiple stranded DNA (Quadruplex) and putative anticancer agents from plant source have shown that one such 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. In addition, applications of conducting polymer based nano materials in biosensing and in developing energy storage devices, single molecule and ensemble spectroscopic studies of protein folding, misfolding and aggregation and different areas of nuclear chemistry, radiochemistry and green chemistry are also being executed. Research in the area of Disease Biology focusing on two major disorders the hematological and neurological are ongoing. The widely prevalent disease of Eastern India, HbE-thalassemia, along with sickle cell anemia and leukemia are being studied as model for hematological disorders while Alzheimer's, Huntington's, and the Prion diseases are being studied for the neurodegenerative diseases.

The School of Biological Sciences, NISER continued the research and teaching programmes with harmonious synthesis of classical and modern biology - always promoting scholarship, original thinking, innovative ideas and cutting edge research. The facilities provided during the year were Confocal Microscope Facility, DNA sequencing and Surface Plasmon Resonance Facility and Micro-array facilities for Genomics.

CANCER

The ACTREC located in Kharghar, Navi Mumbai comprises of the Clinical Research Centre (CRC) and Cancer Research Institute (CRI). The CRC is mandated to perform clinical research, clinical trials and to develop indigenous technology. A 100 bed research hospital where cancer patients enrolled on various protocols. The CRI focuses on basic and applied research on cancer.

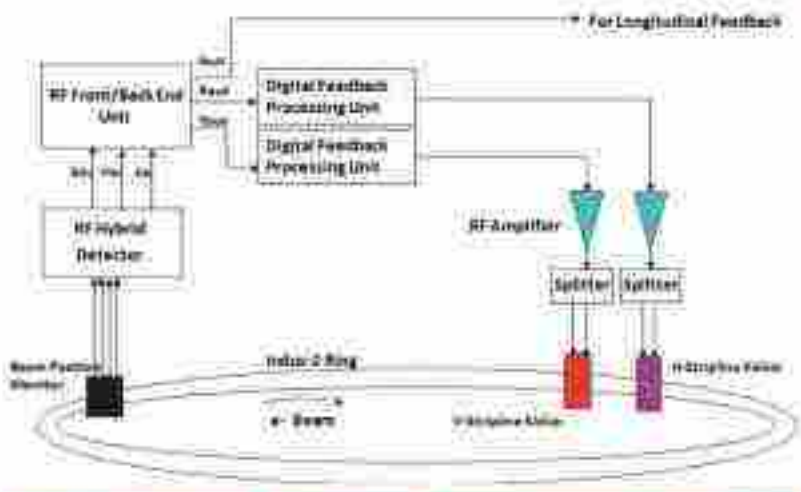
During the year, the CRI received a sum of Rs. 8.30 crore from governmental agencies to support 43 out of 182 on-going projects.

The CRC commissioned a new 22-bed ward. Over 2100 major procedures were conducted and about 1000 in-patients were admitted in the Leukemia/ Lymphoma ward and around 50 outpatients/day were seen in the adult hematolymphoid OPD. Research findings from the Translational Research Lab clearly indicated that chromatin fragments from dead cells induce epigenetic changes, stemness and cancer in living cells.

The Cancer Research Institute is engaged in research on normal, stem cell, cancer cell & molecular biology, structural biology, cell signalling & macromolecular interactions, genetics & epigenetics, immunology & chemoprevention. The protein interaction research focused on identifying novel therapeutic strategies for cancer treatment and their role in regulating cell cycle progression and neoplastic progression. Findings indicated a tissue specific role of K8/K18 in malignant transformation/ progression of carcinomas. Putative driver genes associated with oral carcinogenesis were identified. The significance of epigenetics in gastric cancer and hepatocarcinoma is being investigated. Immunological studies focus on understanding the immune scenario, immune dysfunction in cancer patients and development of cell based immunotherapy for cancer treatment.

SYNCHROTRON & THEIR UTILISATION

During the year at RRCAT, both the



Schematic diagram of transverse bunch by bunch feedback system

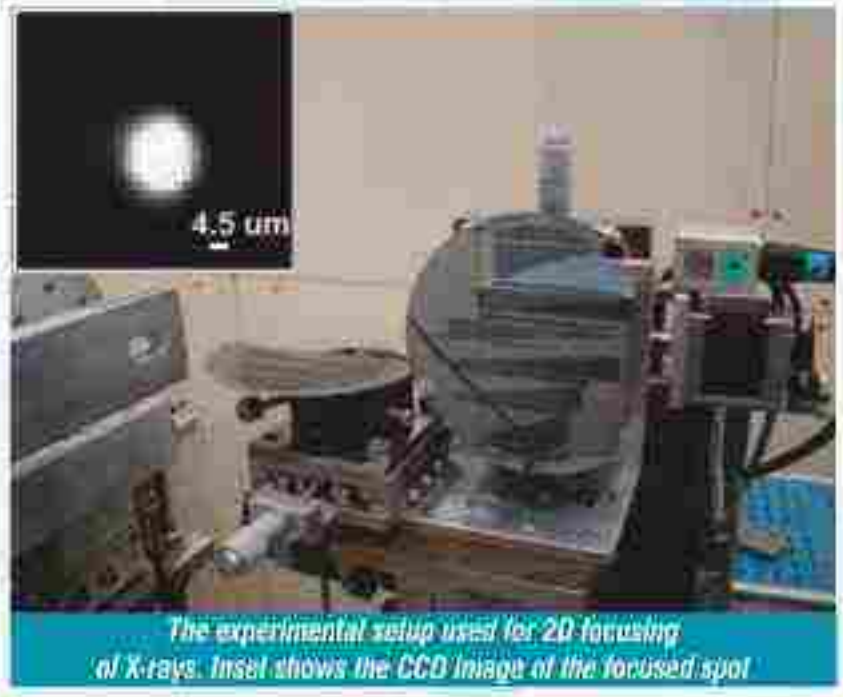
synchrotron radiation sources, Indus-1 and Indus-2 operated in the round-the-clock-mode with Indus-1 at 450 MeV energy, 100 mA current and Indus-2 at 2.5 GeV energy and up to 150 mA. A major milestone was reached in Indus-2 on 19th June, 2014 when a current of more than 200 mA was achieved at 2.5 GeV energy. To achieve the high stored current, a number of improvements in the Indus-2 subsystems were done. The installed capacity of the indigenously developed Solid State RF Amplifiers (SSPA) was increased to 225 kW providing total RF power of 275 kW from Indus-2 RF system. To control the problem of rise in temperature of the vacuum chamber at higher beam currents, the electron beam orbit and the betatron tunes was further optimized.

To improve the injection efficiency facilitating the smooth higher beam current accumulation, a bunch by bunch instability feedback system was tuned to damp the large beam oscillations. To control beam loss during energy ramping, chromaticity in both the planes was optimized in the energy ramping procedure to overcome the resistive wall instabilities. With these efforts, partial beam losses during beam energy ramping at higher beam current were completely eliminated and it was possible to store 255 mA beam current at 2.5 GeV in Indus-2.

An online booking portal for beam-time on Indus Synchrotron Radiation Source (SRS) beamlines has been launched on the RRCAT website. This enables Indus SRS users to plan their experiments by checking the operation schedule and book the required beam-time slot in advance.

The Indus beamlines are national facilities and are used by scientists and researchers from various universities, national institutes and research laboratories all over the country. More than 70 research papers from Indus-1 and Indus-2 beamlines appeared in international journals and peer reviewed international conferences during the year.

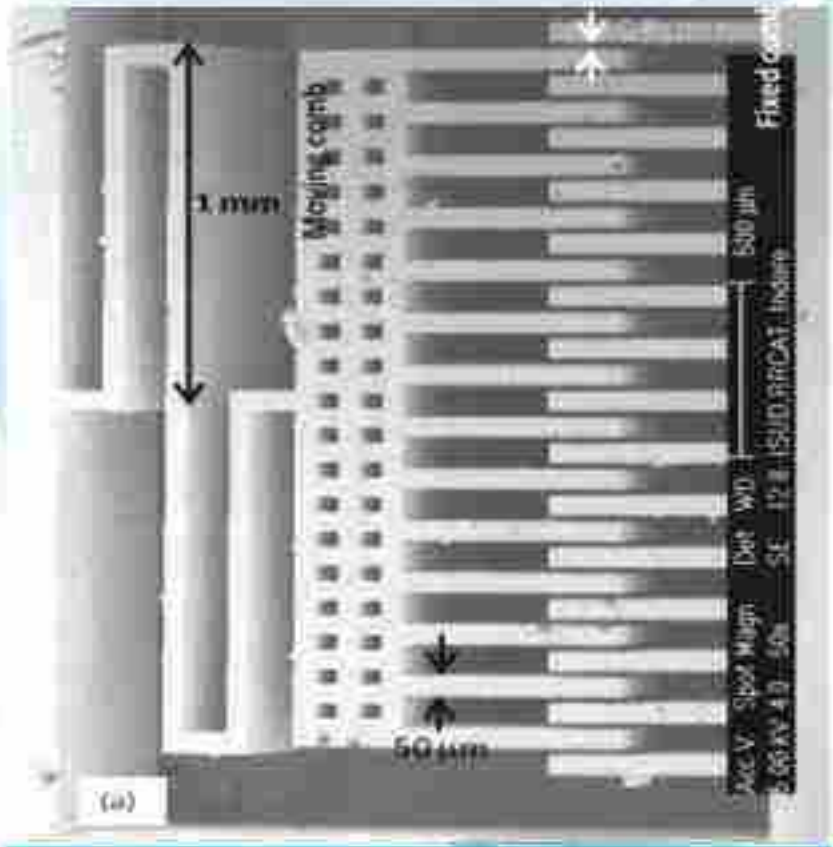
X-ray lithography beam line was used for the development of different types of microstructures that were put to several applications. An important component developed using the x-ray lithography beamline was an array of Compound Refractive x-ray Lens (CRLs). An x-ray focused spot size of 4.5 micron was obtained using these CRLs made in SU-8



The experimental setup used for 2D focusing of X-rays. Inset shows the CCD image of the focused spot

polymer.

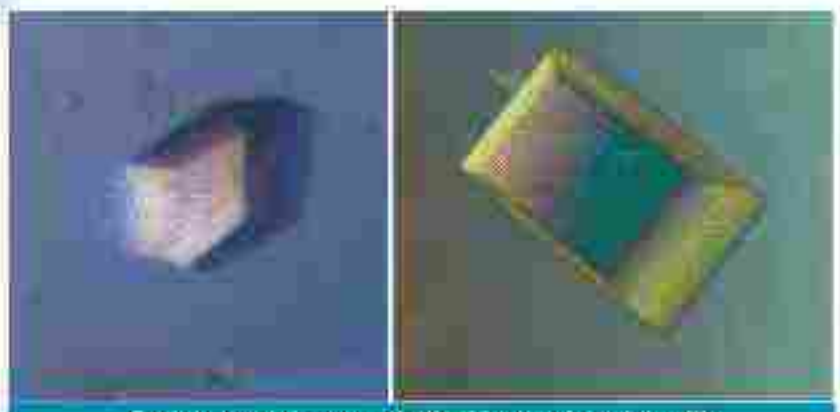
Application of CRLs were also carried out for high pressure x-ray diffraction measurements of samples inside a Diamond Anvil Cell (DAC). The x-ray lithography beam line was also used for the development of high aspect ratio electrostatic comb-drive actuators, which has several advantageous for sensing and actuation application over conventional devices. Comb-drive fabricated in acrylic with aspect ratio of 32 was made by one-step deep x-ray lithography process. A displacement amplification mechanism with an amplification of 10 was also fabricated from acrylic using one-step deep x-ray lithography. Besides these, several other structures including those for MEMS, biosensors and photonics devices were also synthesized at this beamline. The facilities at the scanning Extended X-Ray Absorption Fine Structure (EXAFS) beamline were augmented with a low temperature cryostat for making measurements on samples down to temperature of 5K.



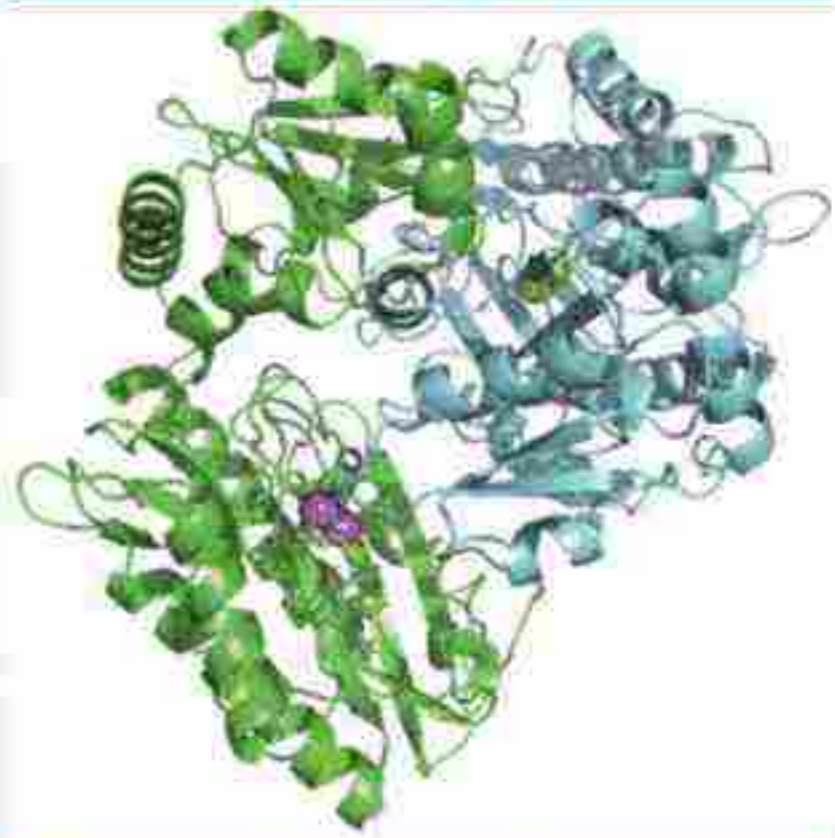
SEM image of high aspect ratio electrostatic comb-drive which works as both sensor and actuator



The low temperature cryostat commissioned at scanning EXAFS beamline for carrying out low temperature EXAFS measurements



Protein crystals grown in the biochemistry lab with dimensions of 500 microns



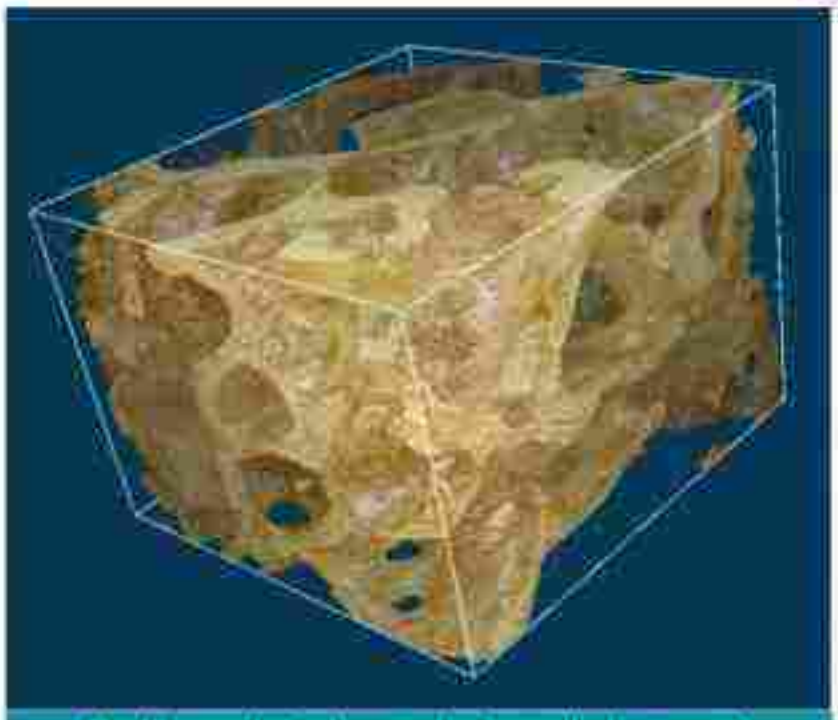
The structure of a protein molecule determined using the protein crystallography beamline

Several user experiments were carried out to study the variation in the bond lengths as a function of temperature. A time resolved EXAFS facility and simultaneous EXAFS-UV-visible spectroscopy measurement facilities were commissioned at the dispersive EXAFS beamline. The protein crystallography beamline was used extensively by researchers from different laboratories all over the country. Several protein crystals were synthesized in the bio-chemistry laboratory. Structure of five new proteins was determined using the protein crystallography beamline. Se K edge anomalous diffraction measurements have been carried out for structure determination.

Several problems related to crystallographic structure were solved using the Angle Dispersive X-ray Diffraction (ADXRD) beamline. One of the major emphasis has been on studying the variation of crystal structure with temperature. X-ray reflectivity studies on multilayer to determine the interfacial structure were also been carried out.

The imaging beamline was used for phase contrast and micro-tomography imaging of several samples including medical samples of doctors from Tata Memorial Hospital at Mumbai. Other studies carried out included structure of fuel pellets for nuclear reactors, pore distribution in metallic and polymer foams, structure of dental implants etc.

A new facility has been setup for combined X-ray Reflectivity (XRR) and X-ray Fluorescence



The 3D reconstructed image of osteoporotic bone sample got from phase contrast imaging at the imaging beamline



The experimental setup for the Grazing Incidence XRR and XRF facility

(XRF) characterization of thin nano-structured materials at the microprobe X-ray fluorescence beamline of Indus-2. The new facility opens up an opportunity for the users to evaluate micro structural parameters of nanostructured thin layered materials on the angstrom length scale using synchrotron X-rays.

The two diagnostic beamlines were extensively used for providing inputs to the Indus machine scientists about the various e-beam parameters. These have contributed significantly towards the performance of the Indus-2 machine. Many experiments for transverse dynamics studies of electron beam related with beam life time improvement, beam coupling reduction, emittance reduction, transverse instabilities etc. were carried in Indus-2 SRS and the measurements were taken at X-ray Diagnostics Beamline (X-DBL). Many experiments to measure longitudinal dynamic parameter were performed at Visible Diagnostics Beamline (V-DBL). In one of the experiments, V-DBL was used to measure the effect of beam current on bunch shape, bunch length and bunch position with an aim to study broad broadband impedance of Indus-2 SRS.

The Angle Resolved Photoelectron Spectroscopy (ARPES) beamline has been upgraded with a state of the art electron energy analyser, Phoibos 150. This facility has been made available to users for experiments. A new image plate has been installed in the high resolution vacuum ultraviolet beamline in Indus-1. This has enabled the acquisition of data in less than a minute, which otherwise took tens of minutes earlier with a



ARPES beamline with the Phoibos 150 analyzer Commissioned



The new image plate with its holder used in the HRVUV beamline

Photomultiplier Tube (PMT).

The soft x-ray reflectivity beamline on Indus-1 has been used to explore new materials for x-ray multilayer optics. Multilayers of C/B4C and W/B4C were tested at high temperature and the structure was found stable upto 700°C. Angle Integrated Photoelectron Spectroscopy (AIPES) beamline has been used for several Photoelectron Spectroscopy (PES) measurements in bulk and thin films. The measurements at the valence band edge in thin films have been used to determine the band offset between the layers and the substrate in ZnO/Ge and



Front End for SAXS beamline



Fabricated water cooled pre-mask



Planar undulator for atomic, molecular and optical science (AMOS) beamline

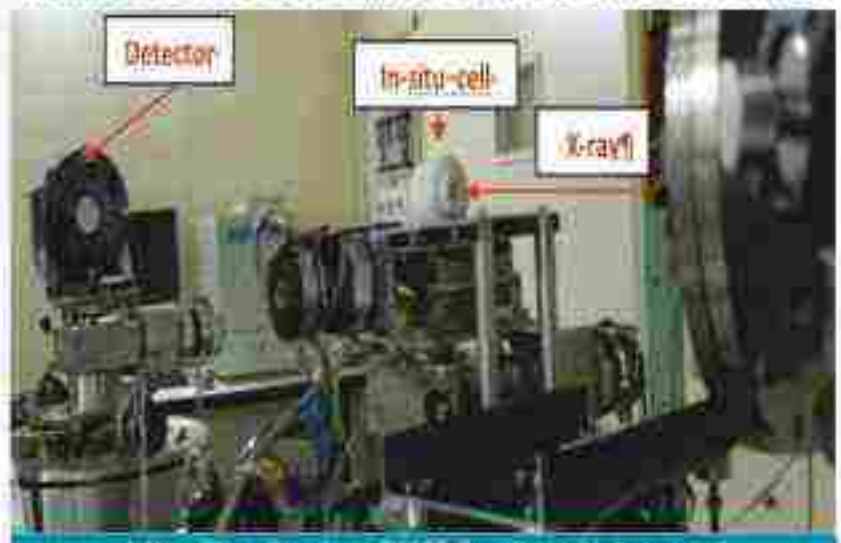


Planar undulator for ARPES beamline

Zn/GaP systems.

The commissioning of the front-ends (FE) for Small Angle X-ray Scattering (SAXS) beamline and for Engineering Applications beamline was completed. All the major components of these two front ends were designed and fabricated indigenously. A vacuum of the order of 10-9 mbar was achieved in both the front ends. The design of frontends for insertion devices based Atomic, Molecular and Optical Studies (AMOS) and Angle Resolved Photo-electron Spectroscopy (ARPES) beamlines were completed. Design of major heat removing components like pre-mask, collimator, mask, water cooled shutter was completed after their thermo-mechanical analysis using FEM package ANSYS. The components layout of two front ends for AMOS and ARPES beamline was finalized. Fabrication of these components was in progress. The water cooled pre-mask was fabricated and tested for its vacuum integrity.

To enhance brilliance of the synchrotron radiation by 2-3 orders of magnitude, Indus-2 synchrotron radiation source was upgraded by incorporating five insertion devices (undulators and wigglers) in the long straight sections of Indus-2 storage rings. The planned insertion devices were already designed. The first milestone in this direction was accomplished by installation of two planar undulators in the straight sections, LS-2 and LS-3, respectively of the Indus-2 storage ring on December 12, 2014. Two undulators were installed in the ring. Undulator U-1 is for Atomic, Molecular and Optical Science (AMOS) experiments which will generate photons having a maximum flux between 6eV to 250eV and undulator U-2 is for Angle Resolved Photoelectron Spectroscopy (ARPES) experiments which will generate photons having a maximum flux between 30 eV to 600 eV. On the development of front-ends and beamlines for these two undulators



A New Time Resolved EXAFS Facility at BL-8, Indus-2



Monochromatization of white SR beam in ADXRD



Vertical and horizontal microfocusing setup in ADXRD

work was underway.

A new time resolved extended x-ray absorption fine structure (EXAFS) facility has been setup at beamline (BL-8), Indus-2 for in-situ studies on growth of nano particles in solution phase simultaneously by in-situ-EXAFS measurement and UV-visible absorption spectroscopy at the energy dispersive EXAFS beamline (BL-08), Indus-2. The studies clearly show evolution of Au-Au bond formation with time.

The capabilities of BL-11 beamline at INDUS-2, RRCAT (Indore) were extended for ADXRD measurements using single crystal Si(111) channel cut monochromator. This arrangement provides easy tunability of monochromatic x-ra ys ranging from 8 keV to 30 keV with a typical energy resolution of ~ 10^{-4}. The flux gain and micro-focusing of these monochromatic x-rays, especially required for high pressure measurements using diamond anvil cell, has been achieved using indigenous Compound Refractive Lens (CRL) developed at lithography beamline.

A dedicated IR beamline for infrared absorption/reflection spectroscopic studies based on



Experimental station of IR beamline installed at Indus -1

a Fourier transform spectrometer synchrotron has been commissioned at Indus-1 (450 MeV) synchrotron. The experimental station has a hyperion microscope facilitating IR microspectroscopy as well as diamond anvil cell based high pressure experiments. This facility was used to carry out several experiments, including studies of materials under high pressures. Extensive high pressure investigation of novel materials has also been carried out.

An Imaging beamline utilizing several advanced imaging modality such as phase contrast imaging, diffraction enhanced imaging and absorption based imaging has been implemented on INDUS-2 synchrotron. It is designed to use both



Imaging beamline



Imaging beamline Experimental Hutch Imaging beamline

monochromatic and white beam. All the necessary hardware and software developed for micromography, phase retrieval and holotomography which will permit basic research in materials and bio-medical science using this beamline. Advanced detectors for conducting experiments on micron to submicron level have been provided in this beamline. This beamline is being used for material science studies, advanced medical imaging studies and micro imaging.

The crystal structures of several novel proteins including Xaa-Pro dipeptidases from Xanthomonascampestris, Deinococcusradiodurans and Escherichia coli and an Intermediate cleaving peptidase (Icp55) protein from Saccharomyces cerevisiae at the resolutions of 1.8, 1.4, 2.7 and 2.4 Å respectively have been solved including single wavelength anomalous diffraction (selenium-SAD) structure using the protein crystallography beamline of Indus-2. The cloning, purification and crystallization of these proteins were carried out at the auxiliary biochemical facility of the PX beamline. About twenty research groups from all over India have used PX beamline and have collected more than 80 datasets on different protein crystals.

The effect on the microstructure of Zr-1 wt.% Nb fuel cladding alloy upon irradiation with 5 MeV proton beam from a Variable Energy Cyclotron has been investigated. The correlation between the damage energy deposition profile and the consequent microstructural modification was obtained for different irradiation doses employing detailed line profile analysis of wide angle and Synchrotron grazing incidence X-ray diffraction data.

CYCLOTRONS & THEIR UTILISATION

K130 Cyclotron BTS Vacuum control system upgradation

As a part of upgradation of Beam Transport System (BTS) control system, the philosophy of computerized distributed control and monitoring has been implemented with our experiences of manual operation taken into account. The BTS vacuum system of RTC is comprised of many vacuum pumps, high vacuum valves, beam line gate valves and several vacuum gauges distributed over cyclotron vault and caves. This system is indispensible for maintaining high quality vacuum in BTS to ensure the quality of the accelerated beam while transporting it from the cyclotron to the experimental target. Therefore, an Ethernet enabled state-of-the-art PLC based control system is commissioned, replacing the relay based system, to enhance the operational reliability and availability of the system. This system facilitates remote monitoring and operation of the vacuum system through Supervisory Control. The system is designed to cater the future requirement of forth beam line to be used for RIB system.

An optimally designed integrated local control panel is provided for in-situ module-wise monitoring and control of all the vacuum components distributed among several channels of BTS vacuum system. This panel plays a crucial role during commissioning and periodic maintenance of the system. The operational logic incorporates the necessary interlocks for safe operation of the field components and hence ensures the overall vacuum level of the BTS system. Since the operation of the cyclotron depends on main machine vacuum and BTS vacuum, few crucial parameters of the main machine are also used to develop the operational interlock. The in-house developed supervisory control system provides facilities of on-line trending, audio-visual alarms, user authentication based operation etc. along with remote monitoring and control of the system. The operator interface of the main machine vacuum system is upgraded to incorporate the BTS system 'mimic' for ease of



Remote Operator interface of BTS vacuum system

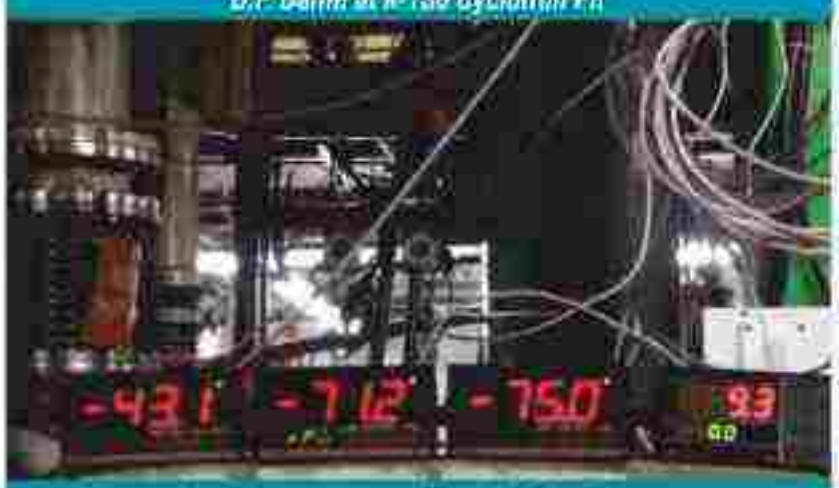
operation. The installation, testing and commissioning of the system is completed successfully.

Development of Two-stage Refrigeration units for D.P. Baffle Cooling by AC Facility Section

In-house developed and fabricated low temperature two stage (cascade type) refrigeration units utilizing the combination of R-404A & R23 refrigerants, which are environmental friendly refrigerant having '0'Ozone Depletion Potential (O.D.P.), have been successfully installed with Diffusion Pump (D.P.) Baffle of Room Temperature Cyclotron. This machine reduces the back streaming and improves the vacuum of D.P. after catering low temperature at the evaporator-baffle (-60°C to -70°C).



Two Stage Low Temperature machine with D.P. Baffle at K-130 Cyclotron Pit



Low temperature reading at D.P. baffle

Design and Development of remote handling device for High voltage deflector of RTC

Electrostatic deflector of K130 cyclotron becomes radioactive due to irradiation of high energy beam accelerated in the cyclotron. The septum is the most radioactive part of the deflector. During maintenance of the cyclotron, the septum is needed to be removed from the deflector assembly and kept in the hot store to reduce the radiation dose of people working in that area. The job of handling the septum, however, leads to high radiation exposure of the personnel handling the septum. A remote handling device was designed and developed for handling the septum as shown in the following pictures. The device is a manually operated spring loaded robotic arm which can be operated from a distance of approximately one meter to take out and insert the septum in deflector assembly by one person very quickly. The device was designed in such a way that the head goes inside the gap between the two graphite plates of the septum and holds the plates and in turn the whole assembly like a clamp. The use of the remote handling device for high voltage deflector has reduced the radiation exposure of personnel involved in deflector maintenance considerably.



Septum taking out by using Septum Handling Device



Head of Septum Handling Device

PLASMA & FUSION TECHNOLOGIES

The Steady-state Superconducting Tokamak-1 (SST-1) experiment progressed well with spectacular milestone achievements. Plasma start-ups with ITER relevant electric fields of 0.3 V/m, plasma formations with both second harmonic and fundamental electron cyclotron assisted pre-ionizations, superconducting magnets with Two Phase cooling are some of the science and technology milestones achieved. Integration of first wall components is about to be completed after which longer plasma discharges would resume.



Steady-state Superconducting Tokamak-1

Discharges duration beyond 230 ms with plasma current in excess of 145 kA were obtained with repeatable characteristics in the Aditya tokamak. The toroidal magnetic field was raised up to 1.125 T to maintain edge safety factor (qedge) 3. The best base vacuum of the order of 3x10^{-8} Torr was achieved after successful baking of Aditya vacuum vessel at 110 ^{o}C. Improved discharges were attempted over a wider parameter range as per requirements of different experiments such as Lower Hybrid Current Drive (LHCD), electron and ion cyclotron heating (ECRH, ICRH) experiments etc. Up gradation of the machine with new circular vacuum vessel and divertor coils was started.

The power launching experiments through Lower Hybrid Current Drive (LHCD) was started in SST-1 with both the klystrons after rigorous conditioning. In Aditya tokamak, using the Ion Cyclotron Resonance Heating (ICRH) system, experiments were carried out to have plasma heating at second harmonic, disruption mitigation and also wall conditioning in presence of toroidal magnetic field. Various procedures to integrate the positive Neutral Beam Injection to SST-1 were in progress.

Under the ambit of the 12th Five Year Plan various technologies are being developed to indigenize the whole spectrum of fusion relevant technologies. In the superconducting magnet technology, various prototypes were tested successfully with all components made from Indian industries and institutes.

For Large Scale Cryogenic systems, a steering committee with national technical and administrative experts was formed to discuss various ways to progress in this ambitious national project. The characterization of the Oxide Dispersion Strengthened (ODS) steel plate made from Indian Reduced Activation Ferritic Martensitic (IN-RAFM) steel powder was done for the mechanical properties.

Exploration of societal benefits from plasma technologies was continued vigorously through the Facilitation Center for Industrial Plasma Technology (FCIPT). Various projects were done through national sponsorships and though international collaborations. The projects cover various area which includes bio-medics, conventional and green power, textiles, waste management, nano-technology etc.

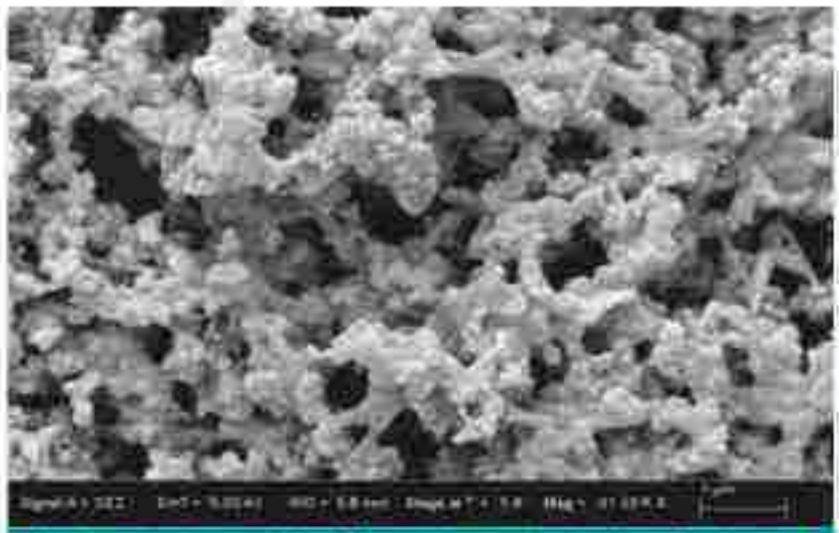
At the Center for Plasma Physics, Guwahati the theory and experimental activities were beefed up in line with the goals of the Institute. The development of a neutron source based on inertial electrostatic confinement fusion scheme and its application in damage study of fusion materials progressed well. Apart from these, dusty plasma experiments, divertor simulation study experiments etc. were also going strong.

At BARC, an innovative space saving online fabrication facility has been set up 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. This has enabled the fabrication of long length Cable-In-

Conduit-Conductor (CICC) in the existing facility. Towards fabrication of 200m long Nb-Ti based 30kA superconducting CICC, required length of final stage cable has been fabricated and wrapped with 25 micron SS foil.

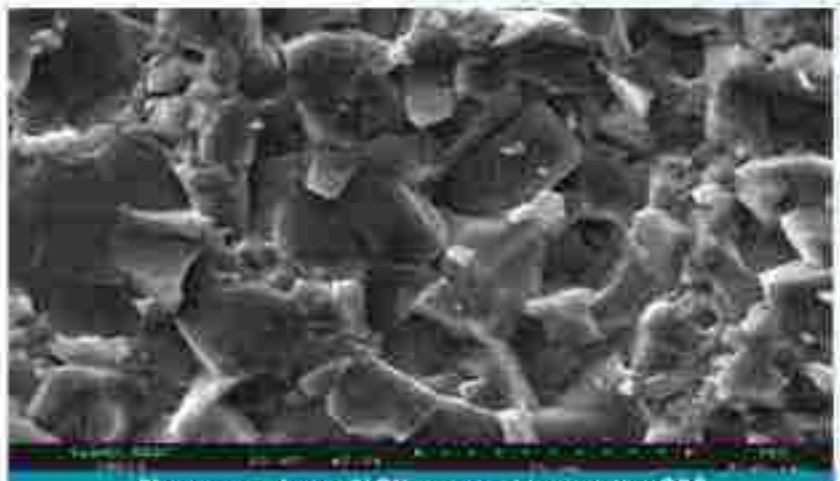
MATERIAL SCIENCE

SiC-SiC composite is a potential candidate material fuel tube in nuclear reactors. At BARC, reaction conversion process was optimized to transform carbon fibre directly to silicon carbide fibre (beta or alpha) for developing SiCf-SiCm and SiCf-MAX phase ceramic composites. Ultrafine SiC powder was synthesized through milling route for developing slurries for joining SiC based monoliths/composites and for making SiC fiber matrix composites. Pure SiC nanoparticles were synthesized by reaction conversion method using natural wastes like wood debris and industrial carbon soot.



Agglomerated nano alpha-SiC powder synthesized from Carbon soot

Aluminium oxynitride (ALON) (9Al2O3.5AlN) ceramics was synthesized from Al_2O_3 and AlN by solid state reaction as well as by reactive Spark Plasma Sintering (SPS) under N2 at 1850°C



Phase pure dense ALON prepared by reactive SPS

for developing transparent ceramic for armour, window and laser host applications. Sintered density 96%TD has been achieved. Effort is on to scale up the synthesis and to optimize the parameters to make transparent material.

Nanostructured Fe-14 Cr-0.25 Ti-0.25 Y_2O_3 (wt%) ferritic ODS steel (oxide dispersion strengthened steels) with ultrahigh density of Y-Ti-O nano-features was synthesized through a novel mechanical alloying-spark plasma sintering route. Microstructural analysis of the powders were used to optimize the milling and sintering conditions.

Rolling Assisted Biaxially Textured Substrate (RABiTS) of Ni-W alloy for fabricating RE123 (RE-Y,Nd,Sm) High Temperature Superconductor (HTSC) tapes (power applications) and seeds for melt grown bulk single crystals (levitation applications) was prepared. Multilayer ceramic thin films were deposited on Ni-W substrate by physical laser deposition for superconducting applications.

A systematic study has been done to establish susceptibility of SS 304L to Stress Corrosion Cracking (SCC) in acidified water containing chloride from 100-10000 ppm at temperatures from 50 to 90 °C using Slow Strain Rate Testing (SSRT). Electrochemical polarization behavior of the stainless steel was established in solutions containing different levels of chloride at 90 °C. Based on the polarization behavior, potentials were applied during the test to control SCC. An "SCC susceptibility index" and fractography after the test was used to quantify and compare the susceptibility to SCC. It has been shown that it is possible to cause SCC even at a temperature of 50°C in water containing chloride. Controlled SSRT in 0.5 M NaCl + 0.5 M H_2SO_4 environment have been done at room temperature and terminated at elongations up to 10% to study precursor and initiation events.

Different techniques such as Optical microscopy, Scanning electron microscopy, Atomic force microscopy and Laser surface profilometry were used to study SCC precursor and initiation events. It was shown that slip band emergence and accelerated attack at the slip bands are the main events leading to SCC initiation for austenitic stainless steel in chloride solution. Role of residual

stress on the chloride SCC and orientation of cracks has also been illustrated for condenser tubes and weldments of austenitic stainless steels.

A hybrid technique of laser surface melting followed by laser peening was shown to seal already existent stress corrosion cracks and resist formation of new stress corrosion cracks in chloride environment.

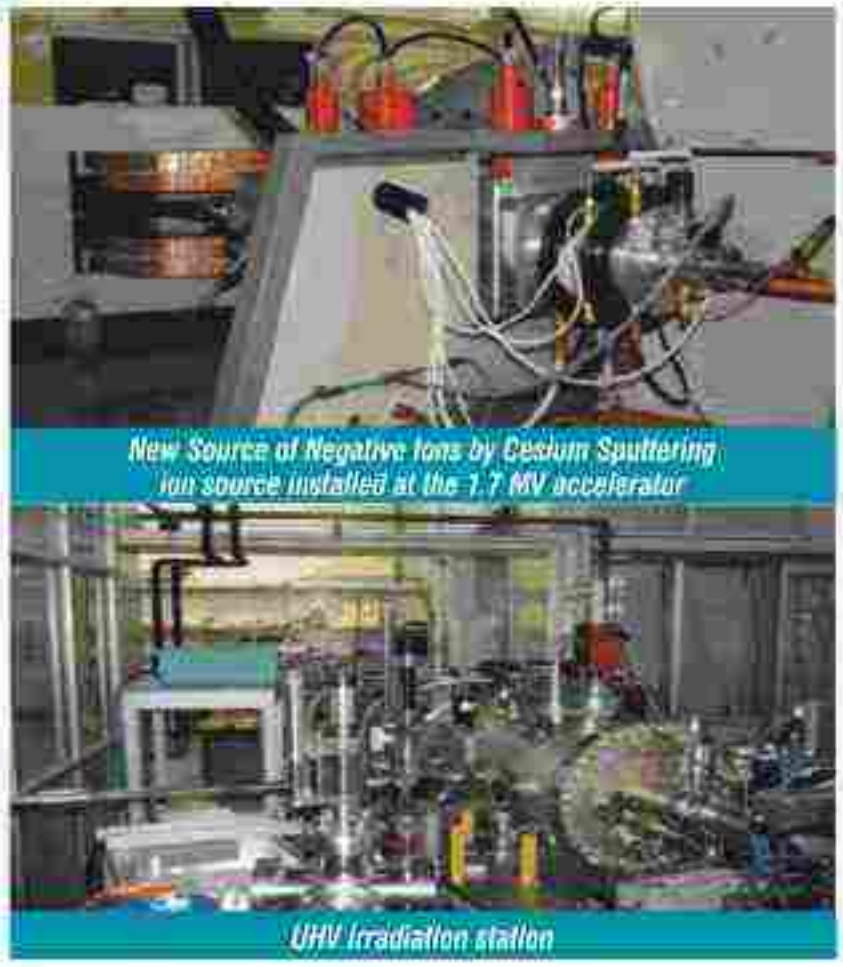
At IGCAR, development of new materials was taken up to obtain large enhancement in thermal conductivity (solid and liquid phase) in the presence of inverse micelles of size ranging from 1.5 to 6 nm. Towards this, new materials with extremely large tunable thermal conductivity were developed. It was found that possibilities of using micellar-templated phase change materials for applications in latent heat thermal storage systems, and new insight into the role of aggregation of nano-fillers in k-enhancement under freezing conditions.

Composition of the V-Ti-Cr alloys alloy was prepared using a vacuum arc melting unit and characterized using advanced electron microscopy techniques of High Angle Annular Dark Field (HAADF) imaging and Scanning Transmission Electron Microscopy coupled Electron Energy Loss Spectroscopy (STEM-EELS).

A bulk nano-crystalline titanium alloy was synthesized by cryo-rolling. Detailed characterization using X-ray diffraction suggested an initial increase in dislocation density following cold work, which later on revealed a decrease with further increase in strain.

A three dimensional visualization of the grain structure evolution upon thermal annealing at about 923K was achieved using Electron Back Scattered Diffraction (EBSD) technique.

A UHV irradiation facility was developed with one of the beam lines of 1.7 MV accelerator for carrying out ion irradiation studies upto a damage level of 150 dpa (displacements per atom). This involved setting up of a new Source of Negative Ions by Cesium Sputtering ion source capable of delivering 1 μA of Fe^- beam on Oxide Dispersion Strengthened (ODS) targets having compositions Fe-14Cr-0.2Ti-0.3 Y_2O_3 kept in a UHV irradiation



New Source of Negative Ions by Cesium Sputtering ion source installed at the 1.7 MV accelerator

UHV Irradiation station

system which was pumped by ion pumps and a Closed Cycled Refrigerant based cold head in order to obtain a clean vacuum of ~ 5×10^{-9} mbar during the high temperature irradiation at 973 K. Beam current measurements were carried out by an automated system.

A Holographic Optical Tweezer set-up was designed and developed for producing about 200 traps in the focal plane. Holographic Optical Tweezers incorporate the technique of beam shaping and holography to hold and independently manipulate multitude of particles in real time. The system can be used to create organized assembly of colloidal particles in any desired geometry.



Holographic Optical Tweezer Set-Up

Topological insulators are a new class of materials that have an insulating bulk and a metallic surface state and occurs as a consequence of spin-orbit coupling. The peculiar band structure of the surface electrons renders them robust to scattering, giving rise to dissipationless transport, which could be useful for several applications. Measurement of magnetoresistance in single crystalline samples of Bi_2Se_3 carried out showed periodic oscillations in resistivity as a function of magnetic field. Positron annihilation was used to characterise the Se vacancies. The results showed that the sample had the lowest positron lifetime, highlighting the importance of controlling the Se vacancies for stabilising the surface state.

Plasma enhanced chemical vapor deposition technique was used to grow vertical graphene sheets. Graphene nano-sheets were successfully grown using CH_4 as the source of carbon and Ar and/or H_2 as diluents. All the process parameters such as feedstock gases, their composition, microwave power, substrate temperature and pressure were optimized to achieve complete tenability in morphology, height, areal density, structural quality and electrical properties of these carbon nanostructures. These vertical graphene sheets were characterized by FE-SEM and Raman spectroscopy. The vertical height of these structures varied from a few nm to several microns and the areal density was up to $10^3 \mu m^{-2}$.

An indigenously designed Ion Beam Sputter Deposition System (IBSD) was assembled for deposition of thin films and multilayers. The system has been extensively used to study the growth kinetics of Al and AlN thin films to investigate the effect of reactive assistance of N_2 ions during the growth. Several other thin films like TiN and Diamond like Carbon (DLC) were also synthesized using this system.

Facilities to measure the extremely weak magnetic fields (50 pico-Tesla or less) associated with the electrical activity of the heart (Magnetocardiography or MCG) and the brain (Magnetoencephalography or MEG) using SQUID sensors were established. An evaluation of the diagnostic performance of MCG was conducted on



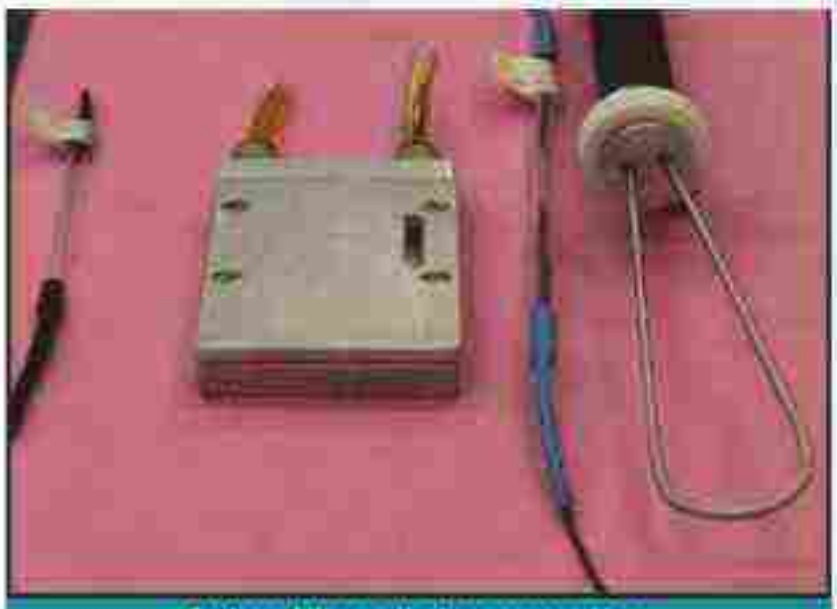
A view of the facility for Magnetocardiography and Magnetoencephalography

patients with cardiac anomalies in collaboration with JIPMER, Puducherry. About 28 patients with various cardiac dysfunctions were brought to IGCAR, accompanied by a cardiologist, and their magneto cardiograms were recorded using a 37 channel MCG system assembled. One of the objectives of the clinical evaluation study was the comparison of the time instants of the activation of the His bundle activity measured using the invasive electrophysiological procedure in a hospital with those measured using the non-invasive MCG facility. The mean difference between the two measurements did not exceed 5 milliseconds, validating the use of MCG for the assessment of His bundle signal.

Irradiation of materials by energetic particles generates man-sized defects at the atomic scale, and their subsequent evolution with other defects affect mechanical behaviour of materials at the macroscopic scale significantly. A statistical framework to incorporate complete size-distribution of the defects along with dislocation density to yield the detailed statistics of dislocation pinning by defects affecting long term behaviour of materials has been developed at VECC. An interesting phenomenon of transition from rare pinning to multiple pinning regime is revealed with increasing irradiation temperature.

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For the radiation damage studies on reactor cladding material, an attempt was made using both wide angle X-ray diffraction and synchrotron Grazing Incidence X-ray Diffraction (GIXRD) to characterize the micro structural parameters like domain size and microstrain within the domains of Zr-1Nb alloy as a function of proton-irradiation dose. The micro structural parameters particularly the domain size and the microstrain within the domains were estimated as a function of irradiation dose and depth by line profile analysis of wide angle XRD and GIXRD data. Model-based approaches of XRDLPA like Simplified Breadth Method, Williamson–Hall Technique, Double Voigt Analysis, all relying on single peak analysis, and modified Rietveld technique, based on whole powder pattern fitting were used to analyze the micro structural parameters. The analyses of wide angle XRD data, in comparison to the GIXRD data at low incidence angles, resulted in an estimation of higher average volume weighted domain size.



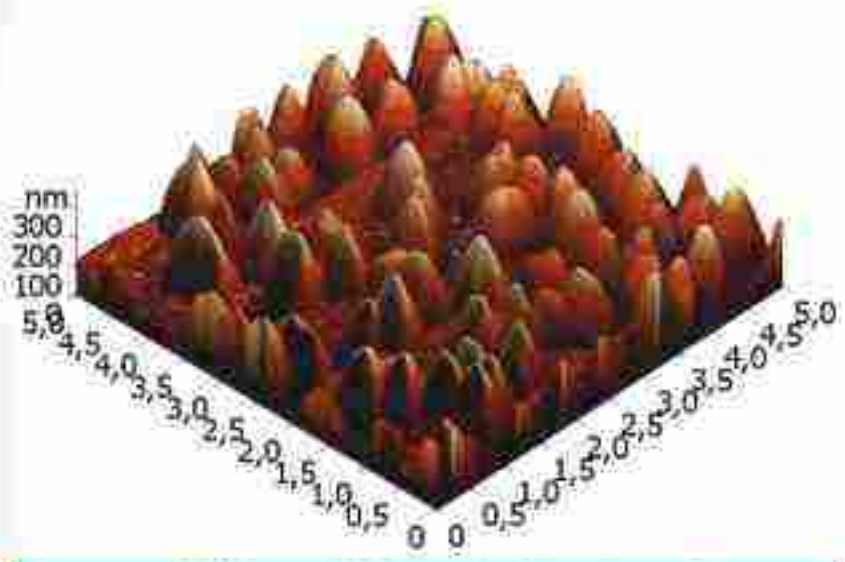
Packaged fiber optic dose sensors Linac



Dose measurement arrangement in for food grade items using the packaged fiber

Two types of packaged fiber optic sensors based on long period fiber gratings and turn around point long period fiber gratings were developed and tested for measurement of radiation dose in the range of 0.1 kGy to 50 kGy for applications in the measurement of radiation dose in the linac based food irradiation programme as well as for applications in radiation environment like hot cells at RRCAT.

GaP/Ge nano structures grown in-house were investigated using the Indus-1 and Indus-2 facilities to analyse band alignments and crystalline structure. These nano structures are potentially promising materials for integration of photonics with electronic circuits.



AFM image of GaP nanostructure grown on Ge

Ultra violet Ga-N based photo detectors were developed and fabricated with a low sensitivity for visible range and a high response in the ultra violet range between 300 to 365 nm. Ultraviolet (UV) Ga-N photodetectors are widely used in spectroscopy, space astronomy, and many industrial as well as military applications. Being a wide band gap material with high thermal conductivity and radiation hardness,Ga-N offers significant potential for visible blind UV detectors that are capable of operating at high temperature and in the hostile environment. Radiation hardness of these devices was also investigated by irradiating the detectors with gamma rays. The post gamma irradiation study indicated an increase in carrier-concentration and a decrease in mobility for moderate dose (~200 kGy) due to increase in scattering centers after irradiation. A



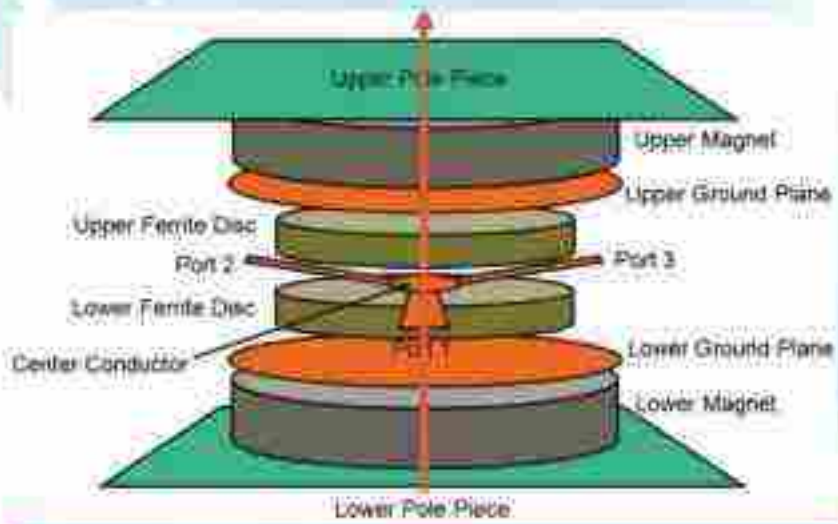
The GaN visible blind UV detector

quick recovery of the irradiated devices, as shown in Fig.86 exposed to 200 kGy of gamma radiation confirmed their suitability for use in harsh radiation environment.

Ferrite circulator technology is advanced, sophisticated and not available in India. A 200 mm Dy-Gd–YIG ferrite disk with stringent magnetic characteristics and composite magnetic circuit was developed indigenously. This technology will be useful for making ferrite circulators for the RF system of Indus-2 and Proton Linac for 650 MHz in the near future.

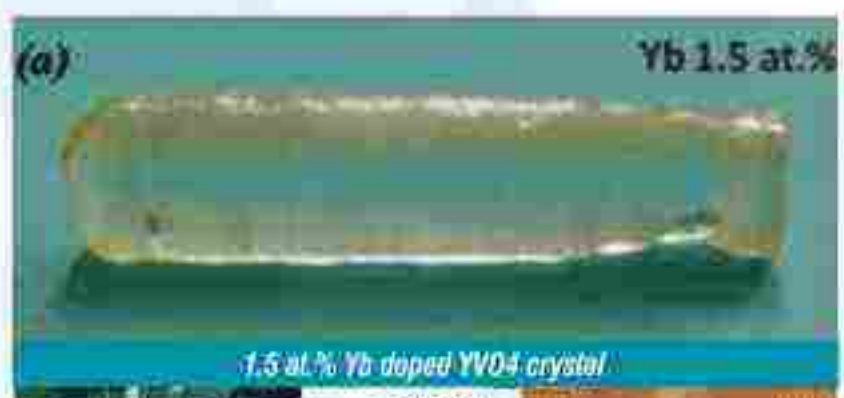


Indigenously developed high power Gd-Dy garnet disks

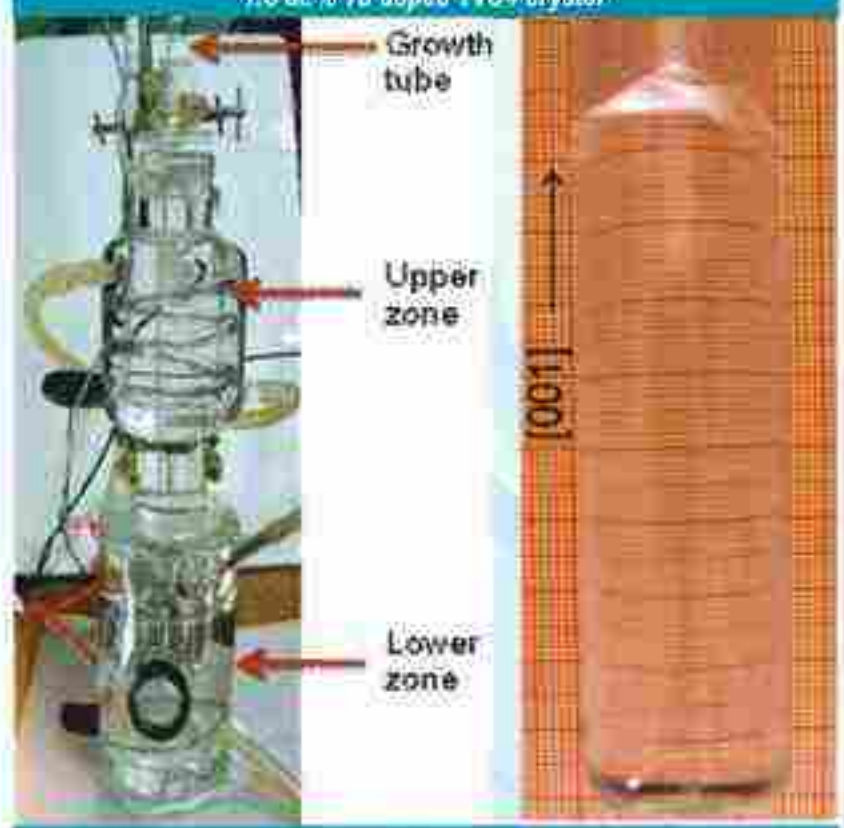


Three port Strip line circulator with permanent magnet

Single crystals of Yb:YVO_4, a diode-pumped solid state laser gain medium, with varied Yb concentrations were grown by optical floating zone technique. The optical absorption studies revealed four distinct transitions in the absorption band of Yb:YVO_4. A new absorption at 962 nm corresponding to the transition from thermally populated first excited Stark level of $^2F_{7/2}$ to the highest stark level of $^2F_{5/2}$ was identified.



1.5 at.% Yb doped YVO4 crystal

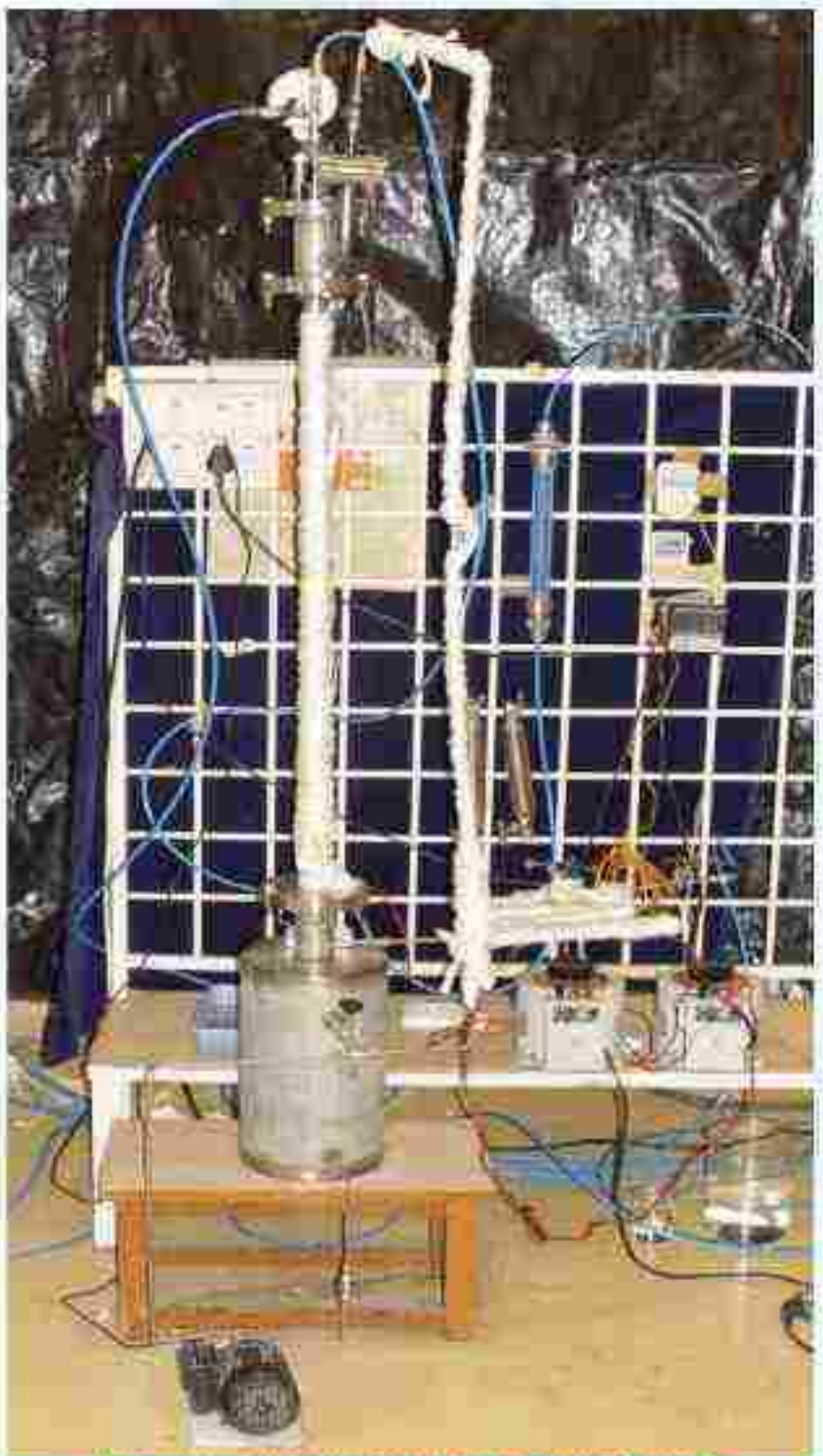


A 2-zone water bath (left) DKDP crystal and a polished (001) plate

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Deuteriated Potassium Di-hydrogen Phosphate (DKDP) single crystals were grown by solute feed based unidirectional technique to reduce requirement of heavy water and increase the usable volume fraction. A DKDP crystal of 81 mm length and 19 mm diameter was grown. The transmission for a sample of 2 mm thick is 91% (without reflection loss correction) in the visible-NIR region with infrared absorption edge near 2.16 µm.

Hydrophobic coating of Platinum loaded carbon aerogel catalyst was improved using Perfluroalkoxy binder (PFA) for achieving catalytic activity at higher pressures above atmosphere. PtCA powder was synthesized employing impregnation method (polyol) on high surface area (>1500 m^2/gm) carbon aerogel. The catalyst performance was evaluated in a high pressure test setup developed to test the catalyst upto10 bar pressure.



High pressure test setup for testing the catalytic activity of Platinum loaded carbon aerogel

TIFR, successfully demonstrated a method to trace diffusion at atomic level quantitatively across interfaces of multilayer thin films using image intensity. This method was used to determine the interface quality of a CRO/ESMO/LAO system. An aligned array of single crystalline trigonal selenium (t-Se) micro-rods not only exhibits a very large birefringence but also rotates the polarization of Tera Hertz radiation by an appreciable amount was shown. This material therefore holds promise as a fully solid state THz phase shifter, an important missing component in THz technology. Plasmonic Antenna structures were designed to generate high intensity THz radiation from SI-GaAs substrates. TIFR, demonstrated the first example of proton-coupled electron transfer reaction inside a nano-confined environment. Polymer-TiO2 interactions have to be controlled at the nanoscale in order to make efficient solar cells was also shown.

INTERDISCIPLINARY AREAS

A Fourier Domain Optical Coherence Tomography (FD-OCT) system has been developed indigenously for depth resolved tomographic imaging of scattering samples for material science research. The system consists of a super-luminescent diode source with central wavelength 840 nm and bandwidth ~40 nm coupled to a fiber-optic Michelson interferometer. The detector output is spectrally



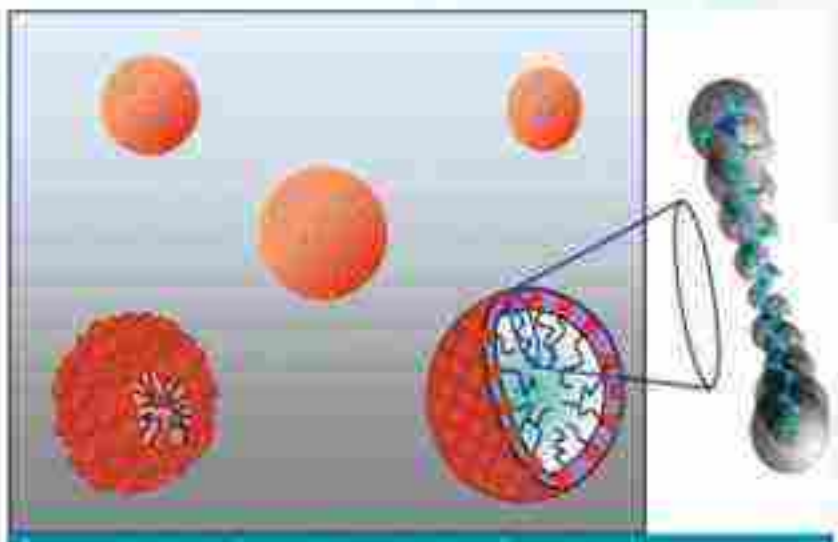
Indigenously developed FD-OCT system

resolved by a spectrometer and detected with a line scan camera. The spectra are Fourier transformed to retrieve depth-resolved information. A galvanometer based scanning mirror is incorporated in the sample arm for lateral scanning.

A six layer TiO_2-SiO_2 thin film magnetron sputtered coating on glass has been designed and developed as potential antireflection structure for solar cell applications at BARC-Vizag facility. The transmission of one side AR coated glass in the broad wavelength region of 450-850 nm is more than 95% as against 92% of bare uncoated glass. The transmission is further improved to more than 98% in the same wavelength region with both sides AR coating.

The hydrogen storage property of core-shell Prussian blue analogue molecular magnet was demonstrated for the first time with the highest storage capacity of 2.0 wt% (20 gm H_2/Kg) at 123 K for the family of Prussian blue.

Amphiphilic molecules in aqueous solution undergo self-association under specific conditions to form aggregates such as micelles. Neutron scattering experiments and molecular dynamics simulation studies on a number of surfactants used in everyday life products that form micelles revealed details of fast local dynamics of surfactant molecules in these assemblies and their correlation with microstructure. The perceived image of a micelle is heavy and therefore fairly static, hydrophilic head groups at the surface and light, dynamic, hydrophobic tails confined in the core. Molecular dynamics simulations studies showed that the solvent surrounding the head groups results in their significant mobility which exceeds that of the tails on the nano-second timescale. The middle of the chain was found to be least mobile, consolidating the micellar configuration. This provided a more realistic model of micelle dynamics and offered new insight into the strongly fluctuating surface of micelles which is important in understanding micelle dispersion and related functionality, like drug delivery.



Schematic of micelles and dynamical configuration of a monomer unit

At the Centre for Interdisciplinary Sciences, TIFR, site-specific fluorescence dynamics in a RNA 'thermometer' was studied to reveal the role of ribosome binding in its temperature-sensitive switch function. Studies were carried out for the dynamics of rising bubbles and falling drops and showed the limits up to which these will be mirror images of each other. In the studies of statistical mechanics of disordered system, very low temperature supercooled liquid state using a new smart Monte Carlo algorithm was reached and showed that the length scale proposed can capture the dramatic slowing down of dynamics near the experimental glass transition temperature. Turbulent flows, in particular the merger of multiple vortices was investigated. Initial results on two-dimensional multicomponent flows showed that the energy transfer mechanism is dramatically modified in comparison to the single component flows. A theory of a fluid film coupled to actively contractile filaments of relevance to the dynamics of the membrane of crawling cells was constructed. By combining NMR experiments and MD simulations the pathway and the barrier height for the interconversion of T4 lysozyme between its buried and exposed forms was determined and the main result obtained was that the process is nearly barrierless.

For the Indian Lattice Gauge Theory Initiative, QCD equation of state was calculated at finite baryon chemical potential. A new method for handling the divergences in quark number susceptibilites was suggested.

The highlights of the Neutrinoless Double Beta decay Experiment: included Tests of Sn cryogenic bolometer with alpha source; successful test of the indigenously developed NTD Ge sensor; Installation of cryo-free low background HPGe detector and Neutron induced background studies in the NDBD detector.

CHAPTER-5

The highlights of the Pelletron Linac Facility were replacement of High gradient HV accelerating tube for 1 module in Pelletron; installation of air cooled magnet power supplies; installation of multi-pocket 10 kV electron gun evaporation system and refurbishment of electrical distribution system, tower elevator and ion source AC.

For the Inter-Institutional Centre for High Energy Physics (IICHEP), R&D for the INO project is near completion. Various components required for the engineering prototype detector to be set up at Madurai were under construction.

The multiple cavity interferometer design and the construction of the dedicated laboratory progressed for the Gravitational Wave Prototype Detector.

INTERNATIONAL RESEARCH COLLABORATION

The Nuclear Data Physics Centre of India (NDPCI) has been pursuing all aspects of nuclear data viz, measurements, analysis, compilation and evaluation involving national laboratories and universities in India. The activities of NDPCI are reported in the annual meeting of International Network of Nuclear Reaction Data Centres of International Atomic Energy Agency (IAEA). NDPCI has been contributing to the EXFOR database of IAEA through entries compiled by participants in various domestic workshops on EXFOR compilation as well as through projects given to various universities. The number of EXFOR entries created in the EXFOR workshops in India is 278 which compares well with those elsewhere.

Under the MoU with the Institut Laue-Langevin (ILL), Grenoble, France, BARC has made in-kind contribution to ILL in the form of lead shields, neutron guide housings, precision alignment tables, stainless steel roof etc. A thin walled (1mm thickness) very large isosceles trapezoidal shaped leak tight aluminium chamber was designed and fabricated in house for the time-of-flight experimental facility. This TOF chamber of size 2500x2000x1500 mm is designed to hold Argon at 1 atm. absolute pressure as shown in figure.



Neutron guide housing made of Aluminium at ILL



Lead shield wall at ILL



Neutron guide housing made of steel at ILL



Roller Assemblies



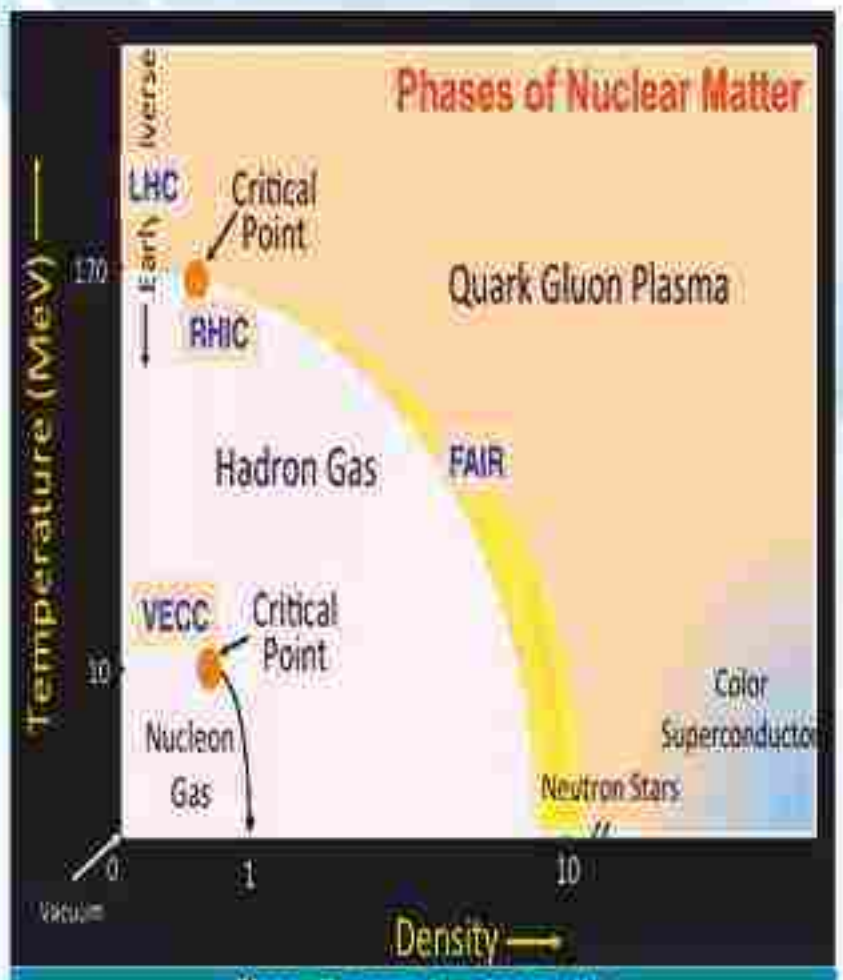
Roller Assemblies: another view



Neutron time of flight chamber

In a collaborative India-UK project, stainless steel to titanium dissimilar materials bonding with strength 112 MPa was developed using vacuum brazing with Ag-28% Cu alloy. The joints did not show any defects such as cracks, discontinuities and pores at the interface. The braze zone (BZ) of the joints were characterized at different length scales using various microscopic and microanalysis techniques to establish the mechanism of bonding. Formation of an amorphous phase at certain locations in the BZ could be confirmed using transmission electron microscopy.

International collaborations at VECC was continued with the participation in three major experiments STAR experiment at the Relativistic Heavy-Ion collider (RHIC) at Brookhaven National Laboratory, New York, USA; ALICE experiment at the Large Hadron Collider (LHC) at CERN, Geneva, Switzerland and CBM experiment at FAIR in GSI, Darmstadt, Germany. These experiments explored different regions of the QCD (Quantum Chromo-Dynamics) phase diagram.

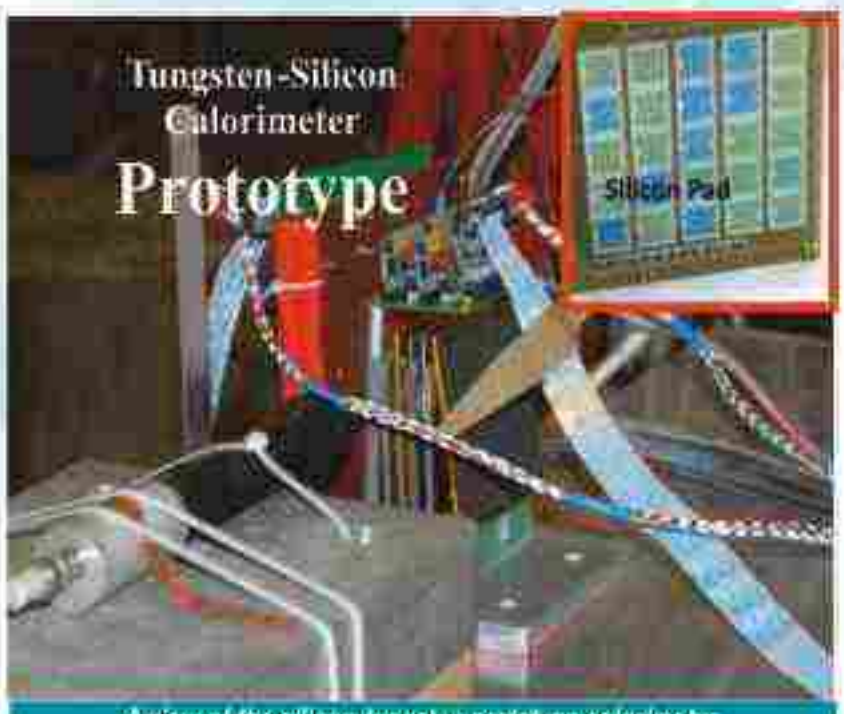


Phase diagram of nuclear matter

In the STAR experiment at RHIC, we have been involved in the beam-energy scan program with the aim of locating the QCD critical point, which is a major landmark on the QCD phase diagram. Recent analysis by VECC scientists using fluctuations of conserved quantities has narrowed down on the possibility of locating the critical point with new data from RHIC. Results from RHIC and LHC indicate hydrodynamic evolution of the matter formed in relativistic heavy ion collisions. In a scenario where medium undergoes QCD Chiral phase transition and rapid cooling, there could be formation of meta-stable domains, which are not in thermal equilibrium with its surroundings. Decay of such domains is predicted to give rise to anti-correlation between produced charged particles and photons.

The analysis results, using the data from a combination of - "Made in India"- Photon Multiplicity Detector (PMD) and the STAR Forward Time Projection Chamber (FTPC) shows the presence of a localized anti-correlation in the production of photons and charged particles. The results have already been communicated for publication.

In the ALICE experiment, the PMD has been conceived, designed, and fabricated by the Indian collaboration. The detector has accumulated



A view of the silicon-tungsten prototype calorimeter
The inset shows the silicon pad detector

valuable data for the proton-proton, proton-lead, and lead-lead collisions at the LHC. Analysis of the first results on the photon multiplicity distributions has been complete and submitted for publication. As an upgrade of the PMD for the next phase of ALICE experiment, a new Silicon-Tungsten (Si-W) calorimeter has been proposed. This calorimeter is expected to meet the demand of new generation of high-energy physics experiment. A prototype mini-calorimeter has been constructed as shown in the figure. The performance of the mini-tower was tested using pion and electron beams at the CERN Proton Synchrotron (PS).

VECC has been playing the lead role in design, simulation, development and fabrication of the muon detection system in the Compressed Baryonic Matter (CBM) experiment in the upcoming Facility for Antiproton and Ion Research (FAIR). The dimuons originating from the decay of low mass vector mesons and charmonia are considered to be highly sensitive probes to the medium created in heavy ion collisions at FAIR energy. A major milestone was achieved this year in the form of submission and subsequent approval of the Technical Design Report (TDR) of this system by the Expert Committee of Experiments of FAIR. The TDR written entirely by the VECC team consists of discussions on physics of dimuon measurement in CBM; detector concept and related R&D; integration of mechanical and readout electronics and project planning and costs.

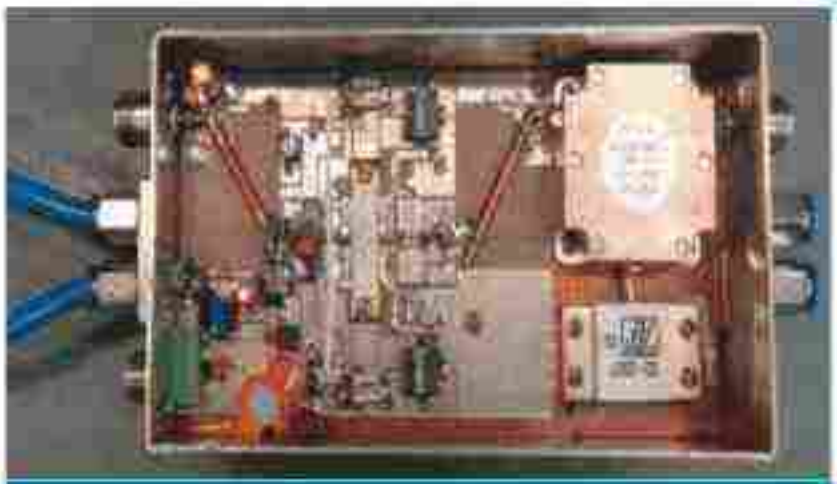
The muon detector system also referred to as Muon Chambers (MUCH) in CBM consists of six segmented absorbers with equal number of detector triplets placed after each absorber segments. Apart from detailed simulation works using GEANT that demonstrated the feasibility of the novel detector concept in heavy ion collisions at FAIR energy, VECC has worked on development of large size (1 m x 0.5 m) gaseous detector modules using the Gas Electron Multiplier (GEM) technology. These advanced detectors were tested to work at 1 MHz/cm2 rate with more than 90% efficiency. The readout system uses self-triggered electronics capable of handling harsh radiation environment. A photo of the large size chamber along with the X-ray spectra from 55Fe source is shown in the following photograph. More such tests with X-rays and with particle beams at appropriate accelerator facilities followed by detailed data analysis would be carried out to study the performance of such a full scale prototype.

During the year, four theses were defended from the EHEP&A group, two on the STAR experiment, one on ALICE and one on the FAIR project.

Under the Novel Accelerator Technology Protocol, WR 2300 high power copper coated stainless steel couplers made at RRCAT were supplied to CERN after leak testing. Two such couplers have been installed in the LINAC 4 DTL-1 and CCDTL tanks respectively and are undergoing high power conditioning at CERN. This is part of India's contribution to the Luminosity upgrade of Large Hadron Collider in which a new injector for Large HC is coming up at CERN.



High Power WR 2300 Coupler installed in DTL-1
in LINAC 4 tunnel at CERN



500 W solid state amplifier module at 650 MHz

A 500 W solid state amplifier at 650 MHz has been designed and developed under the Indian Institutions Fermilab Collaboration (IIFC). The basic building block for this high power amplifier is a 500 W amplifier module. In this design, 12.5 kW of RF power is obtained by summing power output of multiple transistors, developed in the form of amplifier modules. Thirty two 32 such modules were developed and used for power combining with the help of in-house developed 16-way divider, combiner and other passive coaxial components.

TIFR reached an important milestone in its pursuit to build the Belle II silicon micro-vertex detector (SVD) i.e., mechanical mockup meeting the desired geometrical and mechanical precisions. About 80% of the construction work for the new campus of the International Centre for Theoretical Sciences at Bengaluru was completed.

SINP has set-up a Beamline in Photon Factory, Japan. The Indo-German collaboration between SINP and Deutsches Elektronen-Synchrotron (DESY), Hamburg in Synchrotron research has been successfully going on. International Collaboration with CERN in ALLICE and CMS experiments and International Collaboration with SNOLab in PICASSO experiment are ongoing.

The Institute of Physics, Bhubaneswar was involved in a number of international collaborative research programmes. The Institute participated in the PMD collaboration experiment at RHIC and LHC accelerator facilities in USA and CERN, Geneva respectively. The photon multiplicity detectors fabricated at the Institute are being presently installed and tested as part of the STAR experiment at RHIC accelerator. Experiments were also carried out at the Photon Factory, Japan, Elettra Synchrotron facility in Trieste, Italy, and ALPI Linear Accelerator at LNL, Italy.

At IPR for the Indo-Italian program on investigation of local structure and magnetism properties of Cobalt nano-structures, synthesis of Cobalt nano particles under externally applied magnetic fields was carried out. Synthesis of Iron oxide particles under externally applied magnetic fields was completed and their characterization and analysis was in progress. For the DAE-BMBF program on Low Energy Ion Beam for Nano Patterning and its Applications to Plasmonics, the project was successfully completed and the concerned report was submitted. A follow-up project proposal has also been submitted. For the Indo-UK DST program on Plasmonics based CZTS Solar Cells, a project proposal to develop plasmonics based CZTS Solar Cells and to demonstrate an improved solar cell efficiency, using Silver nano particles was submitted and sanctioned. A MoU for research collaboration between IPR and RICMASS (Rome International Centre for Materials Science and Super Stripes), Italy has been signed in March 2014. Under this MoU it has been planned to carry out an in-depth study of defects and atomic level changes in materials exposed to fusion plasma.

IMSc continued the joint projects with other international institutes which were CEFIPRA: Arithmetic circuits computing polynomials with University of Paris; Indo-Swiss PEP Joint Research Project titled "Mathematical Programming in Parameterized and ITRA- Media Lab Asia Project on Decongesting India's transportation networks using mobile devices.

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.



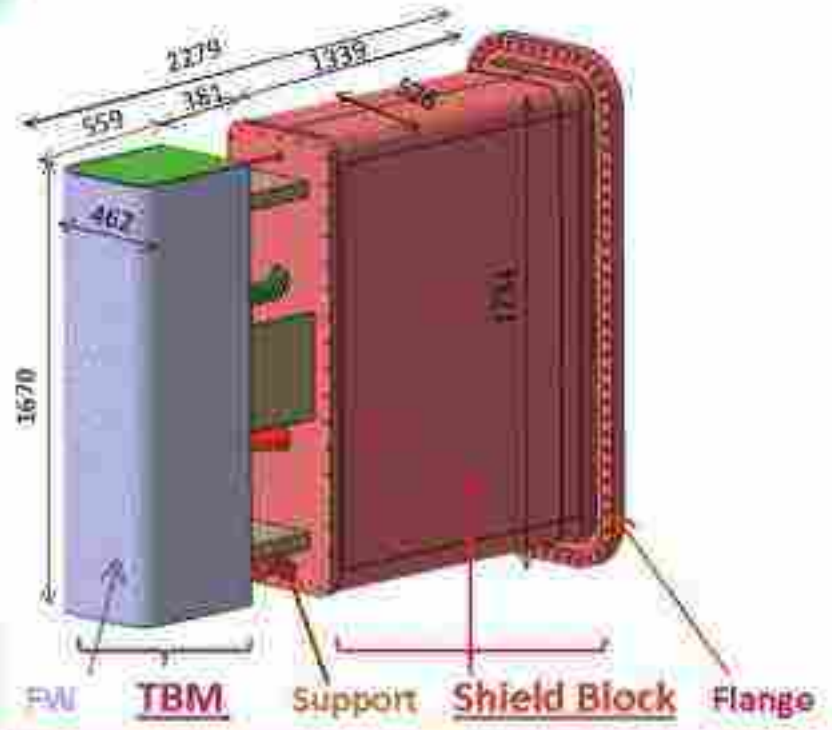
Cryostat: Manufacturing process: bottom plate and horizontal plate



Manufacturing process of shell for cryo-distribution and cryo-lines

Six major contracts for the manufacturing of ITER components have been signed till date for ITER. The progress in the already awarded contracts are being monitored through international quality assurance and control as it is necessary for ITER project. The workshop at the French site for the assembly of biggest cryostat which is being supplied by India was inaugurated. 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.

At IPR, Nuclear design and analyses was carried out for the Lead Lithium Ceramic Breeder (LLCB) Test Blanket Module (TBM) set using the Monte Carlo radiation transport code MCNP and nuclear cross-section data Fendi-2.1. Synthesis of Lithium Titanate powder, testing of critical process sensors, experiments with Lead-Lithium loops are some of the activities being done. The already operational High Heat Flux Test Facility was utilized to test many potential materials for using in first wall



Test Blanket Module (TBM) set design

components of fusion relevant machine. Electromagnetic Analysis of ITER-like Divertor are continued with to compute electromagnetic forces and resulting mechanical stresses under various plasma event scenarios. A laboratory scale Hydrogen Isotope Removal System (HIRS) for He purge gas to validate design concepts for tritium extraction is being developed.



Assembly of left arm heat transfer elements for SPIDER beam dump for Diagnostic Neutral Bam for ITER

Laboratory scale hydrogen isotope storage experiments in metal getter bed were conducted at BARC. The vessel was fabricated and tested to store 2 gm of hydrogen equivalent. Laboratory scale hydrogen solubility studies in liquid lead lithium eutectic have been carried out.

Preliminary experiments to find the solubility of hydrogen in PbLi at ITER operating temperatures have been conducted. Experimental set up for



Test setup for Hydrogen intermittent storage bed



Test setup for Hydrogen solubility studies in PbLi

Hydrogen permeation using Pd based membrane has been installed and commissioned.

CHAPTER-6

RESEARCH EDUCATION LINKAGES



PhD / M.Tech students working on project works related to Indus accelerators and beamlines utilization



New Eddy current thin septum magnet developed at RRCAT, Indore

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), 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 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) has now eight Boards of Studies which are 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, Post Graduate Diploma, M.Sc., Integrated M.Sc., DipRP, DRM, DMRIT, DM, MD, MCh and M.Sc Nursing. About 800 students are admitted every year and number of students enrolled with HBNI is more than 3000 as on November 30, 2014. The number of Ph.D students is about 1500, out of which about 350 are pursuing Ph.D in engineering. The Institute has awarded 430 Ph.D, 669 M.Tech, 9 M.Phil, 118 M.Sc. (Five years integrated and as part of integrated M.Sc.-Ph.D programme), 24 M.Sc. (Engg), 159 diplomas in radiation protection, 47 diplomas in medical radioisotope technology, 40 diploma in radiation medicine and 155 post graduate medical degrees till November, 2014. Cumulative enrolment is over 6000, with Ph.D enrolment number alone being more than 2000. Cumulative enrolment under post-graduate medical programmes is about 500. During the period of report, 12 engineering post-graduate students were inducted into DAE Graduate Fellowship Scheme (DGFS) for Ph.D. 109 students were awarded Ph.D degree till April, 2014. A new diploma course in Fusion Technology has been started during the year.

HBNI continued to strengthen its linkages with premier research and academic institutes in the country and abroad. It has MoU with the 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; The University of Virginia; The Commissariat a l'energie atomique et aux energies alternatives, France; University of North Texas, USA. During the year, two meetings of Council of Management, one meeting of Academic Council and three meetings of Standing Committee of Deans-Academic of HBNI were held.

Training School

The academic programme of the 57th batch of BARC Training School was continued. Screening test for 7 engineering disciplines and 5 science disciplines for the 58th batch was organized at 41 venues in 32 cities. The Outreach programme to publicise the recruitment of Scientific Officers through the BARC Training Schools was further expanded by the participation of officers from IGCAR, NFC and VECC leading to an increased coverage both in terms of cities visited and institutions covered.

A total of 317 candidates were selected for OCES/DGFS-2014 which included 11 DGFS (all

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Discipline wise total selection of candidates for OCES/DGFS

BARC). Out of 317 candidates, 238 engineering graduates were selected for the OCES/DGFS and 79 candidates were selected for the Science disciplines.

The BARC OCES-2013 (57th batch) started with 120 engineering TSOs and 34 science TSOs. A total of 151 TSOs (117 engineering + 34 science) were placed in various units of DAE after successful completion of training. Graduation Function of BARC Training School was held on July 31, 2014 with Dr. S. Banerjee, DAE Homi Bhabha Chair Professor and ex-Chairman AEC as the Chief Guest and Dr. R.K. Sinha, Chairman, AEC, and Secretary DAE as the Guest of Honour. Chief Guest gave away Homi Bhabha Prizes to the toppers of 12 OCES disciplines of 57th batch and the topper of the 10th OCDF course. The OCDF-2013 had 21 trainees.

Preparatory work for OCES/DGFS-2015 programmes commenced in accordance with the last year's decision of 'BARC Training School Apex Committee'. Human Resource Development Division (HRDD) equipped itself to hold screening test for OCES/DGFS-2015 online for all the disciplines including civil engineering. A net job portal 'freshersworld.com' has been engaged to send about 5 lakh emails to the target candidates at the rate of fifty thousand emails per day beginning with the day the Online application process commences. In order to promote DAE activities and thereby attract best talent, plans are afoot to visit as many colleges and universities as possible. The online exam is planned at 32 cities and towns with multiple venues in cosmopolitan cities.

HRDD officers delivered lectures at Vijaynagaram, Andhra Pradesh, DAV Jalandhar, Punjab and NIT, Hamirpur, Himanchal Pradesh on 'Career opportunities in DAE' to motivate young students to join DAE. HRDD officers interacted with NTRO, L&T and CSIR officials engaged in their respective human resource development programmes.

HRDD coordinated summer training and academic projects of BE/B.Tech/M.Tech/ ME/Engg Diploma/MSc/MCA students from all over the country. About 1631 students from different educational institutes visited BARC for training/project work.

During the year, a total of about 150 of over 170 courses consisting of foundation, core and elective courses were conducted for the Trainee Scientific Officers (TSOs). About 500 faculty of practicing scientists and engineers were invited from various Divisions/Units of DAE. A few non-DAE faculty were also invited to teach at BARC Training School, Mumbai. Projects were allotted to TSOs in consultation with their prospective Divisions/Units. About 140 project guides were engaged for the purpose. Revised syllabus document incorporating all the changes up to December 2014 was formulated.

Training and Certification of Nuclear Radiation Professionals for Medical, Industrial, Defence and Research Applications during 2014 were conducted as planned. Total 1337 radiation professionals were trained.

Second National Training Course (NTC-2014) specially designed and conceptualized for security personnel on "Physical Protection of Nuclear Material and Nuclear Facilities" was held at Mumbai during March 24-28, 2014.The training course was attended by 51 participants, 20 departmental security officers from different DAE units and 31 CISF personnel deployed at different DAE units.

A Regional Training Course (RTC) on "Vulnerability Analysis of Physical Protection Systems" was organized jointly with International Atomic Energy Agency (IAEA) during 15-19 September, 2014 in Mumbai. A total of 22 participants took part in the training course. There were 9 foreign participants and 13 Indian participants.

A Workshop on "Vulnerability Assessment for Nuclear Material Security" was organized during

27-31 October, 2014 at Homi Bhabha National Institute (HBNI), Anushaktinagar, Mumbai with active cooperation from National Nuclear Security Administration (NNSA), Department of Energy (DOE), USA. A total of 20 participants from various units of Department of Atomic Energy took part in the training course.

Winter school on 'Radiation detection and measurement' was conducted in the first week of December 2013. Four batches of Radiography Training level 2 (RT-2) courses were conducted to meet the professional needs in Industrial Radiography and to provide instructions on proper and safe use of radiation sources. More than 100 candidates were qualified. Recruitment actions were taken for the empanelment of 180 CAT-I Trainees, 280 CAT-II Trainees, 138 OCES and 25 DGFS. Several in-house training programmes for the benefit of employees of the Centre were organized and 700 officials attended the programmes.

At IGCAR, fifty four Trainee Scientific Officers of the eighth batch completed their training in six disciplines and were placed in various units of DAE. In the present academic year, forty six Trainee Scientific Officers are undergoing training at the Training School. Along with the TSOs of this batch, 24 Research Scholars were inducted to pursue their doctoral programmes in the frontier areas of engineering & basic sciences and employees who are pursuing higher studies under the aegis of Homi Bhabha National Institute (HBNI) also underwent coursework at the Training School. Seven training programmes on various topics and were imparted and 165 employees got benefited & trained. Twenty three candidates were nominated for 12 training programmes conducted by ATI/DAE, Mumbai. About 168 employees have been trained till December, 2014.

BARC Training School AMD Campus, Hyderabad continued its activity in the fifth year with Geology (13 nos.) and Geophysics (6 nos.) Trainee Scientific Officers (TSO). Human Resource Development was continued with in-house (66 officers+ 41 technicians) and external (52 officials) trainings in various institutes such as IIT, ATI, ASCI, MDI etc. About 76 trainees and students from different universities made study visit to AMD establishments at Headquarters and Regional Centres. AMD studentship programme (148 nos.) and BRNS projects (50 nos.) were continued in collaboration with various University & Academic Institutions.

VECC is one of the Constituent Institutions of HBNI, a deemed University. It facilitated conduct of academic programme in Physical Sciences and Engineering Sciences. About, 16 and 48 students are carrying out their Ph D works in Engineering and Physical Sciences respectively at the centre presently. Besides, VECC imparted vocational training to undergraduate B.E/ B.Tech students of IITs, NITs and different universities across India.

Human resource development activities at RRCAT have been greatly enhanced by extending the available research facilities for training of university students in the areas of accelerators, lasers and their applications. At present 30 external students are carrying out research work at RRCAT for their PhD degree under the framework of Homi Bhabha National Institute. Opportunities are also provided to M.Tech/M.Sc students to carry out their one-year / six-months project work towards partial fulfillment of their degrees. A total of 130 such students pursued their project work at RRCAT.

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

NPCIL consists of 11,748 strong and dedicated workforce with 3697 engineers and scientists, 6003 technical employees, 1623 non-technical executives and staff and 425 Auxiliary support staff. During the year, as a part of annual induction program of young talent to NPCIL, 3 Medical professionals, 71 direct recruits in scientific

categories and 33 direct recruits in the non-technical categories (Group A&B) were recruited through centralized recruitment process. During the year in the career progression front, 700 employees in Scientific and Technical categories and 162 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 has proved very successful and instrumental in improving the production by boosting morale of employees and executives. In addition to this, a good award scheme for encouraging employee to work toward achievement of organizational goals in efficient and effective manner is in place in NPCIL.

Sixteen Post M.Sc students were inducted into the research & teaching program of SINP during the year 2014-15. About 10 undergraduate associates and 30 students from different parts of the country for the summer program are being trained in the Institute.

The Institute of Physics (IoP) contributed in a significant way towards quality human resource development in the form of one year pre-doctoral course followed by Ph.D. program. Nine Post-Doctoral Fellows joined the Institute in the year 2014-15. Further, this year six doctoral scholars received their Ph.D. degrees, while eight scholars joined the pre-doctoral programme. The Institute actively promoted interactions with colleges, universities, academic institutions and other National laboratories through visitor programmes, workshops, symposia and other academic events.

The faculty members at HRI attended several conferences both in India and abroad and also visited other institutes, universities, colleges and gave lectures on the latest activity in several areas of mathematics and theoretical physics. The members of the mathematics group also visited various schools and colleges in India to give lectures in the DST Inspire programs. The Department of Mathematics conducted the Summer Program in Mathematics (SPIM) for introducing basic mathematics in Master's level in an interesting way to the highly motivated undergraduates or the post graduates from various colleges and universities across India and other countries like Nepal and Cambodia.

During the year, TMC registered 110 Post Graduate Medical students (including super specialty) in various disciplines under TMH. Two new courses, one year diploma in Fusion Technology and M.Sc. in Clinical Research, (approved by HBNI) were initiated and admitted 10 students to the Fusion technology course. ACTREC inducted research scholars for its Ph.D. program (101 on-going Ph D research), provided short term/ summer training and conducted about 22 workshops, symposia, conferences and seminars on varied aspects of biology and cancer during the year. The centre also supported 185 graduate students from various colleges for their master's dissertation programs.

Administrative Training Institute

The Administrative Training Institute (ATI) continued the professional development of officials from various cadres working in Department of Atomic Energy, through a wide range of training programmes arranged specifically for them. There has been a steady growth in the number of courses being conducted and number of employees being covered. Till now 593 programmes covering over 16500 employees have been organized.

Earnest efforts were made to meet the current need of the training and tuning the delivery to cover topics of relevance using blend of methodologies appropriate to the audience.

110 programmes were organized during the year 2014-15. The additional programmes were conducted to meet the specific requirements that arose from time to time. Besides, Director/Deputy Secretary level Officers were nominated for the workshop on preparation of notes for the Cabinet/Cabinet Committees. Officers working in DAE were also sponsored for the long term and short term courses under the Domestic Funding of Foreign Training scheme of Department of Personnel and Training.

In order to align with the National Training Policy-"Training for All" a number of steps were taken. The strategy of "Training at Doorstep" on various subjects like RTI and Records Management, Ethics and Values in Administration, Works Procedure, Building Blocks for Professional Excellence, Workshop on Communication and Presentation Skills, Workshop on creativity for Innovation and Excellence, Workshop on Administrative Vigilance and Role IO/PO, Security Awareness programme, etc. was continued. Programmes were arranged at different localities like Kolkatta, Kalpakkam, Hyderabad, Bhuabneswar, Bangalore, Kota, Pazhakalyal, Mysore, Tuticorin, Shillong, etc. Large number of officers participated in the programmes.

Post retirement Life Management programmes were organised for employees who were due for retirement. These programmes included an Induction training programme for the newly recruited administrative staff, Assistant Security Officers and Security Guards; Domain Knowledge Series Workshops; Special workshop on 'Right to Information Act, 2005' with the support of Centre for Good Governance, Hyderabad; Capacity building Workshop for Prospective Deputationists to International Projects; Workshop on 'Assessing and Reviewing APAR' and Performance Related Incentive Scheme; Training Programmes for Scientific and Administrative Officers on Project Management at IIM, Ahmedabad, IIM, Kozhikode and IIT, Bombay, Mumbai; Workshop on 'Procurement CVC Guidelines, procurement procedure' for scientific officers and Senior Administrative and Purchase Officers; Workshops on 'Soft Skills' for various target groups; Junior Executive Development Programme for Group B Officials at Mahatma Gandhi State Institute of Public Administration, Punjab and Training Programme on 'MS Project' for Scientific and Technical Officers

SPONSORED RESEARCH

Board of Research in Nuclear Sciences (BRNS)

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) 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. Current activities of the Board of Research in Fusion Sciences & Technology (BRFST) were included into the purview of BRNS by Constitution of Plasma & Fusion Research Committee (PFRC) under BRNS. This year web based processing was introduced with the launch of its own website, www.daebrns.gov.in.

During the year 2014-15, 250 new research projects were sanctioned till December 2014. In addition, BRNS also entered in three new MoUs for "Development, Production and Supply of microwave substrates for 750 W solid state amplifiers" with C-MET (Phase--II), Setting of "A 500 KeV Accelerator Mass Spectrometry facility with special emphasis on Cabon dating" at Mumbai university campus and "Development of a Photo injector based electron gun to produce electron beam of 5 MeV suitable for a free electron laser (FEL)" at IUAC, Delhi.

Under DAE Graduate Fellowship Scheme (DGFS), fellowship was offered/awarded to Fourteen M.Tech. students studying in 7 different IIT's & an NIIT. Nineteen new students were inducted under DGFS-Ph.D programme, bringing the total number of

Ph.D. students under this scheme to 87.

Financial support to the tune of Rs. 244 Lakh was extended for conducting 129 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. Eighty four fellowships were offered under the Raja Ramanna Fellowship Scheme (Senior Scientists Scheme) and seven Homi Bhabha Chairs were awarded.

Promotion of Mathematics

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 and were also provided scholarships & cash prizes.

This year six-member team secured 1 Silver medal and 3 Bronze medals at the 55th International Mathematical Olympiad held at Cape Town, South Africa.

This year onwards the Board has decided for the participation of two girls candidates in the European Girls' Mathematics Olympiad (EGMO).

NBHM conducted Madhava Mathematical Competition for the undergraduate students. The competition is 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 continued giving grants to various mathematical centers engaged in activities of promoting higher mathematics. The Chennai Mathematical Institute that runs a high quality undergraduate programme in mathematics was 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 grant 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. This year NBHM sponsored 47 delegates for participation in prestigious ICM 2014 event held in Seoul, South Korea.

NBHM continued to provide grants to mathematics libraries around the country, enabling them to purchase the latest books and journals in mathematics. Around 96 such libraries took advantage of this scheme of NBHM and updated their collection of Journals & Books in Mathematics. NBHM also distributed selected books to various postgraduate institutions under its book distribution scheme.

Financial support was provided to 57 national and international conferences held in India and 20 research projects. Travel grants were provided to 65 mathematicians to enable them to participate in conferences held in India and abroad. Two institutions were provided faculty support in the form of Visiting Professors to strengthen the research and teaching potential at the institutions. Post-Doctoral Fellowships were awarded to 45 (including the ongoing ones) researchers for the period of 3 years.

The new Web-based interactive system for communication, evaluation of proposals is ready for hoisting on suitable secured server. This will handle NBHM's Web traffic as per the requirements and it will also help researchers obtain the prompt response for their various applications for grants.

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 were undertaken between the Units and Aided Institutions and there was frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. The Department has nine aided institutions (TIFR, TMC, SINP, IOP, IMSc, HRI, IPR, AEES & NISER) 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. Homi Bhabha National Institute (HBNI), Mumbai has been granted the status of 'Aided Institution of DAE in February 2014.

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-₹ 560.91, TMC-₹ 534.50, SINP-₹ 105.28, IOP-₹ 35.08, IMSc,-₹ 53.33, HRI-₹ 36.96, IPR- ₹ 609.23, AEES-₹ 54.2 & NISER –₹ 95.45 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 (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 2014-15, an amount of ₹ 4.00 crore was released to the institute by the department.

The Department also extend financial assistance to Cancer hospitals located in other parts of the country. The budget provision for the year 2014-15 for such partial financial assistance was to the tune of ₹ 19.00 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 included 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 met 18 times till the period of report and 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.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

Private cloud computing service called "Megh" hosted on a cluster of 16 physical servers interconnected by a Gigabit Ethernet network has been developed by BARC for their users which



Megh Cloud Computing Cluster Servers

delivers computer resources such as servers, storage space and software as a "service" over the network. Development of a software tool for the functional verification of hardware designs created in Very High Speed Integrated Circuit (VHSIC) hardware Description Language (VHDL) has been completed. It supports Property Specification Language (PSL) for the specification and VHDL as the input model language.

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Two private cloud has been setup to host the IT services at VECC. At one end, the developed Storage-as-a-Service helps academicians, scientists and engineers to efficiently collaborate by using an e-briefcase service hosted via storage cloud. On the other end, Infrastructure-as-a-Service enables IT manager to efficiently utilize the resources.

The storage cloud called 'Annapurna' has been developed by using the technologies such as Gluster, and open-source software ownCloud. Gluster unifies different storages while ownCloud gives an access to the data via web and/or desktop/mobile client. Common users are able to create, store and share their files securely using this service and research teams can collaborate better utilising its features such as version control, data syncing, calendar service etc. The system has been commissioned and is running satisfactorily for the past several months.

The infrastructure cloud called 'Meghraj' has been developed with the technologies such as Gluster and open-source cloud building software, OpenNebula. The Gluster unifies the different storages and OpenNebula combines all the computing and memory resources using visualization technologies. Advanced features such as high-availability have been incorporated for critical IT services. The Meghraj has been deployed and tested satisfactorily in October 2014. A few Intranet services are being hosted via the cloud. Currently, the system is going through security testing and will be released to users around March 2015.

A centralised SMS-based notification system has been developed for various services of the Centre. Using this system on one hand, information of allotted vehicle, driver etc. are notified and on the other hand this system sends alarm SMS to the designated persons, the occurrence of abnormal environmental condition inside VECC computer hall and failure/restoration of input power line of multiple UPSs feeding power to different servers.

Various IT-enabled services have been developed by Computer Division, VECC to cater to the internal need of the Centre. Web-based services such as Online Annual Performance Appraisal Report (APAR) Management System, Online Immovable Property Return (IPR) Management System and Online Promotion Proposal Generation System have been developed to facilitate users in electronic submission, acceptance and record keeping of various official documents for administrative purposes.

TLD (Thermo Luminescent Dosimetry) Unit of Bhabha Atomic Research Centre (BARC) at VECC has developed a safe, secure and easy-to-use database system for maintaining all the records of this unit and provision has been made to generate various reports like printing wrapper of card, TLD 5 form and covering note etc.

Server virtualization which allows multiple operating systems (OS) to run on a single physical server which acts as a number of virtual machines where each of the OSs has access to the computing resources of the server has been implemented in VECC. This has resulted in reduction of space, power, cooling and financial overhead of maintaining VECC data centre.

VECC has achieved significant progress in the development of RFID-based Automatic Key Management System in collaboration with M/s Webel Mediatronics Limited, Kolkata. In this system, keys are normally held in mechanically locked condition in the key modules so that no unauthorised person can get access to them. Access to a specific key is granted to the respective authorised employee only after his successful authentication through RFID-based identity card by the system. All the major electronic and mechanical components of this system like RFID reader module, central control electronics, key modules etc. have been developed and tested separately for their intended function. Required software for user interface and backend database has also been developed and successfully tested with hardware. Development of a full prototype of the production grade version of the system with integration of all components is under progress.

CHAPTER-7

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES



Nanocomposite Ultrafiltration Membrane based domestic water purifier technology developed by BARC



Roof Top Solar Thermal Test Facility developed by BARC

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES

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 were transferred to industries.

DAE organizations also entered into scientific collaborations with public and private sector organizations. This interaction had given beneficiary organizations a technological edge.

TECHNOLOGY TRANSFER

Fourteen technologies were transferred by BARC till December 2014. Six new technologies introduced into public domain were Robotic system for stacking objects using machine vision, ChemoMechanical Magneto Rheological Finishing (CMMRF) Machine, Body Composition Analyser, Handheld 12-Channel Tele –ECG instrument, CsI:Tl single Crystal growth system & radiation detector fabrication and Nanocomposite DW. Technology of solar Photo-Voltaic BWRO was transferred to 4 entrepreneurs. Four technologies for which Licenses were renewed were "Boron Carbide" technology to M/s Bhukhanvala Industries Pvt. Ltd., Mumbai; "FDK-Fluoride Detection Kit for Ground Water" technology to M/s Orlab Instruments Pvt Ltd., Hyderabad; "Particle Aerodynamic Size Separator (PASS)" technology to M/s Electronic Enterprises (India) Pvt. Ltd, Mumbai and "Dust & Airline respirator" technology to M/s Sheth & Co., Mumbai.

A technology marketing agreement was signed with M/S CSIR-Tech Pvt. Ltd. Pune. BARC technologies posters were displayed in XXVI International Symposium on Discharges and Electrical Installation in Vacuum, Nehru Centre, Worli, Mumbai during October 2014; Global R&D Summit 2014, The Lalit, New Delhi during November 2014 and Symposium on Advances in Control & Instrumentation- 2014, NPCIL NUB Auditorium, Mumbai during November 2014. The field meetings with officials were carried out with RAPS for setting up of DAE Technology Display and Dissemination (DTDD) Centre at RR site, Rajasthan; KAPS, Gujarat Site for setting up of DAE Technology Display and Dissemination (DTDD) Centre at KAPS, Gujarat and Director General of Military Operations (DGMO), South Block, New Delhi in November 2014 regarding BARC's technologies suitable for rural areas and its implementation through Operation Sadbhavana.

The technology of a "production" variant LED based Uranium Analyser was transferred to ECIL in an agreement signed between ECIL and RRCAT in December 2014. Laser based Land Leveler technology developed by RRCAT was provided to Rural Human & Resource Development Facility RHRDF, SVERI, Pandharpur, Maharashtra.

COLLABORATIVE PROGRAMMES

RRCAT signed a MoU with IIT, Indore in July 2014 to enhance collaborative research and academic/teaching interaction in areas of mutual interest and also made available scientific infrastructure at RRCAT to the faculty and students of IIT. A MoU signed between RRCAT and Devi Ahilya Vishwa Vidyalaya (DAVV) was extended for another 5 years. This allowed students from DAVV to do their Project work and also allowed RRCAT scientists to pursue any study courses with DAVV.

For the collaborative programmes, a MoU was signed between IPR and Central Leather Research Institute (CLRI), Chennai, a CSIR lab; in September 2014. The objective is to carry out study on disposal of solid waste generated in leather industry.

SOCIETAL INITIATIVES

Four more AKRUTI agreements were signed with Companies/Organisations and Individuals by BARC during the year. As part of DAE Outreach Centre (DAE-ORC), Two AKRUTI centres were set up in two villages in Sholapur district. Mobile exhibitions as well as stall for DAE technologies were put up. Seventeen farmers from eleven villages participated in a demonstration of BARC developed Groundnut variety. Awareness camps about Soil organic Carbon testing kit were organized in 13 villages for about 285 farmers. The facility required for production and training of domestic water purifier manufacturing was developed. A workshop for FSD/VTD fabrication has been developed.

CHAPTER-7

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 2014, three DAE-IPR cell meetings were held. Eight new inventions and one national phase entry were reviewed for the patentability. DAE filed eleven new patent applications which included one application under PCT (Patent Co-operation Treaty), seven Indian, two Australian and one USA application.

During the year, ten of the previously filed patents were granted to the Department. All the ten patents granted were in foreign countries. These included three each in USA & Japan, two in Europe and one each in Canada & China. Following are the list of patents granted:

1. A flexible magnetic membrane based actuation system and devices involving the same – by BARC (in Europe)
2. Dialkyldiaza-tetraalkyl acetone diamide derivatives useful for the separation of trivalent actinide from lanthanide and process for the preparation thereof – by BARC (in USA, Japan & China)
3. A Method of qualifying Niobium and/or other super conducting materials for reliable fabrication of Superconducting Radio Frequency (SCRF) Cavities – by RRCAT (in USA)
4. Non-ionic, porous, solid resin with chemically bonded crown ether – by IGCAR (in Europe)
5. Single stage purification for uranium refining – by BARC (in Canada)
6. Stabilized natural circulation system with Nano particles – by BARC (in Japan)
7. A polymer composite for extracting cesium from Nuclear waste and / or other inorganic wastes / solutions – by BARC (in USA)
8. Niobium based superconducting radiofrequency (SCRF) cavities comprising niobium components joined by laser welding – by RRCAT (in Japan)

During the year, 125 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 57th BARC Training School. A one day Intellectual Property Awareness program was conducted for scientists in BARC & other DAE units in Mumbai under the ages of Administrative Training Institute.

CHAPTER-8

INFRASTRUCTURE



Medical Cyclotron building at VECC, Kolkata



Creche building at Anupuram Township, Kalpakkam

CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible to provide infrastructure support to various Units of 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 report period, Computer & Information Centre Building at VECC, Kolkata; Medical Cyclotron building, Chakgoria, VECC, Kolkata; Training school core library, hostel, dining /multipurpose hall and quarters for AMD, Hyderabad; RIB lab VECC Kolkata; Creche facility for employees children at Anushaktinagar, Mumbai; Development works such as roads, storm water drains, retaining walls external sewerage system and water supply mains for CISF housing in Western sector, Anushaktinagar, Mumbai were completed.



Core library at AMD, Hyderabad

DCSEM has also completed the Construction of Computer Centre and Computer Science & Engineering Complex for IIT-B Powai, Mumbai; Construction of UG water tank with dry well pump and pump house for VECC at Rajarhat, Kolkata and Upgradation of substation 5 & 6 works at Anushaktinagar, Mumbai.

Prequalification of agencies for 100 bedded hospital and Ancillary bldg. for TMC at Vishakhapatanam was refloated after issue of work order to agency which failed to start the work. Prequalification of agencies for the construction of



Internal (left) and external (right) view of computer centre IIT, Mumbai

312 flats for type V-E at Anushaktinagar and Hostel for TIFR at Colaba, Mumbai were under process.

Various works of DCSEM at Anushaktinagar, Mumbai under progress included the Convention Centre/Sr. Officers Guest House and Administrative Training Institute Complex; Restoration/Renovation of Old Houses more than 20 years old Phase-I; Up gradation of services under 12th plan; Construction of 356 nos. residential quarters; Hostel for trainees of BARC/HBNI Phase- I; Construction of Extension of V.S.Bhavan and Approach road for Convention Centre, Anushaktinagar at Mumbai.

Major construction works of other units/ Autonomous units under progress were First Research and Technical (FReT) Block for TIFR, Hyderabad; Construction of Facilities for Research in experimental Nuclear Astrophysics (FRENA) laboratories for SINP at Bidhannagar Kolkata; Core Library, Training school with Hostel, staff quarters for Atomic Mineral Directorate (AMD) at Hyderabad; UG water tank of 100 KL capacity with pump house & RCC ESR of 75 KL capacity at AMD Cherlapally, Hyderabad; Academic Block and residential quarters along with infrastructure facility for ICTS (International Centre for Theoretical Sciences) of TIFR , Hessarghatta, Bengaluru; Academic Township, Sports complex & Residential Township for NISER, at Bhubaneswar; Building for Fission based ^{99}Mo Production facility for BRIT adjacent to ISOMED in BARC and Blower building for Medical Cyclotron Project VECC Kolkata.

The major work order issued during the report period included the works relating to 100 bedded hospital and Ancillary building for TMC at Vishakhapatinam; Hostel for trainees of BARC/HBNI Phase- II; Renovation of houses for internal finishes at Anushaktinagar, Mumbai; Phase-I construction of GCNEP including residential building and Guest

house along with associated Electrical works at Kheri Jassaur near Bahadurgarh, Haryana.

Engineering Services Division of DCSEM maintained residential flats (10169nos.) and public buildings of the Department in Mumbai including execution of up-gradation works required for the buildings. DCSEM also fulfilled the responsibility for the operation & maintenance as well as up-gradation of electrical power distribution, lifts, water supply, sewer lines, sewage treatment plant, firefighting system, rain water harvesting system and energy conservation of the services in the large township at Anushaktinagar, Mumbai

The Estate Management Section of DCSEM 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 year, schemes worth Rs. 348 Crores were executed for various DAE units and other departments including projects for DCSEM worth Rs. 130 Crores.

PURCHASE & STORES

The primary goal of the Directorate of Purchase and Stores (DPS) is to procure right material at right price from right source, storing the same and issue to various constituent Units of Department of Atomic Energy. 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. 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

As a systematic approach without compromising on Security aspects of data and activities of DAE, steps for creating infrastructure for implementation of end-to-end e-procurement was initiated. For this, a two part tender is in advanced stage of processing. Action for entering into an agreement with ECIL for providing support to enhance better handling of IT related activities was on for the purchase unit. For the stores unit, it is planned to have a fully integrated solution which will be available 24x7. Materials management System will help reduce substantial lead time for procurements and other services.

Procurement of Equipment from Domestic Manufacturers

Majority of user requirements were met from domestic manufacturers. Requirements over 25 lakhs were 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 web site as well as on Central Public Procurement portal. Import substitution activities were also considered to reduce dependence on import. In addition to the above, a policy for providing preference to domestically manufactured electronic goods in government procurement and due to security consideration as notified by the Department of Electronics & Information Technology, Ministry of Communications & Information Technology, Government of India, has been put in force.

Procurement of Equipment from Foreign Suppliers

Depending on value, certain equipment which were not available locally were imported from other countries by floating tenders. Help of Minister, Atomic Energy Wing, Embassy of India, Paris was sought for sourcing reliable suppliers abroad to meet specific requirements of DAE as well as arranging pre-despatch inspection, technical evaluation, etc.

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 has become pertinent. During the

year, 283.60 MT Tri Uranium Oct-oxide were imported from M/s NAC Kazatomprom, Kazakhstan. 296.45 MT Natural Uranium Dioxide Fuel Pellets were imported from TVEL, Russia.

GENERAL SERVICES ORGANISATION

General Services Organisation, Kalpakkam takes care of the common facilities such as Housing, Medical services, Office transport services, Water supply, Solid waste collection and disposal and all maintenance activities in the Atomic Energy Townships at Kalpakkam and Anupuram which cater to the needs of various DAE Organisations located at Kalpakkam Viz. IGCAR, MAPS, BARCF and BHAVINI. GSO also provides administrative support to various common advisory committees constituted by Kalpakkam Management Committee (KMC).

GSO provides infrastructural facilities and administrative support to Kendriya Vidyalayas, Atomic Energy Central Schools and Atomic Energy Central Higher Secondary School. Infrastructure support was provided to Nuclear Employees Sports and Cultural Organization. All Departmental administrative work relating to Kalpakkam Nuclear Installation Local Authority (KNILA) was carried out by GSO.

The Civil Engineering Division of GSO took care of the construction and maintenance of the residential quarters for the employees and office buildings. Its other activities included maintenance of roads, water treatment plant, sewage treatment plant and horticulture. The Electrical and Telecommunication Section provided and maintained uninterrupted power supply to all the quarters and buildings. It also carried out the operation and maintenance of the electronic Telephone Exchange. The Mechanical Section handled the two Water Treatment Plants and two Sewage Treatment Plants, one each at the two townships and also looked after industrial safety, fire safety, air conditioning and Autoshop activities. Computerization of activities and providing hardware, software and networking support to office and public buildings were done by the Computer Section.

Medical needs of DAE, NPCIL, BHAVINI and AEES employees and their family members covered under Contributory Health Service Scheme were looked after by the DAE Hospital at GSO,Kalpakkam.

General Services Organization (GSO) attends to liaison works with State Government Departments for supply of water and with BSNL for telecommunication network to the Township.

All the activities of GSO are supported by Administration and Accounts who also look after Personnel Management, Estate Management, Recruitment, Transportation etc. Some of the significant achievements during the year 2014-15 include:

Civil Construction

The Architectural and Structural Wing carried out in-house architectural & structural engineering design for various construction works that were initiated during the year. The Estimate & Contract Wing carried out all preliminary procedures for processing of tenders and release of work orders. E-Tendering process has been started for the works costing Rs. 1 Crores and above. Nine NITs were released through e-tender mode during this year. The Construction team completed the construction of the "Fencing over compound wall for Augmentation of Security System" and the "Crèche Building at Anupuram Township". The Structural Works for one



Efficiency Apartments – Tower Block-1, Kalpakkam

block of Efficiency Plus apartments was completed and one sample apartments was made ready with all the proposed finishing.

Electrical & Telecommunication

Some of the major works completed included introduction of LED street lights in both townships; installation of 10 KW solar panels (1 on grid & 1 off grid); installation testing and commissioning of 62.5 KVA DG set; testing & commissioning of MSS2 substation 11 KV switchgear and 1.5 MVA transformers; installation testing and commissioning of two 750 KVA transformers; AMF panel; 11 KV VCB panel; procurement, installation testing and commissioning of 1 No 180 KVA and 1 No 250 KVA DG sets and introduction of fire alarm system at both Townships.

Mechanical

Design of Wet riser fire hydrant system was carried out along with external ring main as per the guidelines given in National Building Code (NBC) for three tower blocks. Variable Refrigerant Flow (VRF) Air- conditioning system of 28 HP capacity was installed, tested and commissioned for various facilities like Library, Server room, Office room etc. in JRS Mess block at DAE Township Kalpakkam. E-Bike Test facility was made ready in-house for the diagnosis of E-Bikes at Autoshop.

Computer

The Wide Area Network connectivity between the two townships was utilized to provide internet connectivity to offices in Anupuram Township through NKN facility available at the Kalpakkam Township. Local Area Network was established in DAE Guest House at Kalpakkam and internet facility has been provided in all rooms. Online "Complaints Management System" was developed to enable the residents to register and view the status of Civil and Electrical maintenance complaints. The Hospital Information System was successfully implemented. E-Tendering was introduced and successfully used for major Civil & Electrical Works. The Online-APAR system was upgraded to include online assessment by Reporting Officers. The GSO Campus Network was disconnected from the IGCAR Campus Network.

Quality Circle

Sixteen Quality Circles participated in the event 3rd GSO QCAM meet in 2014. Judges from QCFI, Chennai Chapter evaluated the Case Studies and Presentations. Five Trophies namely, VISVESWARAYA, JAMES WATT, EDSION, CHANAKYA, SUSHRUTHA were awarded to KURUNJI QC, SAKTHI QC, ELECTRON QC, SARATHY QC and Dr. HAR GOBIND KURANA QC respectively. The SAKTHI QC and ELECTRON QC represented the Unit at the Regional Meet and were awarded the GOLD and SILVER trophy respectively. The SAKTHI QC was nominated for the National Meet at Kolkata and was adjudged as "PAR EXCELLENT"



SAKTHI QC Team with the Par-Excellence Trophy at the National Convention on Quality Concepts

CHAPTER-9

PUBLIC SECTOR UNDERTAKINGS

(FINANCIAL PERFORMANCE)



Control Room of Prototype Fast Breeder Reactor (PFBR)



MACE Telescope

PUBLIC SECTOR UNDERTAKINGS
(FINANCIAL PERFORMANCE)

Financial performance of DAE's public sector undertakings namely, the Nuclear Power Corporation of India Ltd., Uranium Corporation of India Ltd., Indian Rare Earth Ltd. and Electronics Corporation of India Ltd. are given below. (BHAVINI is yet to commence commercial operations). 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 projected net Profit After Tax (PAT) for the year 2014-15 is about ₹ 2000 crore. The net profit after tax for previous financial year 2013-14 was ₹ 2299 crore. The NPCIL bonds were 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 2013-14 was satisfying. The total income of the Company during the year 2013-14 was ₹ 814.2 Cr. The Company's profit before tax during the year 2013-14 was ₹ 16.32 Cr. Performance of the Company in terms of MoU signed with DAE was rated as "Very Good" during 2013-14.

INDIAN RARE EARTHS LTD.

During the year 2014-15 the Sales Turnover was ₹ 379.29 crore (provisional) against ₹ 413.44 crore of previous year. Profit Before Tax in 2014-15 is ₹13.14 crore (provisional) compared to ₹71.77 crore in 2013-14.

The fall in revenue for 2014-15 was mainly on account of the extensive damage to OSCOM Plant due to cyclone Phailin which resulted in production losses and deferment of shipments which were effected from Vizag Port in place of Gopalpur Port. In addition to the above, non-lifting of Zircon earmarked for NFC from Manavalakuirchi, mandatory MDCC & licensing for customers sourcing minerals from OSCOM Unit by Odisha Government, levy of Excise Duty on major minerals of IREL and buyers preferring to source material from competitors to ensure supply security were other major contributors for dip in revenue.

Besides the above, certain delay in obtaining necessary statutory clearances which were beyond the normal managerial control, literally no production from Chavara due to prevailing socio political conditions in and around, delay in production at Monazite Processing Plant (MoPP) and being non-committal on supply security due to inconsistent production have also attributed to fall in revenue. Depressed demand of titanium feedstock and titanium dioxide pigment globally due to reliance of Chinese industries on local feedstock and accumulation of high level of inventory were attributed to reduction of prices in international market and were partially responsible for fall in revenue.

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 secto₹ 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 and academic institutions. The linkages with DAE laboratories have enabled ECIL to provide indigenous solutions for electronic equipment. ECIL has emerged as a major player in providing integrated security solutions to the vital installations in the country.

ECIL is also a key partner in the implementation of National Population Register (NPR) project of the Government of India. The company also played an important role in the General Elections with the Electronic Voting Machines (EVM) and the Voter Verifiable Paper Audit Trail (VVPAT) printers which were extensively used. The EVMs are

also being deployed by the states in the elections for local bodies and cooperative societies.

Performance

Against the target of ₹ 1800 crore each for production and net sales, the company achieved a production of ₹ 737 crore and a net sale of ₹ 767 crore upto December 2014.

The sector-wise significant achievements during the year 2014-15 are as follows:

Atomic Energy Sector

- Control and Instrumentation and SCADA systems for nuclear power plants including PFBR and associated facilities
- Control and Instrumentation systems for Advanced Technology Vessel Project of BARC
- High Voltage Power Supplies for ITER program
- Radiation Detection Equipment for seaports

Defence Sector

- Communication Radios
- C4I systems for Akash and BrahMos missile programs
- Equipment for secure communication

Defence Sector

- Communication Radios
- C4I systems for Akash and BrahMos missile programs
- Equipment for secure communication

Aerospace Sector

- Integrated Communication Systems Network
- MACE Telescope
- Antennas for aerospace and defence applications



MACE Telescope



Control Room at Prototype Fast Breeder Reactor (PFBR)



Radiation Detection Equipment at Jawaharlal Nehru Port Trust, Mumbai



Pramanika smart card reader

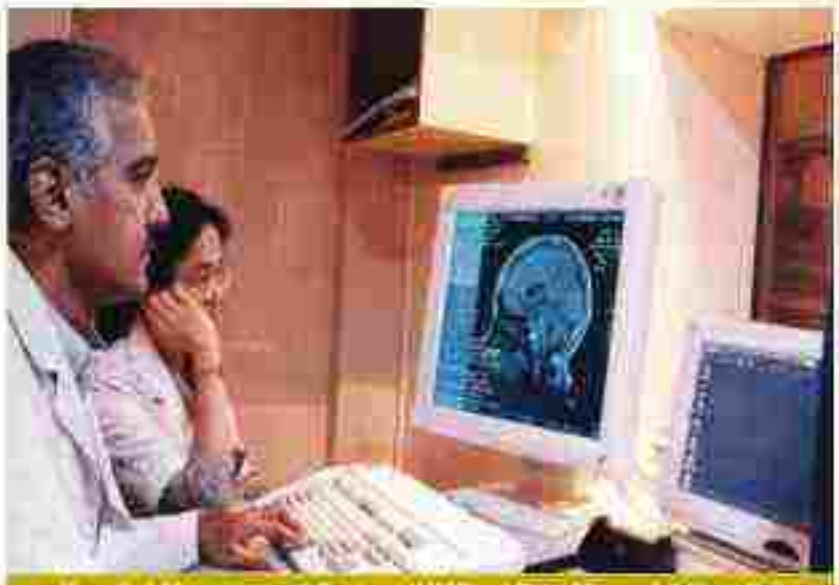

Vehicle mounted Jammer

Security Sector

- Video Surveillance Systems for strategic installations
- Mobile Container Scanning Systems
- Communication Jammers
- Information Security Equipment

Other Sectors

- Electronic Voting Machines for the General Elections 2014 and State Local Body elections
- Supervisory Control and Data Acquisition Systems for oil and gas pipelines
- Hospital Management System


Hospital Management System (HMS) at Tata Memorial Hospital

Research & Development

The in-house R&D programme is guided and supported by the Technology Development Council (TDC) leading to several new products and enhancements being introduced into the market. Currently the work is going on in the areas of High Temperature Fission Counters, Continuous Air Monitors, Portal Monitoring Systems, Iodine and Particulate Monitors, Integrated Search and Direction Finding Systems, Explosives detectors and encryption systems for mobile handsets.

New Products Introduced

Several new products introduced during the year were as follows:

- Weather Radar System
- Smart Energy Meters
- Secure mobile communication systems
- Ultra stable Power Converters
- Long stroke length LVDTs
- Actuators for missile programs

Quality Management Systems

Surveillance and recertification audits for ISO 9001:2008 have been completed in the applicable divisions. Surveillance audits for ISO 14001 Environment Management System and BS OHSAS 18001 have also been completed.

Tie-ups and Agreements

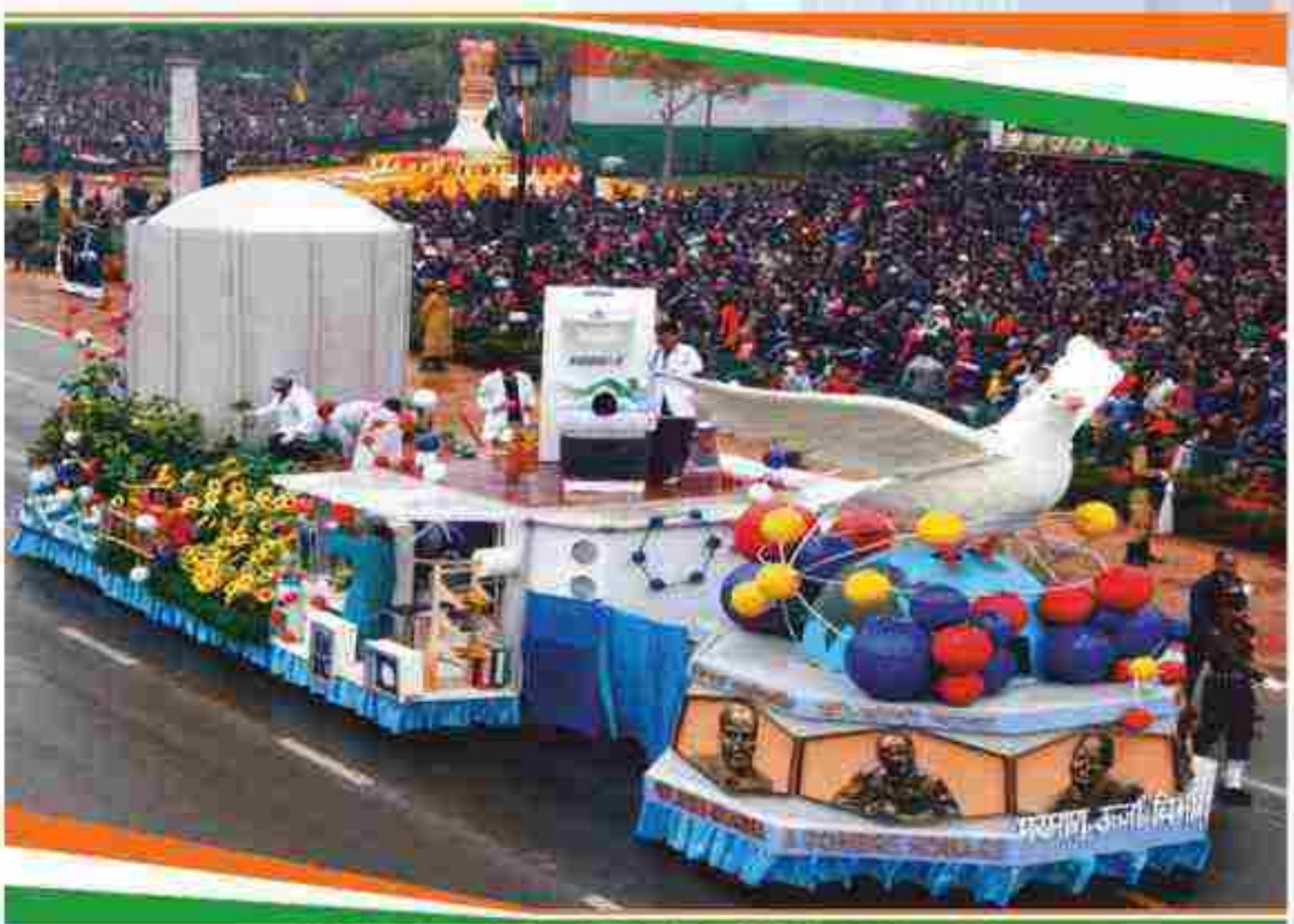
The company has entered into agreements with C-DoT for transfer of technology for manufacture and supply of MAX-NG Migration, Terabit Router (TBR) and Broad Band Wireless Terminal (BBWT).

The company has entered into a Memorandum of Understanding (MoU) with SAMEER, Kolkata for design, development and production of radio frequency sub-systems for Missile and Airborne Radar Systems.

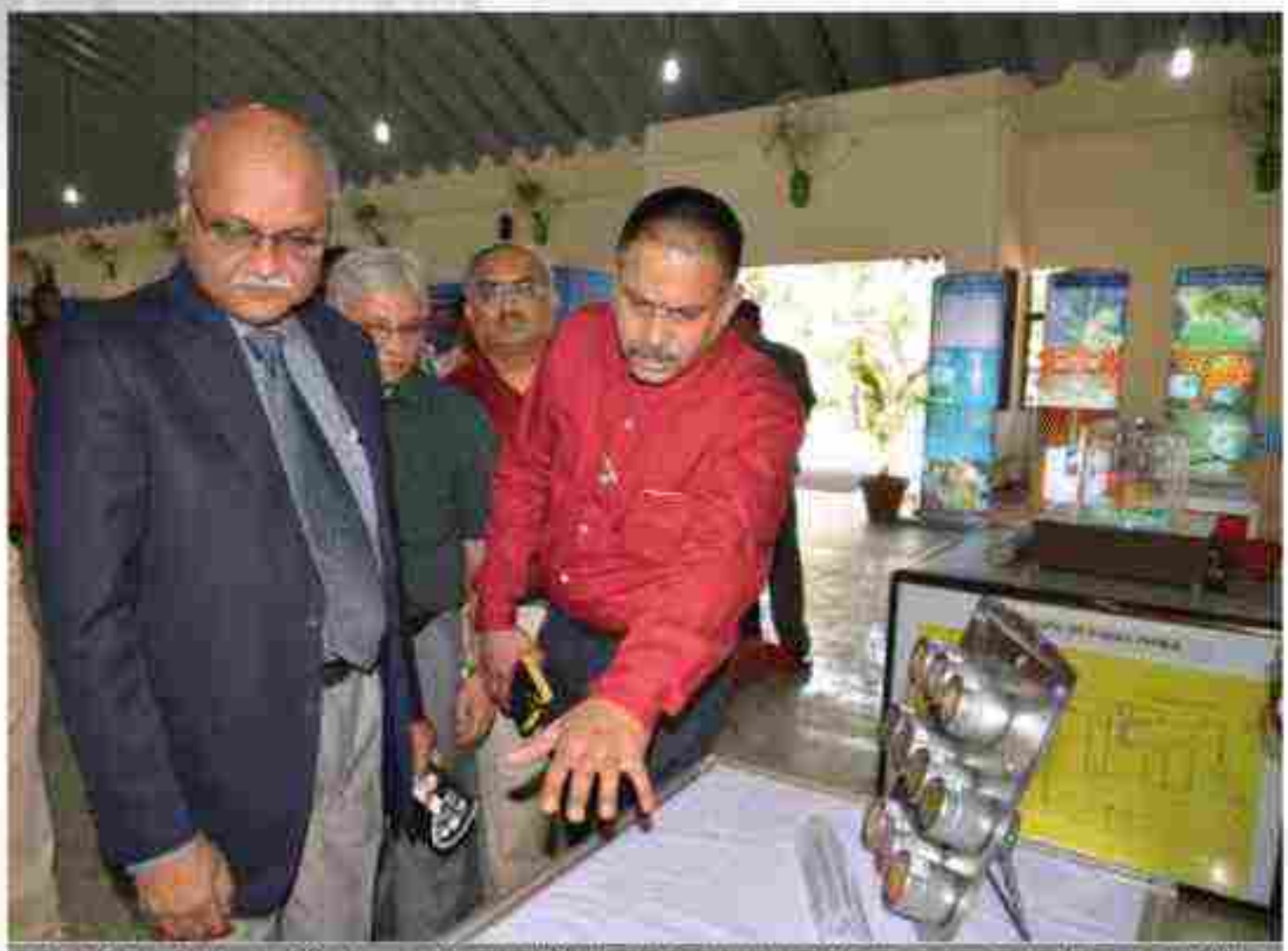
The company has also entered into a Memorandum of Understanding (MoU) with C-DAC for Transfer of Technology for iRose SCADA software as well as for manufacture of Phasor Measurement Units.

CHAPTER-10

OTHER ACTIVITIES



UAE Tableau in the 66th Republic Day Parade 2015 at Rajpath, New Delhi



Dr R K Sinha, Chairman AEC along with Director NSC, Mumbai (center)at the DAE pavilion during The Science Expo 2015

NATIONAL SECURITY

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

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 preparedness & response systems are in place and are tested regularly to ensure their effectiveness. All these activities are overseen by an independent regulatory authority, which ensures that all radiological safety issues are adequately addressed. Further, in case an unlikely event occurs and leads to a radiation emergency in the public domain, a response system is in place to tackle such situations with mobilization of the experts of the Department of Atomic Energy in the field of radiation measurement & 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 disaster 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 to provide necessary guidance on matters related to radiological safety in the public domain to prevent the recurrence of any 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 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, CMG Members, Key Officials at Mumbai & Delhi, Resource groups of DAE, NDMA, MHA Control Room as well as with the Incident & Emergency Centre (IEC) of International Atomic Energy Agency (IAEA) at Vienna.

India is party to the 'Convention on Early Notification of a Nuclear Accident' and the 'Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency'. India participated in ConvEx-2a & ConvEx-2b exercises conducted in the year 2014 and could successfully demonstrate its capabilities of meeting convention requirements.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and hydrogen sulphide based heavy water plants periodically carry out a variety of emergency exercises. The number of exercises carried out during the year 2014 were Communication Exercises – 412 nos., Fire Emergency Exercises – 65 nos., Plant Emergency Exercises – 48 nos., On-Site Emergency Exercises – 16 nos. and Off-Site Emergency Exercises – 2 nos.

During the year, a "National Workshop on Transportation of Radioactive Material" was organized by CMG which provided a platform to the relevant safety & security experts to share their experiences.

CHAPTER-10

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 designated member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA) since its inception, continued to take active part in policy management and programmes of IAEA. India was represented on a number of IAEA committees, including those on safety, safeguards, nuclear radiation, nuclear engineering & application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings and offered the services of its experts under the IAEA Technical Cooperation Scheme 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. Besides, India has also made contribution to Indian Pugwash Society for its research & development activities.

In addition to participation in the annual General Conference of the IAEA in September, 2014, India was represented in the meeting of Sherpas and Nuclear Security Summit in the Hague (Netherlands, March 2014), the Global Centre for Nuclear Energy Partnership (GCNEP) working Group Meeting with the US National Nuclear Security Administration (Washington, USA, April 2014), Indo-US Civil Nuclear Energy Working Group Meeting at Idaho National Laboratory (Washington, USA – July 2014), and Joint Collaborative Meeting (Canada, Nov 2014). India remained involved with nuclear security issues within the Nuclear Security Summit process and the Global Initiative to Combating Nuclear Terrorism.

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

Intensive discussions under the existing bilateral Inter-Governmental Agreements on cooperation in the peaceful uses of nuclear energy took place with major partner countries. These resulted in signing of an Inter-Governmental agreement with Australia for co-operation in the peaceful uses of Nuclear Energy on 5th September, 2014 and finalization of the text of the Administrative Arrangement with the United States pursuant to India-U.S. Civil Nuclear Co-operation Agreement signed on 10th October, 2008. In addition, India and Russia signed a "Strategic Vision for Strengthening Co-operation in Peaceful Uses of Atomic Energy" on 11th December, 2014. An agreement for co-operation with the Radiation & Nuclear Safety Authority of Finland was also signed on 15th of October, 2014 by Atomic Energy Regulatory Board.

Pursuant to the "Separation Plan" issued by India in 2008 voluntarily identifying the civilian facilities open for international collaboration and available for the International Atomic Energy Agency (IAEA) safeguards, the Department of Atomic Energy notified the IAEA about placing the Narora Atomic Power Station Units-1&2 under IAEA safeguards in accordance with the India Specific Safeguards Agreement signed between India and the IAEA in 2009. With this, India has fulfilled its commitment to place voluntarily 14 of its nuclear power reactors under the Separation Plan before the end of 2014.

Global Centre for Nuclear Energy Partnership (GCNEP) is being set up to enable India 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 various 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 forensic and Establishing accreditation facilities for radiation monitoring.

The Directorate of Construction Services & Estate Management (DCSEM) of DAE is responsible for the construction of GCNEP centre. Two plots of land approximately 130 Acre for the 'Campus' & 105 Acres for the 'Township' at Kheri Jasaur, Bahadurgarh, District Jhajjar, Haryana have been acquired for the purpose.

The land acquisition for the centre has been completed and the master plan of the institute is ready. Boundary wall construction has been completed along both the institutional as well as the residential campus. The Foundation Plaque for the Institute was unveiled on 3rd January, 2014 by the then Prime Minister of India Dr. Manmohan Singh. The contract for Phase-I construction has been finalized and the Environment Clearance has been received.

Even as the permanent infrastructure is being built, GCNEP has been conducting national and international training programs. GCNEP hosts trainees & visiting faculties from India and abroad as a part of collaborative research. National and international conferences, seminars & workshops are a regular feature of the centre. During the year, eleven training programs/symposium/ workshops were conducted under the aegis of GCNEP.

NPCIL is a member of various international organizations viz. World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), World Nuclear Association (WNA), Institute of Nuclear Power Operation (INPO) etc. NPCIL continued to participate 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. NPCIL representatives are in the governing board of WANO Tokyo and Moscow centres. During the year WANO Peer Review of NAPS and WANO Follow-up reviews of KGS-3&4 and RAPS-5&6 were carried out. Further, WANO Peer Reviews of RAPS-2 and TAPS-3&4 and WANO follow-up review of MAPS are planned during January to March 2015. WANO organized three Technical Support Missions (TSMs) on different topics at NPCIL stations. Two 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 KGS-3&4 visited Bruce



Group photograph on the occasion of unveiling of GCNEP Plaque

NPP in Canada under WANO's Benchmarking programme. Many experts from NPCIL participated in the peer reviews and corporate peer reviews of overseas NPPs/other WANO members. WANO Operating Experience Caravan was held at NAPS and Rajasthan Rawatbhata Site. Further a WANO team carried out special Significant Operating Experience Report (SOER) review of RAPS-5&6. Corporate Peer Review of NPCIL by WANO is planned during 25 May to 5 June 2015. This will be the first such review of NPCIL. To familiarize NPCIL about WANO CPR, a Training Programme was organized at HQ by WANO.

NPCIL participated in some of the COG meetings held through video conference. In addition COG representative visited NPCIL and discussed issues of mutual cooperation. One expert participated in a COG workshop held in Canada. The cooperation with COG is presently limited to Operating Experience sharing.

NPCIL held a meeting with INPO representative to discuss enhanced cooperation. Several persons at NPCIL stations and HQ were provided access to INPO website and access to high value operating experience documents.

Many personnel 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. Some of the representatives from NPCIL are the members in WNA Working Groups.

MANAGEMENT SERVICES

MSG provides and manages Information Technology facilities in DAE headquarters. During the year, MSG executed plans to upgrade the client systems providing state of the art systems with pre-installed software for office applications. Office Procedure applications running on networks were upgraded to meet the requirements of increase in volume of data as well as software obsolescence. Network uptime was near 100% enabled through provision of adequate redundancies in systems and network facilities.

MSG is part of the Task Force for development of a DAE wide Integrated Management Information System. This ambitious application will integrate databases of all DAE and its constituent Units in the area of human resources, finance and accounts, information banks, project monitoring and security data. The application will provide sophisticated views and analysis to support decision making. A prototype of the application is ready with test data, after testing phase-1 of the application is expected to be rolled out in April 2015. This application will be available to top management of all the DAE units across the country through DAE's wide area network Anunet.

MSG coordinated 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. All DAE units conduct quarterly IT security audits and submit reports to MSG. Through this, network vulnerabilities (if any) are attended immediately to prevent any breach. It also ensures compliance of the IT security guidelines issued by CISAG as well as Government of India Security policies. In December 2014, MSG coordinated the participation of three DAE units in Cyber Security drills conducted by CERT-In. Performance of the Units in the Drill was rated as excellent.

MSG continued to maintain the DAE's web site. It has links to all DAE and its constituent units. DAE's website is a repository of information which provided access to parliament question and answers, press releases, acts, rules, agreements, orders, publications, achievements of the department and access to downloadable forms for the benefit of the public.

MSG also managed various applications relating to administration and accounts activities in DAE Secretariat. MSG operated a helpdesk in DAE Secretariat which enabled delivery of all IT services to the users.

VIGILANCE

The overall responsibility for vigilance in any unit of DAE rests with its Vigilance Officer/Chief Vigilance Officer (CVO). To ensure effective

functioning of the vigilance machinery a senior officer in each of the Constituent Unit and Aided Institution of the Department has been designated as Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time CVOs discharge responsibilities.



Dr. R.K. Sinha, Chairman, AEC & Secretary, DAE administering pledge during Vigilance Awareness Week in October 2014

Vigilance functions include investigation of complaints, timely submission of various vigilance returns to the Central Vigilance Commission (CVC), Department of Personnel and Training (DoPT), Central Bureau of Investigation (CBI); issuance of vigilance clearances and sanctions for prosecution, processing of vigilance and disciplinary cases and monitoring of progress in inquiry in disciplinary proceedings and others. To sensitize all the employees in the Department on the various guidelines issued by CVC on procurement issues, a workshop on CVC guidelines on tendering procedure was organised by the Department for officers of all DAE units involved in procurement and tendering process.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week 2014" was observed in the Department of Atomic Energy, Mumbai from 27th October to 1st November 2014. The week commenced with administering pledge by The Secretary, Department of Atomic Energy to all officers and staff on October 27, 2014. During the "Vigilance Awareness Week", various competitions such as Quiz, Slogan Competition, Poster Competition, Essay writing competition were held where officials and staff of the Department actively participated. On December 31, 2014 Shri T.P. Singh, Chief Vigilance Officer, Central Railway delivered a talk on the theme "Combating Corruption-Technology as an enabler". The key note address was delivered by Dr. C.B.S. Venkataramana, Additional Secretary & Chief Vigilance Officer, DAE. The programme was well attended by staff and senior officers of the Department. Prizes for the winners in the competition were also distributed during the function held on December 31, 2014. Vigilance Awareness Week was also observed in the Constituent Units/ Public Sector Undertakings and Aided Institutions of the Department.

IGCAR also observed the Vigilance awareness Week-2014 with the theme "Combating corruption-Technology as an enabler". Various competitions were conducted and lectures on the theme were also arranged.

Vigilance awareness being one of the important parameter of good Corporate Governance, a number of initiatives were undertaken and innovative methods were adopted in spreading awareness and imparting knowledge to employees by NPCIL. The first edition of book on 'Vigilance for All' was published. Vigilance Awareness Week with the theme of 'Combating Corruption – Technology as an enabler' was observed in NPCIL headquarters in Mumbai and all the Units located outside Mumbai during the Week from 27th October to 1st November, 2014. A number of programmes viz. debate competitions, Seminars, Quiz competitions, etc. were organized during this period. A competition to communicate anti-corruption message through innovative short films was conducted at all the Units of NPCIL and the first prize winner film titled 'Jo Boya Wahi Paya' produced in-house by employees of NPCIL, headquarters was screened. CHETNA (Vol.13), an annual edition of vigilance magazine was



Release of CHETNA Annual edition of Vigilance Magazine by Shri K.P. Rajput, CVO, NPCIL (second from left)

released at NPCIL as a preventive vigilance measure and to spread vigilance awareness.

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:

DAE conducted 16th All India Rajbhasha Sammelan on 29th and 30th January, 2015 at Institute Of Plasma Research, Gandhi Nagar and organised various lectures and programmes during the course of the Sammelan. A souvenir in Hindi on the proceedings of the Sammelan was also brought out.

Under the Official Language Rule 10(4), 36 offices have been notified so far. The Parliamentary Committee on Official Language inspected AMD (Southern Region), Bangalore; RMP, Mysore; AMD (Western Region), Jaipur; NAPS, Bulandshahar and BARC, Mumbai.

DAE inspected TIFR, Baloon Facility, Hyderabad; TIFR, TCIS, Hyderabad ; VECC & SINP, Kolkata; AMD, Delhi & Hyderabad; NPCIL (Quality Assurance), Noida; NFC, Hyderabad; NRB, Mumbai; HWB, Mumbai; BARC, Mumbai; AEES, Mumbai and HRI, Allahabad. 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.

About 55 Seminars and 46 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, Agreements, MoUs and other documents furnished to the various Committees of the Parliament were prepared bilingually.

Around 2273 officers and employees were imparted training in Hindi noting and Drafting during Hindi Workshops. Total 910 officers and employees under the incentive scheme for doing original noting and drafting in Hindi, 93 Typists under the incentive scheme for Hindi Typing and 52 Stenographers under the incentive scheme for Hindi Stenography were awarded.

Training in Hindi, Hindi Typing and Hindi Stenography were given to 455 Officials, 27 Typists and 56 Stenographers respectively. Total 492 Officials, 53 Typists and 42 Stenographers underwent training in Hindi, Hindi Typing and Hindi Stenography respectively. About 382 Officials, 12 Typists and 14 Stenographers were given cash awards and other incentives for successfully passing Hindi, Hindi Typing and Hindi Stenography examinations. Hindi books worth Rs. 7,70,283/- were purchased.

Quarterly meetings of OLICs (Official Language Implementation Committee) 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 22 establishments have their Websites in bilingual form and these were updated regularly. Presently, there are 22,387 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. 34 House Magazines and 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. To encourage the officers/employees of NPCIL to do their official work in Hindi and allay their apprehensions regarding use of the language, 32 workshops were organized

during the year and 800 officers/employees were imparted training in these workshops. During the report period, total 96 Hindi monthly competitions were conducted to promote the use of official language which saw participation of over 1900 contestants.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

The Scientific Information Resource Centre (SIRC) of Public Awareness Division in DAE continued to provide library user services such as Circulation, News Clippings, Reference & Information, Reprography, etc. uninterruptedly. During the year, the centre enriched the resource collection by procuring new books, periodicals and other reading materials on topics of interest to DAE patrons. The Centre played an important role in executing and co-ordinating the printing, publication and dissemination of various public information literature such as 'Nuclear India', 'Parmanu', 'DAE Perspective', 'Atoms & Development' etc. Publication and printing of statutory documents such as 'Annual Report', 'Outcome Budget' and internal publications such as 'Cyber-Diligence', 'Accounts at a Glance', 'DAE Diary', "CVC-Guidelines on Tenders", "DAE Essay Contest Announcement" etc. were also executed by the Centre.

The Scientific Information Resource facility of BARC continued to provide seamless access of information to scientists and engineers with a large number of online and print journals, databases and standards useful for various R & D activities. The library at present has a collection of about 5000 books and about 2100 alternate forms of materials such as BARC Reports, NPCIL Design Manuals, floppy disks, Compiled Study materials, etc.

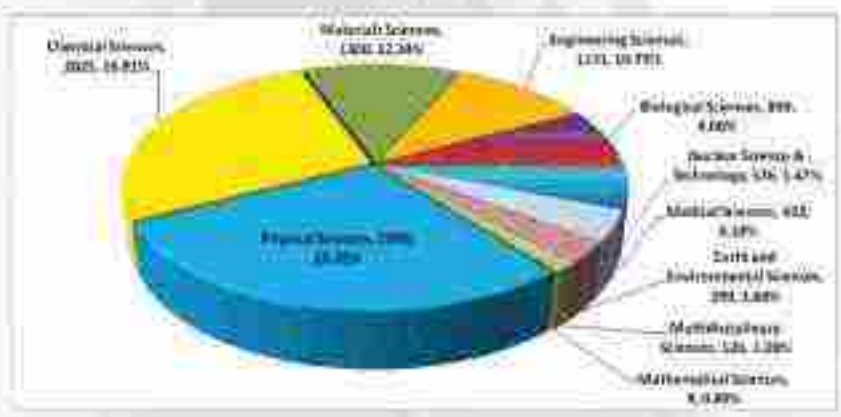
During the year, 824 books, 2560 scientific and technical reports and 514 bound periodicals were added to the Library collection and various standards and codes were procured. Subscription to 980 periodicals and 11 Databases continued. More than 3500 online journals are available on the online information gateway for e-resources 'Lakshya'.

Interactions with other National and International organizations to identify and acquire the information not available in BARC library for the benefit of scientists were pursued. Publications by BARC scientists and engineers were compiled and displayed in the Central Library and listed in the monthly publication 'Scientific Information Resource Bulletin'. The full text of these publications was uploaded on Intranet server 'Saraswati'. Photocopy services through ten self-operated photocopiers in the Library were continued.

Content management, designing and maintenance of portals such as BARC website accessible in the public domain, 'Lakshya', library portal 'Saraswati' and SIRD portal on BTS were carried out. Library management software, RFID based library automation, customized software development to meet specialized needs was managed and implemented.

Remote access of online Elsevier resources to scientists and engineers were facilitated and more than 750 BARC scientists availed the access facility. Web based OPAC for online book reservation and renewal is enabled. Feasibility of providing extended access of 'Saraswati' to remote DAE units is completed. Institutional Repository of published articles and PhD theses now holds more than 9200 journal articles and 210 full text theses. Registered users for the email based NUCNET facility reached more than 250.

A total of 10537 publications were published during 2007-2014. The highlights are given below in the following chart:



Research activities in Library & Information Science and Scientometrics on various topics related to Nuclear Science and Technology as well as major thrust areas and published over 14 papers in national

and international journals. Six regular issues of the 'BARC Newsletter' and the Founder's day special issue containing 60 award-winning papers of DAE scientists were released. Brochures on "DAE Vision on Accelerators and Beams", "Atoms in the Service of the Nation: Chemical Sciences", "Fifty Years of the Plutonium Plant", "Information Security Threats and Measures", "HBNI Annual Report" were published. Scientific Information Resource Bulletin, Pulse and several internal & external reports (100 nos.) were also brought out by the Scientific Information Resource Division.

In 2014, 3001 bibliographic records were added to the INIS database. Document delivery services were provided to various INIS member countries. NEA Data Codes were procured for BARC scientists and engineers. Bibliographic sheets of 27 external technical reports were made and the digital copies of the reports were sent to INIS for including in the Non-Conventional Literature collection of IAEA.

The Foreign Languages Section provided specialized English translations from Chinese, French, German, Japanese, Korean and Russian sources of scientific literature. 45 translation requests involving over 2445 pages of translation was undertaken. A CMS for Translation Management System (TMS) to upload documents produced by translating from other languages was developed and the archival facility was under advance stage of testing.

Printing and binding services for restricted reports, reprints, invitation, visiting cards, etc. were provided and printing of posters for various exhibitions were coordinated.

Photography & Videographic services to national and international conferences in BARC and VIP visits were extended. A theme based event showcasing the best photographs clicked during the year was arranged. An 8.25 minute audio-visual clip on Prime Minister's visit of BARC on July 21, 2014 was made in-house.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) and its constituent units promote the awareness about peaceful uses of atomic energy in the correct perspective with prime focus on benefits to the society by keeping the public abreast with current trends and developments in the areas of power production, applications of radiation technologies, healthcare, food & agriculture, industry, water, environment, advanced technologies etc., The main objective of the public awareness activities is to elucidate the uses of atomic energy to the general public and alleviate unwarranted fears, misconceptions and address apprehensions harboured against nuclear energy. This was done on a mission mode in a structured manner through a multi-pronged approach by organising and participating in exhibitions; seminars for academicians, general public and the media in different regions of the country and organising essay and quiz contests etc.

During the year, DAE participated in and organised several events as follows:

The 102nd Indian Science Congress was held at Mumbai University, Mumbai during February



Visitors at the DAE Pavilion during the 102nd Indian Science Congress, Mumbai



Visitors being briefed at the DAE Pavilion during IITF 2014

3-7, 2015. The theme of the exhibition was India Vision 2020, with focal theme as "Innovations in Science & Technology for Inclusive Development". DAE participated in the exhibition displaying all its activities.

During 102nd ISC, a public outreach session on Atomic Energy was arranged. DAE also participated in the 8th science communicators meet organised as part of the congress.

DAE participated in the 7th Vibrant Gujarat Global Trade Show at Gujarat during Jan 8-13, 2015. The event was a platform for National and International professionals as well as for general public and young students to meet together.

The 18th National Exhibition with the theme, "Service to the Nation for progress of India" was held at Belguria, Kolkata, West Bengal during September 3-7, 2014. 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 26th All India Essay Contest on 'Nuclear Science and Technology' was held in October 2014. About 450 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, October 30, 2014.

"Indian Technology Congress 2014", a two day exhibition with focal theme "Advanced Technology as change Agent to make India as Economic Superpower" was organised at Bengaluru during August 21-22, 2014. 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 high school, college level and academicians benefited from this event.

The 26th International symposium on Discharge and Electrical insulation in vacuum was held at Nehru Centre during September 28 – October 3, 2014. DAE put up an exhibition on its activities on Vacuum Technology. Industry leaders and academicians benefited from this event. BARC, Mumbai and IPR, Gandhinagar also participated in the event.

"Swasraya Bharat 2014" was organised by Swadeshi Science Movement at Kasargod, Kerala during October 14-19, 2014. Members of the general public, students at the high school, college level and academicians visited the pavilion.

DAE organised the 6th International Exhibition and Conference, 'India Nuclear Energy 2014' at the Nehru Centre, Mumbai during November 6-8, 2014. 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 various applications of radioisotopes, advanced technologies etc.

The 34th India International Trade Fair 2014 organised by the ITPO, was held at the Pragati

Maidan, New Delhi during November 14-27, 2014. DAE exhibited all its activities as in nuclear power, applications of radioisotopes in various areas, water and hydrology, advanced technologies etc. 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.

The 6th edition of AGROVISION with theme as "Building Sustainable Livelihoods & Increasing Farmers 'Income" was held at Nagpur during December 4-7, 2014. 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.

A two day public awareness and outreach programme on DAE Technologies was held at Kalpakkam as part of The Diamond Jubilee Celebration during January 24-25, 2015. Various DAE technologies were exhibited. Students from nearby schools and colleges and the local neighbourhood public took keen interest in the exhibits.

The 39th International Kolkata Book Fair was organised by the Book Publishers Guild at Kolkata during January 28 – February 08, 2015. International participation included Great Britain, USA, France and Canada. As part of Diamond Jubilee Celebrations, DAE along with Variable Energy Cyclotron Centre, Kolkata also participated and exhibited their R&D activities. About one lakh people visited DAE pavilion.

"Science Expo 2015 – An Interface of Science and Society" was held at Nehru Science Centre, Mumbai during February 4-7, 2015. Some of the other participants included Haffkine Institute, IIT Bombay, C-DAC, Indian Institute of Geomagnetism, TMC etc. Dr R K Sinha, Chairman AEC & Secretary DAE inaugurated the event. Several schools and colleges in and around Mumbai, academicians and members of the general public visited the pavilion.



Dr R.K Sinha, Chairman AEC along with Director NSC, Mumbai (center)at the DAE pavilion during the Science Expo 2015



Students at the DAE pavilion during the Science Expo 2015, Mumbai

The 4th Bhopal Vigyan Mela was held at Bhopal during February 20 – 23, 2015 on the theme of "Development of Ingenious and Indigenous Technology in every field as Mangal Orbiter Misssion (MOM)". The exhibition was visited by number of the general public, students and academicians.

The 3rd Rajasthan Science Congress with the theme of "Food and Water" was held at Jaipur, Rajasthan during February 28 – March 02, 2015 in collaboration with the Manipal University, Jaipur. DAE put up an exhibition on all its activities and future programs. Students, academicians, faculty members immensely benefitted from the event.

DAE also participated in a number of seminars and workshops in different regions on various themes. National Workshop on the theme of "Ionising Radiation Detection" was held at Government College of Arts, Tiruvannamalai during April 10-11, 2014. Rare Earth Processing and

Utilisation 2014 (REPUT2014) Seminar and Exhibition was arrange at Multipurpose Hall, Anushaktinagar, Mumbai during May 2-3, 2014. 11th International Workshop on Positron & Positronium Chemistry (PPC II) was organised by Indian Association of Nuclear Chemists and Allied Scientists (IANCAS) at Goa during November 9-14, 2014. The Global R&D Summit 2014 on the theme "Next – Gen Innovations through Interdisciplinary Research" was held at New Delhi during November 12-13, 2014. 12th NUCAR (Nuclear Radiochemistry) 2015 was held at Nabhikiya Urja Bhavan, Anushaktinagar, Mumbai during February 09-13, 2015.

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.

This year, the Department displayed a tableau in the 66th Republic Day Parade Ceremony at Rajpath, New Delhi. The tableau, based on the theme "Atoms in the Service of the Nation", presented nuclear power as a clean and environment friendly energy option for peace, power and prosperity by showcasing the achievements and services of the Department in the areas of healthcare management and food & agriculture.



DAE Contingent in Mumbai Marathon 2015

Under the banner "uranium leads the way", the Department participated in the popular Mumbai Marathon 2015 with over a hundred participants from its various units including the school children from Atomic Energy Education Society, Jaduguda. The event offered the Department a unique opportunity to reach out to people on the street and spread the message of public service espoused by the Department.

The on-going campaign on broadcast media was augmented with new advertisement films on nuclear power; Bengali language has been added to the plan to comprehensively cover major activity areas of the Department including the North Eastern states of the country. The newly constituted Public Outreach Management Cell of DAE spearheaded and financially supported the outreach activities under the aegis of Diamond Jubilee Year celebration across the constituent Units encouraging some units to take their first steps in the all-important area of public outreach. Conventional methods of public awareness such as lectures and seminar in schools and colleges, public awareness events, participation in science fairs and exhibitions etc. are also continuing.

Public understanding of nuclear power and other associated aspects is one of the major goals of 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 included 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 such as 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 centers across the country to allay the apprehensions of public on nuclear power.

Several innovative public awareness programmes were conceived and implemented across the nation in this regard. Use of street plays, TV commercials, advertisements, radio jingles, single-sheet publications, innovative comic books and animated films in vernacular languages, enhanced interaction with press and media, e-public

awareness campaigns, exhibitions to name a few that were adopted to scale up outreach activities. NPCIL has entered into partnership with several specialized agencies like National Geographic TV channel, National Council of Science Museums, Tamil Nadu Science and Technology Center and Department of Science and Technology etc.

NPCIL has been reaching out to an average of around one lakh people per month as a result of these multi-pronged initiatives.

During the year, following innovative moves in public outreach activities were undertaken by NPCIL:

Publications

Lakhs of copies of publications were distributed amongst members of public, students, teachers & doctors and informative articles were published in popular newspapers and magazines. A special publication titled "Quest for Excellence" was also published this year to commemorate the world's second longest continuous run of RAPS-5.



Media persons being briefed about plant operation at RAPS-5 control room

Multimedia and Short Films

To make the common man aware about the working of nuclear power plant and its safety features, a 3-dimesion short film was produced. The film "a virtual tour of 540-MWe PHWR" provided understanding on the functioning of Indian Pressurised Heavy Water Reactor in a simple but interesting way. During the report period, NPCIL made a short film on its Human Resource Management highlighting the company's positive attributes. In addition, the company had entered into a partnership with the National Geographic TV channel to produce a world class documentary on Indian nuclear power. The documentary "Inside Tarapur Nuclear Power Plant" addressed the myths the public have about nuclear power.

Hall of Nuclear Power

Every year around 10 lakh people, particularly students visit the Hall of Nuclear Power, a permanent nuclear gallery at Nehru Science Centre, Mumbai set up by NPCIL in association with Nehru Science Centre. Similar permanent exhibition centers are in the advanced stage of completion at Chennai and New Delhi science centers. Many more are planned at various prominent locations across the country.

Exhibitions

As a part of DAE diamond jubilee celebrations, NPCIL participated in 57 exhibitions at various locations across the country to make around 8.5 lakh people aware about the various aspects of nuclear energy. Kota Dussehra Mela-2014 and India International Trade Fair held at New Delhi were some of the notable exhibitions where large visitors were attracted.



NPCIL took part in the India International Trade Fair (IITF) – 2014 Exhibition under Ministry of Power pavilion at Pragati Maidan, New Delhi

To provide the common man a hands-on experience on working of a nuclear power plant, NPCIL has fabricated and distributed dynamic nuclear power plant models to various science centers. Three such models have been developed during last year and installed at Goa Science Center

at Goa, Raman Science Center and Planetarium at Nagpur and Pathani Samanta Planetarium at Bhubaneswar.

Site Visits

Visits of over 55,000 people to nuclear power plants which included local residents, media-persons and students among others were facilitated by NPCIL.

Web based Public Awareness

NPCIL web site has been providing large amount of information on nuclear energy and about the corporation. A link for public has been provided for seeking information. 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.

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, 90 lecture programs were organized during the year.

Awareness programmes in schools and colleges

NPCIL in partnership with professional organizations, took several initiatives to reach out to around 28,000 students and teachers and educationalists. There was a wide coverage of these events in the press and media.

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 journo from leading mass communication institutes and universities by arranging their visit to the nuclear power plants to have firsthand experience under the very unique programme M-SAP. Till the report period, four visits of media students from Amity University, UP, Mumbai University, Makhan Lal Chaturvedi University, Noida



Media Students Adaptation Programme organized by NPCIL

and Guru Govind Singh Indraprastha University, New Delhi were organized along with detailed briefing on benefits of nuclear power.

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 helped students to understand nuclear science in a better was and to learn factual information. Under the student connect programme, activities such as creative workshops on nuclear energy (48 nos.) and distribution of public awareness materials etc were organized in various schools and colleges across the country with a massive coverage.

Farmers Integration Programme (FIP)

Farmers Integration Programme (FIP) is a very unique public awareness activity specially designed for the farmers to allay prevailing apprehensions related to radiation and to develop the positive understanding of nuclear energy especially to improve their agricultural yields, food irradiation technology, improvement of shelf life of crops by sprout inhibition, early ripening of fruits and prevention from insecticides etc. Under this programme, two interactive workshops were organized for farmers in collaboration with Amity University at Noida, Krishi Vigyan Kendra (Under ICAR, Govt. of India) at Bhivani and Jind in Haryana. The workshops were attended by more than 160 farmers of various villages under Bhivani and Jind

districts.

KV Teacher Adoption Programme

Zonal Institute of Education and Training (ZIET), Mumbai has been offering regular opportunities to NPCIL to extend its awareness campaign to teachers and Principals of Kendriya Vidyalayas from all over India who are deputed for in-service training at the Institute. Four such awareness seminars were conducted by NPCIL at the Institute.

Capacity-building for outreach

During the year, 75 resource-persons of NPCIL were trained by the expert faculty in the various training programmes on Media Communication and Public Communication organized at various sites. In addition, orientation training programme was organized for 30 selected resource-persons for conducting awareness in villages around Chutka, Madhya Pradesh site prior to its public hearing on environment clearance.

RRCAT conducted several events to increase public awareness of the scientific activities of DAE to motivate young students to take up a career in science research. Visits to RRCAT were arranged for more than 2100 persons. These included college and school students, teachers and members of Madhya Pradesh Government agencies.



A section of "Vigyan Manthan Yatra" students during the interaction session with RRCAT scientists

Public awareness programmes were continued at AMD in various cities as well as in remote field areas and a total of 30 events were organised for students, teachers and general public.

GCNEP has taken major initiatives towards enhancing public awareness and acceptance of nuclear energy programs with particular focus on students and faculty. In this direction, GCNEP organized a series of three Public Awareness & Outreach Programs in the Year 2013-14, entitled DAE Technologies for Rural India (DTRI-2013). DTRI-2013 was also aimed at holding a parallel two days exhibition. The third DTRI-2013 program was organized on 27th & 28th February 2014, at MRK Institute of Engineering & Technology (MRKIET), Rewari, Haryana. A parallel two day exhibition was also organized with the help of Media Relations & Public Awareness Section, Bhabha Atomic Research Centre, Mumbai. The exhibition was open to all and many school children from the nearby schools were facilitated to visit the exhibition. The students found the program very informative and they appreciated GCNEP's efforts in reaching out to the rural institutes. Students, desired that more of such outreach programs be conducted at the level of schools & colleges to remove the misconceptions about nuclear energy.



Visitors at DTRI exhibition organised by GCNEP

SOCIAL WELFARE

Corporate Social Responsibility

Corporate Social Responsibility and Sustainability activities were performed on the thrust areas of education, health , infrastructure development, skill development and environmental sustainability within the gamut of the Notification of the Ministry of Corporate Affairs and the activities are decided taking into account the actual needs of the stakeholders.

There has been a progressive increase in CSR activities on each of the above thrust areas since 2011-12. During the financial year, total 157



Skill Development Programme on Welding & Mason work



Infrastructure Projects on Borewell & Construction of classrooms

projects were been taken up. Rs. 42 Crores of fund was sanctioned for all these projects. Out of additional CSR fund of Rs. 125 Crores, the CSR projects about Rs. 50 Crores have been planned and being implemented. In addition to the ongoing CSR projects, implementation of three projects namely 'ASAN' for supporting Specially Abled Persons by providing 'Assistive Devices', School Sanitation project as part of 'Swachh Bharat Abhiyan' and Drinking water project by providing BARC developed water filters to the families were also taken up.



Assessment camp conducted by NPCIL on World Disability Day at Tarapur

The project 'ASAN' is for persons living at villages within 16 KM radius of nuclear power stations and projects at fourteen locations. This is in participation with Artificial Limb Manufacturing Corporation of India. For this project, assessment camps were completed and Distribution Camps are expected to be completed by the end of this financial year.

Under School Sanitation project, construction work was in progress for 92 toilet facilities and 11 urinal facilities in different schools. In addition to these, sanitation facilities is expected to be provided to 181 village schools located within 16 km radius of fourteen Stations and Project locations of NPCIL. For implementation, the first priority will be for girl's schools without toilet facility.



School sanitation project

For the purpose of providing drinking water, BARC developed water filters are planned to be distributed to families living at villages within 5 km radius of NPCIL Stations and Projects.

Artificial reef structures were deployed in the



Artificial reefs are being lowered at sea near MAPS, Kalpakkam, Tamilnadu

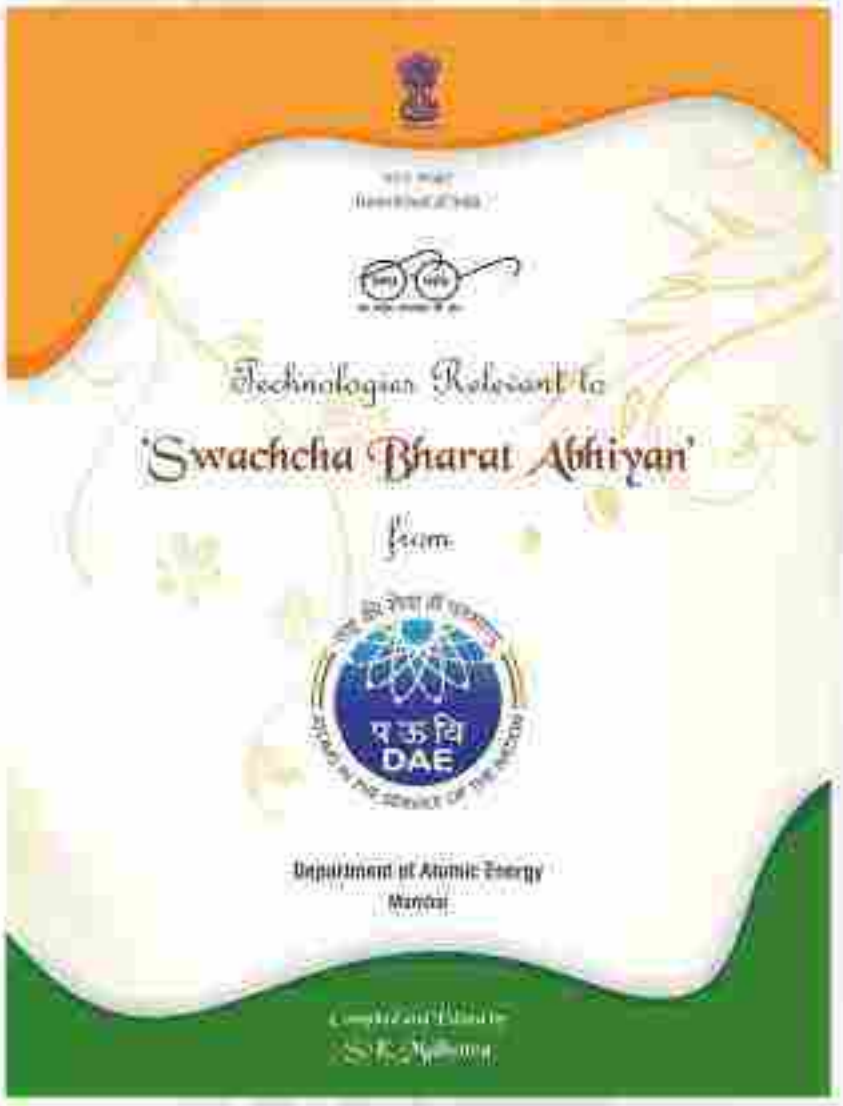
sea at Kalpakkam distance of about 4 to 5 nautical miles and at a depth of about 50 to 60 meters. These structures start biological process and settlement of various marine species. This helps continuous migration and breeding of fish resulting in increase in yield of marine fish and other species. The Artificial Reef Deployment Project has been implemented to improve biodiversity and availability of fish in the reef area of MAPS, Kalpakkam.

Swachha Bharat Mission

The Department of Atomic Energy and its

constituent units organized collective cleaning programme on 2nd October, 2015 on the eve of 150th Birth Anniversary of Father of the Nation, Mahatma Gandhi under the "Swachha Bharat Mission" along with Swachchata Shapath.

A series of seminars on 'DAE technologies relevant to Swachcha Bharat Abhiyan' have been started. First such seminar in the series was held at Gujrat Technological University, Ahmedabad. A publication with details of such technologies has also been brought out.



As part of the Swachh Bharat Mission, a cleanliness pledge (Swachhata Shapath) in trilingual was administered in the presence of staffs at office premises of GSO on 2nd October 2014. This was followed by a cleanliness drive by employees of General Services Organisation along with volunteers of ExNoRa, Kalpakkam in the Govt. Higher Secondary School, situated in DAE Township premises, Kalpakkam.



Swachcha Bharat Mission: Employees administering cleanliness pledge



'Swachcha Bharat Mission' Employees Cleaning the Township

EMPLOYEES' WELFARE

Employees' 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 February 1, 1998.

The Department reviewed the scheme from time to time and the orders amending/substituting or inserting new rules in the scheme were issued.

The CHS scheme was framed particularly for Mumbai but the same has been extended to other places such as Tarapur, Indore, Kota, Talcher, Manuguru, Kalpakkam, Chennai, Baroda, Kolkata, Tuticorin, Mysore and Hyderabad. In addition to DAE employees, the scheme also covered the staff of some of the PSUs & Aided Institutions among DAE family. Recently, DAE has provided the CHSS facility at Greater Visakhapatnam.

BARC provided healthcare facilities to entire Mumbai based CHSS beneficiaries through its 390 bedded hospital, 13 zonal dispensaries 3 occupational health centers and 24 hour Casualty

facility. All these units of Medical Division are running successfully with unique Hospital Information System (HIS).

Total number of CHSS Beneficiaries as in December, 2014 was 85,523. During the year, around 2,30,818 patients were attended by the OPD's. Around 4,83,925 patient visits were recorded by all the dispensaries together while 32,637 patients attended casualty services. Kharghar, navi Mumbai dispensary was inaugurated and this dispensary will have dental and diagnostic lab units also. A new building is proposed to be constructed near BARC Hospital building for OT Complex comprising of 6 major OTs including Cardiac and also intensive care units, CSSD and some specialty clinics Gynaec/Maternity, Surgical and Ortho etc. Sialendoscopy procedure is started in ENT. Advanced Electro Surgical unit and two specialized yellow fin leg stirrups were installed in Obstetrics and Gynecology Unit for uterovaginal prolapsed surgery. Six high end multipara monitors, Blood Analyzer for Surgical ICCU and four LED fitted laryngoscope were installed in Anesthesia Department. Ophthalmic Unit has procured instrument of Retinal Laser Treatment, fundus camera, Optical coherence tomography machines.

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 which 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. For broader development of personality of its students through modern and technical educational infrastructure, AEES has launched several long-term key projects such as Application of Science and Technology for Educational Reforms (ASTER). At present there are 1651 employees in AEES out of which 1338 belong to the teaching category.

Total 2434 students appeared in the CBSE Board examination in March, 2013 and the pass percentage was 100. Overall 375 students secured CGPA 10 points and 517 students secured CGPA 9 point or more. Total 1771 students of 17 AEC Schools and Junior Colleges appeared in the Class XII examination in March, 2014. The pass percentage was 94.41 as compared to 87.80 last year and the overall Excellence Index stood at 72.56 as compared to 62.39 last year. The pass percentage of AECS-1, Tarapur and AECS, Mysore was 100%.

About 132 students cleared the IIT-JEE mains examination, 45 students secured good ranks in National and State level Engineering Entrance Examinations. 10 students secured admission in medical stream. Six students of AECS-4, Mumbai were awarded the National Talent Search Scholarships and 23 students from different AEC Schools (AECS-4 Rawatbhata/AECS Indore/AECS Narora/AECS Kudankulam/AECS-2 Rawatbhata) cleared the state level exam of NTSE conducted by National Council of Educational Research and Training (NCERT). One Student of AECS-4, Mumbai qualified for KVPY Fellowship Award instituted by Indian Institute of Science, Bengaluru. One Student of AECS, Kaiga got admission in the prestigious Indian Institute of Science, Bengaluru.

The Inter AECS Hindi Vigyan Prashna Manch (Zonal Level) was held at four places in four zones of AECS, Narora, AECS- Kudankulam, AECS-Turamdih, and AECS-2, Mumbai. The winners of zonal level participated in the All India level Inter AECS Science Quiz conducted by Hindi Vigyan Sahitya Parishad, BARC, Mumbai. AECS, Indore emerged as the National winners.

Junior Science Olympiad and Junior Mathematics Olympiad (JSO/JMO) Orientation Programme was conceived by Atomic Energy Education Society (AEES) in collaboration with Homi Bhabha Centre for Science Education (HBCSE), Mumbai for the students of Class IX. A total of 58 students were finalized to participate in the JS&MO. The 10 day orientation programme was held at

AECS-4, Mumbai from 6-15th May 2014. A visit to Nehru Science Centre and Nehru Planetarium was also arranged. The JSO-JMO examination was conducted on 13.5.2014. The top performers in each subject will be awarded medals and prizes in the form of cash. The topmost performer in each group will be awarded the Sunil Mehta Cash Award.

AEES has been recognized as a separate body by NCERT to participate at the Jawaharlal Nehru National Science Exhibition, an annual event. Projects from AEC Schools are selected at AEES level for JNNSE. The All India Inter AECS/AEJC Science, Social science, Mathematics and Teaching Aids Exhibition –2013 was held at AECS, Manuguru in August, 2013. More than 100 exhibits in all categories from all the 30 schools were displayed in the exhibition. The three best-selected exhibits were sent to Jawaharlal Nehru National Science Exhibition organized by the National Council for Educational Research and Training (NCERT), New Delhi.

The Grade Examination of Directorate of Art (Elementary and Intermediate Drawing Grade Exams), Maharashtra State Board, was held in September, 2013. About 59 students from AEC schools of Mumbai and Tarapur passed the elementary level and 25 students passed the intermediate level.

The All India Inter AECS/AEJC Cultural Meet in singing was organized at AECS-4, Rawatbhata. This was an attempt to offer the students of Secondary and Higher Secondary sections of all AEC Schools a platform to showcase their talents in the field of Singing (Solo Song, Classical Vocal Karnatic, Classical Vocal Hindustani, Instrumental (Percussion), Instrumental (String/Wind)).

All India Inter AECS Junior Athletic meet & Table Tennis Tournament was organized at AECS, Kaiga. AECS, Turamdih won the Boys Team Championship Trophy and ACES-2, Kalpakkam won the Girls Team Championship Trophy in Athletics. AECS, Narora won the Boys Team Championship Trophy and ACES, Kudankulam won the Girls Team Championship Trophy in Table Tennis.

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.

Orientation programmes were organized by AEES for the PRTs, TGTs and PGTs with a view to empower them to plan and execute the various classroom activities to be used for better evaluation. Orientation programmes for PRTs were organized in 8 schools across the country.

The Application of Science and Technology for Educational Reforms (ASTER) is now an integral part of AEES educational system. According to the Secondary School Curriculum prescribed by the CBSE, New Delhi, it is mandatory to implement academic programmes based on ICT as required in the Continuous and Comprehensive Evaluation (CCE) scheme. The ISRO provided free of charge bandwidth through their EDUSAT satellite programme for propagating transmission of educational content through the ASTER studio to Satellite Interactive Terminals (SIT) in all the AEC Schools. There were around 30 programmes recorded and telecast from ASTER during the year 2014.

The Rolling Trophies for the Best Overall Performance among AEC Schools and Junior Colleges were awarded to AECS-2, Kalpakkam and AECS-4, Mumbai respectively for the academic year 2012-2013.

DAE SPORTS & CULTURAL ACTIVITIES

The DAE Sports and Cultural Council (S&CC) promotes sports and cultural activities among DAE employees and their families located at various units all over India.

The major activities for 2014-15 are given below.

Special Summer Coaching camps were organized jointly by DAE S&CC and Atomic Energy Education Society (AEES) with more than 1500 children of DAE employees in the age group of 10-14 years receiving entry level coaching in various games and sports like Athletics, Swimming, Cricket, Football, Basketball, Table Tennis, Badminton, Lawn Tennis etc. This was conducted at 15 AEES centers



Kalark team receiving fare play trophy from chief guest for the chess event conducted at Anushakting, Mumbai

covering 30 schools all over India. Based on the camps, advanced coaching scholarship is provided in various games. Advanced Coaching Scheme was organised for selected players who showed promise of excellence and Sports Scholarships were provided for encouraging them.

A Summer Sports Camp is organized with the help of Sausheelya Special School for special children in AnushaktiNagar. Camps in badminton and table tennis were organized in Mumbai with training organized by National level coaches for highly talented youngsters. For creating competitive match environment and promoting competitiveness in employees and their children, a combined sports and cultural meet SPLASH-2014 was organized at DAE S&CCs New Community Centre as well as the new AEES sports complex at Anushaktingar, Mumbai with participation reaching more than 900 people. The Splash-2014 included various indoor, outdoor as well as aquatic sports events, fitness workshop and music and dance competitions.

Under its Health and Fitness Activities, regular yoga activities and camps were organized at different centers at various levels for employees as well as for their family members. Yoga magazines were supplied to all the schools and different units of DAE. Units of DAE were encouraged and financially supported to set up fitness centers for employees and family members. Sidhi Samadhi Yoga was conducted for the employee and their family members during SPLASH-2014 from 2nd-9th November, 2014 at New Community Center, Anushaktinagar, Mumbai. Total 72 participants took part in this program.

DAE's annual all India trekking programme "Girirsanchar-26" was organized during January 5 to 17, 2014. About 223 participants and 25 trekker volunteers from the entire DAE covered a total distance of about 80 kms in a period of six days. The 6th DAE Himalayan Trekking Expedition for employees of DAE was conducted in Hamta Pass region near Manali, Himachal Pradesh. In all 25 employees including two Camp Leaders had participated in this Expedition.

Under nature and adventure related activities, 6th DAE S & CC Nature and adventure Camp for the Children of DAE Employees was organized in Vanvihar, Ambivali near Karjat during 25th to 28th December, 2014. In all, 75 Children (girls and boys) between age group of 9-13 yrs participated in this camp. The objective of the camp was to promote the spirit for adventure among the youngsters. The activities included Rock climbing, Rappelling, River Crossing, Rafting, Star gazing and a short Trek to Peth Fort. A lecture with slide shows on Snakes and medical first aid was arranged during the Camp. This camp is organized every year in collaboration with BARC staff Club's Nature and Adventure Circle.

DAE S&CC supported New Community Centre in Anushaktinagar for sports and cultural activities. The membership of NCC is about 1500. DAE S&CC supported district level promotional tournaments at Anushaktinagar to facilitate advanced coaching children. It provided subsidy to welfare groups of various units and new community center for Annual competitions, fests and Shantiniketan Residents for setting up of Gym Facility. It subsidized Prizes for all India AEES Painting Competition.

The XXIX Inter DAE Sports and Cultural Meet was conducted in eleven different sports and cultural events (Athletics, Volleyball, Hockey, Football, Kabaddi, Lawn tennis , Chess, Ball Badminton, Basketball, music and dance, carom, at various units of DAE at various locations in the country. During this year, more than 2600 employees took part in the selection trials and 1000 employees participated in the inter DAE Annual Sports & Cultural Meet. Playing facilities at various units have been upgraded to conduct the meets. DAE S&CC provided

suitable mementoes to all participants and volunteers. Teams to participate in National events like Ball Badminton, Kabaddi, Bridge, Table Tennis, Badminton etc. were selected during the meet.

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 907 RTI applications out of which 881 were answered and out of 63 appeals received 61 appeals were disposed.

BARC RTI Cell received 349 RTI requests and proactive disclosure was done to the extent possible. The provisions contained in RTI Act 2005 were fully complied with at IGCAR. Suo Motu disclosure under Section 4 of RTI Act 2005 and updated information were uploaded in the website. During the year, 69 applications were received, 3 applications were transferred to other PIOs. Information was provided to all the remaining applicants.

An elaborate mechanism exists at NPCIL with 7 Central Public Information Officers and 7 Assistant Public Information Officers, one at each site. One Central Public Information Officer, one Assistant Central Public Information Officer and one Appellate Authority at Headquarters to deal with the requests received under the RTI Act, 2005. RTI computerised management system has been developed in-house and implemented for effective disposal of RTI applications and appeals in timely manner in NPCIL.

The mandatory information required under the Act [section 4(1) (b)] has been posted on NPCIL website and the information was updated as required. Presentations & lectures were organised in NPCIL for creating awareness about the importance and ways to implement the Act. During the financial year, 950 RTI applications and 135 appeals were received under the RTI Act, 2005 and were disposed.

RTI related issues were dealt efficiently at AMD. A total of 178 RTI applications were received, out of which 172 replied, 5 transferred, 1 rejected. 28 first and 7 second appeals are received and attended 2 CIC hearing on second appeal. IREL received 146 RTI queries during the year and 152 RTI queries were replied. The Tata Memorial Centre received 100 RTI queries and 13 appeals which were replied within the stipulated time period. SINP received 45 applications of which 44 were replied and out of the 3 appeals 2 were replied. NBHM received 4 RTI queries and they were all answered during the report period.

AWARDS & PRIZES

NPCIL won several awards in area of stations safety and performance, Public Outreach Activities, Corporate Social Responsibility and Official Language.

The units of NPCIL received several awards during the year for performance in safety, environment protection and other areas. TAPS-1&2 won AERB Industrial Safety Award winner for the year 2013 and it was appreciated by Ministry of Labour, Govt. of India for achievement in Occupational Safety & Health during the assessment period of three years 2010-2012. TAPS-3&4 won "Certificate of Merit to TAPS (1400 MWe) for performance of Nuclear Power Stations" for meritorious performance in Power Sector in recognition of outstanding performance during 2011-12 & 2012-13; AERB Industrial Safety Award-2013 for Production Units National Safety Council-Maharashtra Chapter-Maharashtra Safety awards-2013 for lowest accident frequency; National Safety Council-Maharashtra Chapter-Maharashtra Safety awards-2013 for lowest accident frequency; National Safety Council-Maharashtra Chapter - Maharashtra Safety awards-2013 for longest accident period and SIRVA Shreshtha Suraksha Puraskar (Golden trophy and Certificate) in Group C under the manufacturing sector category by NSCI for the year 2013.

RAPS-3&4 was the winner of the "Fire Safety Award" by AERB amongst all DAE installations in Category-1 for the Year-2013.Bronze shield was awarded in "Suraksha Puraskar" by "National Safety Council of India" under category-C "Manufacturing Sector of Power Generation" for Year-2012. RAPS-3&4 bagged this award consecutively for the last two financial years. RAPS-5&6 won India Power Award



Shri H.N.Bhatt,site Director, Kaiga Site receiving the award for KGS 3&4 from Hon'ble Central Labour minister at Vigyan Bhawan, New Delhi

for best overall performance among PSUs and Private Sector and 8th Enertia Award in the Category of Power Generation Award - Nuclear.

MAPS-1&2 won the Annual GreenTech Award under Gold Category in power - Nuclear Sector. NAPS-1&2 won 'AERB Environment Protection Award' for the year 2013. KAPS-1&2 won the National Award (Gold shield) for Meritorious Performance in Power Sector for the year 2011-12 by Ministry of Power.

KGS-1&2 won NSCI Safety Award-2013, Shreshta Suraksha Puraskar (Silver trophy) from National Safety Council, Mumbai and runner-up award in the category of Accident Free year in the performance year-2012 from Directorate General, Factory Advice Service & Labour Institute (DGFASLI), Faridabad), Ministry of Labour & Employment, Govt. of India. KGS-3&4 won the National Safety Award 2013 "Suraksha Puraskar" from National Safety Council of India and Safety award from DGFASLI in lowest frequency rate category for the performance year 2012. An employee of KGS 3&4 bagged the prestigious award 'Vishwakarma Rashtriya Purshkar' for the performance year 2012 for his outstanding contribution in improving performance of Fuel Handling System.

KAPP-3&4 won "Sarvsrestha Suraksha Puraskar" in the construction sector from "National Safety Council" for two consecutive years 2011 and 2012. RAPP-7&8 won 'AERB Environment Protection Award-2013' in 2014.

In the field of public awareness, NPCIL won the Best coffee-table book (first prize) for "The Realms of Flowers" by Public Relation Society of India (PRSI). Best public awareness (second prize) by PRSI.

NPCIL headquarters was felicitated with special award for "Excellence for Implementation of the Official Language" for the year 2013-14 on 31st October, 2014 in 23rd Ashirwad Rajbhasha Puraskar Samaroh by Ashirwad Sansthan, an NGO committed for propagation of the Official Language in Mumbai since 1967. Urjaswi, the house-magazine of NPCIL headquarters was awarded Second Prize for the year 2013-14 by PSU TOLIC. NPCIL headquarters was honoured with Rajbhasha Shield of DAE for the year 2013 for its excellence in implementation of Official Language Policy of Govt. of India. KGS-1&2 won Rolling Shield for "Implementing Official language effectively in the offices of entire region of PSU" for the year2013-14 from Hindi Training Scheme (Southern Region) Bangluru.

The Madras Atomic Power Station was selected for "4th Annual Greentech CSR Award-2015 under Gold Category in Power-Nuclear Sector" for the Artificial Reef Deployment project off the coast of the Bay of Bengal for the benefit of fishermen living in the nearby villages in the neighbourhood of Kalpakkam under CSR.

AMD conferred various awards such as Homi Bhabha Science and Technology Award – 2013, Outstanding Service Award-2013, Outstanding Achievement Award - 2013, DAE Group Achievement Award - 2013, Journal Geological Society of India (JGSI) Radhakrishna Prize – 2013 and Dr. G.R.Udas-Dr.K.K.Dwivedi Medal - 2014 to their officials.

BARC received an IAEA award for outstanding contributions in mutation breeding for crop improvement.

The HWP, Manuguru was awarded with "Shresta Suraksha Puraskar. HWP, Kota won AERB's Fire Safety Award jointly with RAPS-3&4 for the year-2013 in Category-I. It bagged Certificate of

Appreciation" by National Safety Council of India, Safety Awards-2013 in Manufacturing Sector. DAE's Group Achievement Award, 2013 was conferred to HWP, Kota for "Indigenous development of crank rotor shaft of High pressure Nitrogen gas Compressor in HEWAC facility and Turbine Rotor Assembly (including impeller and bearings) of Liquid Nitrogen Plant". A Certificate of Appreciation from National Safety Council (Manufacturing Sector) under Group-B was awarded to HWP, Hazira for the year 2013. The HWP, Thal bagged Golden Peacock Environment Management Award 2014 for RCF Thal complex. "Duleep Singh Safety Award-2013" organized by RCF was awarded to HWP (Thal) for safety performance on 15th August-2014. Quality Circle (Astitva) of HWP, Thal Instrument Section and Quality Circle (Kshitij) of HWP, Thal Production Section received gold at QC competitions held at Baroda & Madurai during September 2014.

Shri P Sudhakar, Chairman & Managing Director, ECIL was selected as the "Electronics Man of the Year" by the Electronics Industries Association (ELCINA). ECIL received the Industrial Excellence Award for the year for the year 2013 from the Indian Nuclear Society. The company's Quality Circle LAKSHYA won the Gold Award from the Quality Circle Forum of India.

During the year, UCIL received many accolades for its outstanding activities in different domains which included the "Best in CSR & Sustainability Award" among 'other PSUs' by India Today Group; "Most Eco-Friendly Award" among 'other PSUs' by India Today Group; "Dr. J. Coggin Brown Award-2014" to C&MD UCIL by Mining, Geological and Metallurgical Institute of India (MGMI); "Distinguished Alumnus Award -2014" to C&MD UCIL by IIT Kharagpur; "Greentech HR Gold Award for outstanding achievement in Technology excellence in HR"; "Engineering Excellence Award 2014" by Engineering Watch magazine for remote monitoring of noxious gases and automated control of ventilation fan at UCIL Turamdih underground mines; "Aqua Foundation's Excellence Award" for 'Outstanding Contribution towards cause of sustainability, Public Sector' and "Skoch Order of Merit" for 'Corporate Social Responsibility for qualifying in India's Best Projects – 2014'.

At HRI, Shri S. D. Adhikari was awarded the M K Singhal Memorial Award by the Indian Science Congress Association. B. Ramakrishnan was elected as a fellow of National Academy of Sciences, India (Allahabad). Ashoke Sen received the Dirac medal of the International Centre for Theoretical Physics (ICTP, Trieste, Italy) and M. P. Birla Golden jubilee award. R. Gopakumar was the recipient of the TWAS physics prize (TWAS, Trieste) and G.D. Birla award. Aditi Sen De received the Butti Foundation Award of the Indian Physics Association. Raj Gandhi was awarded the Intensify Frontier Fellowship of Fermilab (USA). Sudhakar Panda was elected as a fellow of the Indian National Science Academy (New Delhi) while R. Gopakumar and A.K. Pati were elected as fellows of National Academy of Sciences, India (Allahabad).

CHAPTER -11

IMPLEMENTATION OF PERSONS WITH DISABILITIES (EQUAL OPPORTUNITIES, PROTECTION OF RIGHTS & FULL PARTICIPATION) ACT, 1995

The Department of Atomic Energy has a mandate to develop peaceful uses of nuclear energy in areas like power generation and basic research in frontier areas of science and technology. In view of the nature of activities carried out by the Scientific and Technical persons in various Research Centres, Public Sector Undertakings, Industrial Units and Aided Institutions of the Department, this Department is not in a position to implement the provisions of reservation of posts fully as required under the "Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act, 1995". Therefore, this Department has already sought exemption for the Units like Heavy Water Boards and Nuclear Power Corporation of India Ltd. From the provisions of the said Act. No specific scheme under plan projects for the benefit of persons with disabilities has been introduced in the Department. In-spite of the constraints, all the Units/PSUs/Aided Institutions have attempted to identify posts, where persons with disabilities could be employed without impairing the activities or causing inconvenience.

The sanctioned strength and number of persons with disabilities in various posts in Group A, B, C & D against 3% vacancies to be reserved for them under Section 33 of the said Act is indicated in the pages that follow.

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 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	8015	0	1	40	0	0	1	242	0	0	8	NIL	NIL	NIL	37	0	0	0
Group B	10092	5	7	55	1	7	1	46	0	0	13	NIL	NIL	NIL	112	0	0	0
Group C	11343	15	27	104	7	10	11	711	1	2	17	0	1	1	90	0	1	0
TOTAL	**29450**	**20**	**35**	**199**	**8**	**17**	**13**	**999**	**1**	**2**	**38**	**0**	**1**	**1**	**239**	**0**	**1**	**0**

Note 1 : (i) VH stands for Visually Handicapped (persons suffering from blindness or low visions)

(ii) HH stands for Hearing Handicapped (persons suffering from hearing impairment)

(iii) OH stands for Orthopaedically Handicapped (persons suffering from locomotor disability or cerebral palsy)

(iv) There is no reservation for persons with disabilities in case of promotion to Group A and B posts. However, persons with disabilities can be promoted to such posts, provided the concerned post is identified suitable for persons with disabilities.

Note 2 : Column No. 9 and 16 show the sum total appointments made in the Department by way of Direct Recruitment and Promotion

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 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	1221	2	0	6	1	1	1	0	0	0	0	NIL	NIL	NIL	0	0	0	0
Group B	2883	6	2	17	1	2	2	1	0	0	1	NIL	NIL	NIL	0	0	0	0
Group C	2612	5	10	37	3	4	5	7	0	1	5	0	0	0	0	0	0	0
TOTAL	**6716**	**13**	**12**	**60**	**5**	**7**	**8**	**8**	**0**	**1**	**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

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 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	7023	6	3	41	2	2	1	49	0	0	0	NIL	NIL	NIL	9	11	0	0
Group B	5966	10	3	56	0	0	0	28	0	0	0	NIL	NIL	NIL	8	0	0	0
Group C	8660	7	7	57	4	1	2	69	1	0	0	0	0	0	44	26	0	0
TOTAL	**21649**	**23**	**13**	**154**	**6**	**3**	**3**	**146**	**1**	**0**	**0**	**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

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II. Public Relations

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Government of India
Department of Atomic Energy
Anushakti Bhavan, C.S.M. Marg,
Mumbai - 400 001

NOTICE

WE, THE PUBLIC SERVANTS OF INDIA DO HEREBY SOLEMNLY PLEDGE THAT WE SHALL CONTINUOUSLY STRIVE TO BRING ABOUT INTEGRITY AND TRANSPARENCY IN ALL SPHERES OF OUR ACTIVITIES. WE ALSO PLEDGE THAT WE SHALL WORK UNSTINTINGLY FOR ERADICATION OF CORRUPTION IN ALL SPEHERES OF LIFE. WE SHALL REMAIN VIGILANT AND WORK TOWARDS THE GROWTH AND REPUTATION OF OUR ORGANISATION. THROUGH OUR COLLECTIVE EFFORTS, WE SHALL BRING PRIDE TO OUR ORGANISATIONS AND PROVIDE VALUE BASED SERVICE TO OUR CONTRYMEN. WE SHALL DO OUR DUTY CONSCIENTIOUSLY AND ACT WITHOUT FEAR OR FAVOUR.

THIS OFFICE IS THUS COMMITTEED TO MAINTAINING THE HIGHEST LEVEL OF ETHICS IN ITS WORKING TOWARDS ACHIEVING THE ABOVE OBJECTIVE, ALL ARE REQUESTED :

- NOT TO PAY BRIBE
- IF ANYBODY IN THIS DEPARTMENT OR ITS OFFICES ASKS FOR BRIBE : OR
- IF YOU HAVE ANY INFORMATION ON CORRUPTION: OR IF YOU ARE A VICTIM OF CORRUPTION IN ANY OF OUR OFFICES.

YOU MAY COMPLAIN TO:

Dr. C.B.S. Venkataramana,
Additional Secretary,
Public Grievances Officer & Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
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YOU CAN ALSO COMPLAIN TO:

THE CENTRAL VIGILANCE COMMISSION,

SATARKTA BHAWAN, BLOCK 'A',
GPO COMPLEX, INA,
NEW DELHI – 110 023.

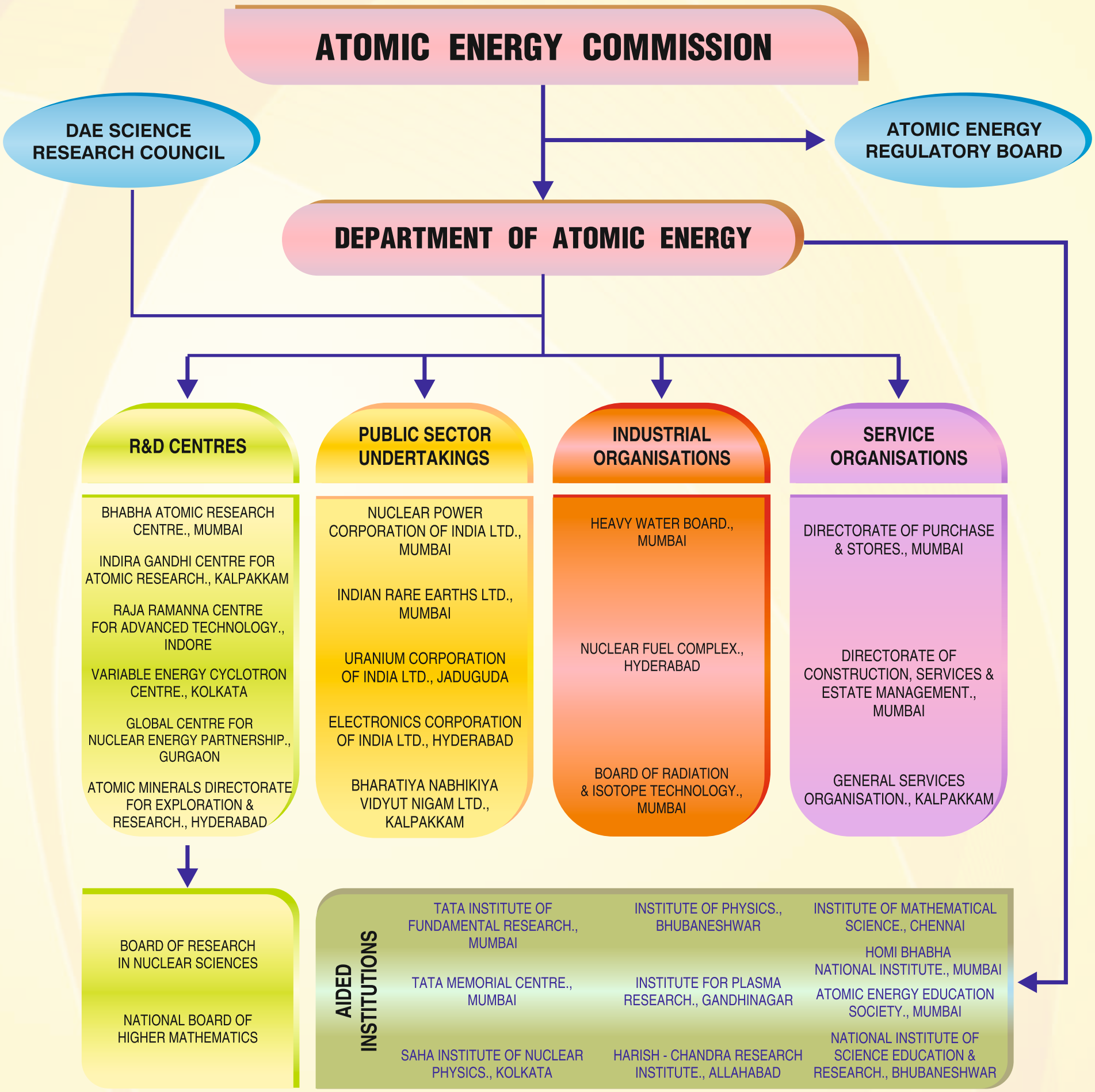
ANNEX-I

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 nine 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 SCIENCE., CHENNAI
HOMI BHABHA NATIONAL INSTITUTE., MUMBAI
ATOMIC ENERGY EDUCATION SOCIETY., MUMBAI
NATIONAL INSTITUTE OF SCIENCE EDUCATION & RESEARCH., BHUBANESHWAR

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



BRNS : Board of Research in Nuclear Sciences
HBNI : Homi Bhabha National Institute
NBHM : National Board for Higher Mathematics
SSSF : Solid Storage Surveillance Facility
WIP : Waste Immobilisation Plant
AEES : Atomic Energy Education Society
ACTREC : Advanced Centre for Treatment, Research & Education in Cancer
TIFR : Tata Institute of FundamentalResearch
TMC : Tata Memorial Centre
DCS&EM : Directorate of Construction, Services & Estate Management
DPS : Directorate of Purchase & Stores

Research & Development Organisations
Public Sector Undertakings
Industrial Facilities
Grant-in-aid Organisations
Service Organisations

ANNEX-II

REPLY TO AUDIT OBSERVATIONS

Report No.13 of 2014 Loss of Rs.13.47 crore due to non recovery of by product. Union Government (Commercial) Report of the Controller & Auditor General of India on Compliance observations.

Para No. 1.1 Delay in setting up of By-product Recovery Plant for magnetite by Uranium Corporation of India (UCIL) AT Turamdih mill resulted in a loss of Rs.13.47 crore during the period from March 2009 to November 2013.

Uranium Corporation of India(Company), appointed M/s. Development Consultants Pvt. Limited (DCPL) as consultant for setting up of a uranium ore mine at Turamdih (1982) in the district of Singhbum East, Jharkhand. The Detailed Project Report (DPR) prepared (1984) by DCPL was approved by the Department of Atomic Energy (DAE), Government of India (GOI) in April 1989, after the environment and forest clearances. The project work was started accordingly, but in May 1992, the activities of Turamdih mines were shelved by GOI after reviewing the overall nuclear, power programme. The Company again received approval during 2001 from GOI for re-opening Turamdih mine. The Company re-engaged DCPL for updating the DPR of the Turamdih Process Plant and its Board of Directors approved the updated report in December 2002. The construction work of the Uranium plant was commenced from September 2003. The trial run of the plant began in June 2007 and the plant was commissioned at a cost of Rs.3423.27 crore in March 2009. The ore fed in the plant for production of uranium also contained magnetite. The Company decided (November 2011) to invest a sum of Rs.20 crore for setting up of a by-product Recovery Plant to recover magnetite from the tailings generated from the Turamdih mill which was approved (May 2013) by GOI.

In this connection, Audit observed the following :

- The company had already commissioned a uranium plant at Jaduguda in 1968 in Singhbhum belt of Jharkhand, the ore from which contained 3.2% magnetite. Thus, the Company constructed a magnetite recovery plant in 1982 and further upgraded it in 1984. Later in 2003, the ore mined out from Turamdih mine was used in the Jaduguda mill.

- The delayed decision of setting up of a magnetite recovery plant resulted in a loss of Rs.13.47 crore due to non-recovery of magnetite from the tailings of Turamdih Plant during the period, March 2009 to November 2013. National resources would continue to be wasted and the Company would continue to suffer losses for not being able to sell magnetite till commissioning of the magnetite recovery facility, although it has a good market.

ACTION TAKEN

The observation of C&AG are not tenable because the Govt. of India report talks about presence of magnetite in Singbhum and these surrrouding areas on a regional scale. Apart from UCIL there are many minerals based of industries in that area but magnetite is not in the product list of any of these industries. It is

commonly accepted that for any minerals to be viable for commercial exploitation, it should have continuity, concentration and potential for economic extraction of the mineral. Magnetite is recovered as a by-product after completion of processing of uranium. The detailed knowledge of physical and chemical characteristics of the tailings is required for planning and engineering the design of the Magnetite Recovery Plant. This analysis was done soon after stabilization of Turamdih Process Plant and subsequently inference was drawn for exploitation of magnetite and planning was made to set up a magnetite plant. Therefore, there is no unusual delay between gathering knowledge and taking up technical and commercial planning for setting up of the plant.

ANNEX-III

REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2015)				Number of appointments made during the calendar year 2014									
					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	8015	586	119	626	287	5	0	22	212	19	8	2	0	1
Group B	10092	1893	702	1873	83	64	14	197	310	51	26	6	0	0
Group C	11343	2314	1137	2960	1046	117	23	233	331	82	34	3	0	1
TOTAL	**29450**	**4793**	**1958**	**5459**	**1416**	**186**	**37**	**452**	**853**	**152**	**68**	**11**	**0**	**2**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2015)				Number of appointments made during the calendar year 2014									
					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	1221	55	8	80	39	3	3	1	21	1	1	0	0	0
Group B	2883	405	97	397	67	10	17	6	3	2	0	0	0	0
Group C	2612	743	140	389	91	23	18	10	1	1	1	2	0	0
TOTAL	**6716**	**1203**	**245**	**866**	**197**	**36**	**38**	**17**	**25**	**4**	**2**	**2**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2015 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2014 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2015)				Number of appointments made during the calendar year 2014									
					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	7023	777	217	933	45	10	3	5	221	12	1	2	0	0
Group B	5966	959	448	1455	28	5	2	25	600	99	40	0	0	0
Group C	8660	1399	2309	1626	75	13	6	46	466	120	58	1	0	0
TOTAL	**21649**	**3135**	**2974**	**4014**	**148**	**28**	**11**	**76**	**1287**	**231**	**99**	**3**	**0**	**0**

ABBREVIATIONS

ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADU	Aammonium Diuranate
ADXRD	Angle Dispersive X-ray Diffraction
AEC	Atomic Energy Commission
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AFM	Atom Force Microscopy
AFMTF	AHWR Fuelling Machine Test Facility
AHWR	Advanced Heavy Water Reactor
AIPES	Angle Integrated Photoelectron Spectroscopy
ALARA	As Low as Reasonably Achievable
AMD	Atomic Minerals Directorate for Exploration & Research
AMOS	Atomic, Molecular and Optical Science
ANURIB	Advance National facility for Unstable and Rare Isotope Beams
APAR	Annual Performance Appraisal Report
ARCH	Analysis of Reactor Transients in Cartesian and Hexagonal Geometry
ARGT	Adjusted Rod Guide Tube
ARPES	Angle Resolved Photoelectron Spectroscopy
ASFSF	Additional Spent Fuel Storage Facility
ASTER	Application of Science and Technology for Educational Reforms
ATI	Administrative Training Institute
A-TIG	Activated Tungsten Inert Gas
ATM	Advanced Training in Mathematics
AVS	Advance Vitrification System
AVT	Advanced Variety Trial
BARC	Bhabha Atomic Research Centre
BARCIS	BARC Inspection System
BARVIS	BARC Vessel Inspection System
BBWT	Broad Band Wireless Terminal
BCD	Bleed Condenser
BDBA	Beyond Design Basis Accident
BEXD	Boron Enrichment Exchange Distillation
BEP	Boron Enrichment Plant
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BOC	Beginning of Cycle
BORL	Bharat Oman Refineries Limited
BPCL	Bharat Petroleum Corporation Limited
BRFST	Board of Research in Fusion Sciences & Technology
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BSD	Biennial Shut Down
BTS	Beam Transport System
BWR	Boiling Water Reactor
CBI	Central Bureau of Investigation
CBS	Computer Based System
CBM	Compressed Baryonic Matter
CCE	Centre for Cancer Epidemiology
CCE	Continuous and Comprehensive Evaluation
CCM	Capture Cryo Module
CCU	Catalyst Cracking Unit
CERN	European Organisation for Nuclear Research
CFD	Computational Fluid Dynamics
CFVS	Containment Filtered Venting System
CHSS	Contributory Health Service Scheme
CHTR	Compact High Temperature Reactor
CICC	Cable-In-Conduit-Conductors
CLND	Civil Liability for Nuclear Damage
CLRI	Central Leather Research Institute
CMC	Constant Mean Curvature
CMMRF	ChemoMechanical Magneto Rheological Finishing
CNT	Carbon Nanotubes
COG	Candu Owner's Group
CORAL	Compact Reprcessing faciliy for Advanced fuels of Lead cells
CPC	Compound Parabolic Concentrator
CPSAR	Control & Protection System Absorber Rods
CRC	Clinical Research Centre
CRGT	Control Rod Guide Tubes
CRI	Cancer Research Institute
CRL	Compound Refractive X-ray Lens
CRP	Coordinate Research Project
CRS	Clinical Research Secretariat
CSRDM	Control & Safety Rod Drive Mechanism
CTA	Carrier Tube Assembly
CTE	Consent to Establish
CTFM	Critical Temperature included Fluctuation Model
CTS	Co-60 Teletherapy Sources
CVC	Central Vigilance Commission
CVO	Chief Vigilance Officer
DAC	Diamond Anvil Cell
DAE	Department of Atomic Energy
DBGM	Design Basis Ground Motion
DBPARL	Doppler Broadening of Positron Annihilation Radiation Line-Shape
DBR	Design Basis Report
DCBS	Double Contrast Barium Swallow
DCSEM	Directorate of Construction Services & Estate Management
DESY	Deutsches Elektronen-Synchrotron
DFRP	Demonstration Fast reactor fuel Reprocessing Plant
DGFASLI	Directorate General, Factory Advice Service & Labour Institute
DGFS	DAE Graduate Fellowship Scheme
DGMO	Director General of Military Operations
DHR	Decay Heat Removal
DKDP	Deuteriated Potassium Di-hydrogen Phosphate
DLC	Diamond Like Carbon
DLLRF	Digital Low Level RF
DMG	Disease Management Groups
DMRL	Defence Metallurgical Research Laboratory
DOE	Department of Energy
DOF	Degree Of Freedom
DoPT	Department of Personnel and Training
DPS	Directorate of Purchase & Stores
DPSS	Diode Pumped Solid State
DRX	Dynamically Recrystallized
DSA	Dynamic Strain Ageing
DSC	Differential Scanning Calorimeter
DSRDM	Diverse Safety Rod Drive Mechanism
DSS	Decision Support System
DTDD	DAE Technology Display and Dissemination
DTRI	DAE Technologies for Rural India
DVR	Dynamic Voltage Restorer
DWT	Double Wedge Tuner
EBM	Evidence Based Medicine
EBSD	Electron Back-Scattered Diffraction
ECCS	Emergency Core Cooling System
ECIL	Electronic Corporation of India Limited
EDI	Electro-De-Ionisation
EDXA	Energy Dispersive X-ray Analysis
EDXRF	Energy Dispersive X-ray Fluorescence
EED	Electro-Electrodialysis
EGMO	European Girls Mathematics Olympiad
EHSST	Electro Hydraulic Servo Shake Table
EIA	Environmental Impact Assessment
ELCINA	Electronics Industries Association
EMAT	Electromagnetic Acoustic Transducers
EMI	Electromagnetic Interference
EMS	Environmental Management System

ABBREVIATIONS

EMTR	Emergency Load Transfer Test
EOI	Expression of Interest
EPA	Electrical Penetration Assembly
EPR	Evolutionary Pressurized water Reactor
EQ	Environmental Qualification
ESI-MS	Electrospray Ionization-Mass Spectrometry
ESPS	Electrostatic Plate Separators
ESCADA	Electrical Supervisory Control and Data Acquisition
ESP	Environment Stewardship Programme
ETT	Electronic Topological Transition
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
FCIPT	Facilitation Center for Industrial Plasma Technology
FBR	Fast Breeder Reactor
FD-OCT	Fourier Domain Optical Coherence Tomography
FEL	Free Electron Laser
FFD	Fuel Failure Detection
FFSA	Failed Fuel Subassembly
FIP	Farmers Integration Programme
FMTF	Fuelling Machine Test Facility
FMS	Flight Motion Simulator
FPC	First Pour of Concrete
FPDs	Full Power Days
FRENA	Facilities for Research in Experimental Nuclear Astrophysics
FRFCF	Fast Reactor Fuel Cycle Facility
FSC	Flexible Screw Conveying
FTIR	Fourier Transform Infrared
FTPC	Forward Time Projection Chamber
FVDTM	Fruit Vegetable Dip Treatment Machine
GAIL	Gujarat Agro Industries Corporation Ltd
GCNEP	Global Centre for Nuclear Energy Partnership
GEM	Gas Electron Multiplier
GFA	General Framework Agreement
GGA	Generalized Gradient Approximation
GHAVP	Gorakhpur Anu Vidyut Pariyojana
GIXRD	Grazing Incidence X-Ray Diffraction
GMP	Good Manufacturing Practices
GPCB	Gujarat Pollution Control Board
GSO	General Services Organisation
GUI	Graphics User Interface
HAADF	High Angle Annular Dark Field
HBCSE	Homi Bhabha Centre for Science Education
HBNI	Homi Bhabha Nationa Institute
HDR	High Dose Rate
HEPA	High Efficiency Particulate Attenuator
HFRR	High Flux Research Reactor
HFU	Horizontal Flux Unit
HILS	Hardware-in-the Loop Simulation
HIRS	Hydrogen Isotope Removal System
HIS	Hospital Information System
HPCL	Hindustan Petroleum Corporation Limited
HPGe	High Purity Gemanium
HPR	High Pressure Rinsing
HRDD	Human Resource Development Division
HRI	Harish-Chandra Research Institute
HRTF	Hydrogen Recombiner Test Facility
HTRS	High Tension Roll Separator
HTSC	High Temperature Superconductor
HT-XRD	High Temperature X-ray Diffraction
HWB	Heavy Water Board
HSPCB	Haryana State Pollution Control Board
IAEA	International Atomic Energy Agency
IANCAS	Indian Association of Nuclear Chemists and Allied Scientists
IASCC	Irradiation Assisted Stress Corrosion Cracking
IBSD	Ion Beam Sputter Deposition
ICAR	Indian Council of Agricultural Research
ICM	Injector Cryo-Module
ICRH	Ion Cyclotron Resonance Heating
ICTS	International Centre for Theoretical Sciences
IDMT	Inside Diameter Measurement ToolIECIncident & Emergency Centre
IETP	Integrated Effluent Treatment Plant
IFRT	Integrated Facility for Radiation Technology
IFTM	Inclined Fuel Transfer Machine
IGCAR	Indira Gandhi Centre for Atomic Research
IHTR	Innovative High Temperature Reactor
IICHEP	Inter-Institutional Centre for High Energy Physics
IIFC	Indian Institute Fermilab Collaboration
ILL	Institut Laue-Langevin
IMO	International Mathematics Olympiad
IMS	Ion Mobility Spectrometer
IMSc	Institute of Mathematical Science
INGA	Indian Nuclear Gamma Array
INMO	Indian National Mathematics Olympiad
INO	India-based Neutrino Observatory
INPO	Institute of Nuclear Power Operation
INPRO	Innovative Nuclear Reactors and Fuel Cycles
INRP	Integrated Nuclear Recycle Plant
IOP	Institute of Physics
IPG	Iron Phosphate Glass
IPR	Intellectual Property Rights
IPR	Immovable Property Return
IPR	Institute for Plasma Research
IPWR	Indian Pressurised Water Reactor
IREL	Indian Rare Earths Limited
IRMA	Immunoradiometric Assay
IRSIS	Infrared Spectroscopic Imaging Survey
ISI	In-service Inspection Campaign
ISOCAD	Integrated System of Computer Aided Dosimetry
ITER	International Thermonuclear Experimental Reactor
ITF	Integrated Test Facility
ITFT	Integrated Thermal Hydraulic Test Facility
IVRI	Indian Veterinary Research Institute
JNPP	Jaitapur Nuclear Power Project
KAMINI	KAlpakkam MINI Reactor
KAPP	Kakrapar Atomic Power Project
KARP	KAlpakkam Reprocessing Plant
KKNPP	Kudankulam Nuclear Power Project
KMC	Kalpakkam Management Committee
KNILA	Kalpakkam Nuclear Installation Local Authority
KTL	Kilo Temperature Loop
LBNE	Long Baseline Neutrino Experiments
LBE	Lead Bismuth Eutectic
LEHIPA	Low Energy High Intensity Proton Accelerator
LEPS	Low Energy Photon Spectrometer
LEU	Low Enriched Uranium
LHC	Large Hadron Collider
LHCD	Lower Hybrid Current Drive
LIBS	Laser Induced Breakdown Spectra
LLCB	Lead-Lithium Cooled Ceramic Breeder
LOCA	Loss of Coolant Accident
LORA	Loss of Regulation Accident
LORI	Loss of Regulation Incident
LPI	Liquid Poison Injection
LREE	Lighter Rare Earth Elements
LTE	Low Temperature Evaporation
LZC	Liquid Zone Control
MABB	Marker Assisted Backcross Breeding
MaPLE	Magnetized Plasma Linear Experimental
MAPO	Mixed Alky Phosphine Oxide

ABBREVIATIONS

MAPS	Madras Atomic Power Station
MCF	Medical Cyclotron Facility
MCG	Magnetocardiography
MCHFR	Minimum Critical Heat Flux Ratio
MCR	Main Control Room
MCSD	Multi-wire Cathode Strip gas Detector
MDA	Minimum Detectable Activity
MDBFP	Motor Driven Boiler Feed Pump
MDIMJ	Monoblock Distributor with Integrated Microfluidic Junctions
MEBT	Medium Energy Beam Transport
MED-TVC	Multi Effect Distillation-Thermal Vapor Compression
MEE	Multiple Effect Evaporator
MEG	Magnetoncephalography
MEK	Methyl Ethyl Ketone
MFCI	Molten Fuel Coolant Interaction
MGMI	Mining, Geological and Metallurgical Institute of India
MHC	Mobile Hot Cell
MoEF	Ministry of Environment and Forest
MOIS	Medical Oncology Information System
MOM	Mangal Orbitor Misssion
MoPP	Monazite Processing Plant
MoU	Memorandum of Understanding
MOVPE	Metal-Organic Vapour Phase Epitaxy
MRKIET	MRK Institute of Engineering & Technology
MROD	Multisource Remote Operating Device
MRT	Mean Residence Time
MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
MSP	Mineral Separation Plant
MSG	Management Services Group
MUCH	Muon Chambers
MULLaRP	Mungbean, Urudbean, Lentil, Lathyrus, Rajmash and Pea
MUSIC	Multi Ultrasonic Sensor InspeCtion
NBC	National Building Code
NBHM	National Board of Higher Mathematics
NCC	New Community Centre
NCERT	National Council of Educational Research and Training
NDPCI	Nuclear Data Physics Centre of India
NFC	Nuclear Fuel Complex
NIE	Newspaper in Education
NISER	National Institute of Science Education & Research
NNSA	National Nuclear Security Administration
NOLM	Nonlinear Optical Loop Mirror
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NPR	National Population Register
NPR	Nonlinear Polarization Rotation
NRB	Nuclear Recycle Board
NSCI	National Safety Council of India
NSSS	Nuclear Steam Supply System
NTC	National Training Course
NTPF	Niobium Thermit Production Facility
NTTF	NPCIL Thermal Hydraulic Test Facility
OCT	Optical Coherence Tomography
ODS	Oxide Dispersion Strengthened
OHSMS	Occupational Health and Safety Management System
OLIC	Official Language Implementation Committee
ORMoN	Online Radon Monitoring Network
OSCOM	Orissa Sand Complex
PAHR	Post Accident Heat Removal
PALS	Positron Annihilation Lifetime Spectroscopy
PARD	Passive Autocatalytic Recombiner Devices
PAT	Profit After Tax
PAT	Porous Alumina Templates
PASS	Particle Aerodynamic Size Separator
PCD	Programmed Cell Death
PCI	Peripheral Component Interconnect
PCP	Primary Coolant Pumps
PCP	Probabilistically Checkable Proof
PCRD	Passive Catalytic Recombiner Devices
PCT	Patent Co-operation Treaty
PDHRS	Passive Decay Heat Removal System
PEC	Pulsed Eddy Current
PEEM	Photo Emission Electron Microscopy
PES	Photoelectron Spectroscopy
PFBR	Prototype Fast Breeder Reactor
PFCV	Proportional Flow Control Valves
PFRC	Plasma & Fusion Research Committee
PHT	Primary Heat Transport
PHWR	Pressurised Heavy Water Reactors
PIP	Proton Improvement Plan
PIP	Position Identification of Perforation
PLF	Plant Load Factor
PLIS	Performance Linked Incentive Scheme
PLSR	Partial Least Square Regression
PMD	Photon Multiplicity Detector
PMT	Potassium Metal Plant
PMT	Photomultiplier Tube
PREFRE	Power Reactor Fuel Reprocessing Plant
PRL	Prefabricated Ring Liner
PRSI	Public Relation Society of India
PRTRF	Power Reactor Thorium Reprocessing Facility
PSD	Position Sensitive neutron Detectors
PSR	Primary Shutoff Rods
QCD	Quantum Chromo-Dynamics
QWR	Quarter Wave Resonators
RABiTS	Rolling Assisted Biaxially Textured Substrate
RAFMS	Reduced Activation Ferritic Martensitic Steel
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RBC	Red Blood Cell
RCR	Regional Centre for Radiopharmaceuticals
RECAPP	Regional Centre for Accelerator-based Particle Physics
RFCCL	Randomisation of Face Centred Cubic Lattice
RFID	Radio Frequency Identification
RFQ	Radio Frequency Quadrupole
RHIC	Relativistic Heavy-Ion Collider
RIA	Radioimmunoassay
RIB	Radioactive Ion Beam
RICMASS	Rome International Centre for Materials Science and Super Stripes
RMC	Radiation Medicine Centre
RMO	Regional Mathematics Olympiad
RPhP	Radiopharmaceuticals Production
RPPO	Renewable Power Purchase Obligation
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RTC	Regional Training Course
RTD	Residence Time Distribution
RTE	Ready-to-Eat
SANS	Small Angle Neutron Scattering
SAR	Safety Analysis Report
SAU	State Agricultural University
SAXS	Small Angle X-ray Scattering
SBO	Station Blackout
SCADE	Safety Critical Application Development Environment
SCC	Super Conducting Cyclotron
SCC	Stress Corrosion Cracking
SCRF	Super Conducting Radio Frequency
SDU	Sodium Di Uranate
SEM	Scanning Electron Microscopy

ABBREVIATIONS

SERC	Structural Engineering Research Centre
SGDHR	Safety Grade Decay Heat Removal
SHPB	Sub-harmonic Pre Buncher
SIA	Social Impact Assessment
SINP	Saha Institute of Nuclear Physics
SMD	Standard Magnet Dewar
SMES	Superconducting Magnetic Energy Storage
SOEC	Solid Oxide Eelectrolyser Cell
SOER	Significant Operating Experience Report
SPAC	Standing Project Appraisal Committee
SPIM	Summer Program in Mathematics
SPF	Special Plan for Fisheries
SPME-GCMS	Solid Phase Micro Extraction-Gas Chromatography-Mass Spectrometry
SPND	Self Powered Neutron Detector
SPP	Solvent Production Plant
SPS	Spark Plasma Sintering
SRDMS	hut-off Rod Drive Mechanism
SRGT	Shut off Rod Guide Tube
SRS	Synchrotron Radiation Source
SRV	Safety Relief Valves
SSFM	Structural Steel Floor Module
SSRP	Solid State Reaction Process
SSRT	Slow Strain Rate Testing
SST	Steady-state Superconducting Tokamak
SSTP	Stainless Steel Tube Plant
STEM-EELS	Scanning Transmission Electron Microscopy coupled Electron Energy Loss Spectroscopy
STEP	Southern Tsete Fly Eradication Project
SUT	Sodium Uranyl Tricarbonate
SWRO	Seawater Reverse Osmosis
TARA	Trombay Akola Red Arhar
TBM	Test Blanket Module
TBP	Tributyl Phosphate
TBR	Terabit Router
TCF	Technical Cooperation Fund
TCO	Transparent Conducting Oxides
TCS	Tri Chloro Silane
TDBFP	Turbine Driven Boiler Feed Pump
TDC	Technology Development Council
TD-OCT	Time Domain Optical Coherence Tomography
TDP	Technology Demonstration Plant
TDR	Technical Design Report
TDS	Total Dissolved Solids
TEM	Transmission Electron Microscope
TFC	Thin Film Composite
TFS	Tritium Filled Self-luminous
THM	Total Heavy Mineral
ThRR	Thermal Research Reactor
TiAP	Tri-isoamyl Phosphate
TID	Total Integrated Dose
TIFR	Tata Institute of Fundamental Research
TIMS	Thermal Ionization Mass Spectrometry
TLD	Thermo Luminescence Dosimeters
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TMS	Target Motion Simulator
TMS	Translation Management System
TNPCB	Tamil Nadu Pollution Control Board
TOF	Time of Flight
TOPO	Tri-Octyl Phjosphine Oxide
ToR	Terms of Reference
TRISO	TRIstructural ISOtropic
TRIUMF	TRI University Meson Factory
TSM	Technical Support Missions
TSO	Trainee Scientific Officers
TTIP	Titanium Tetra Isopropoxide
TXRF	Total Reflection X-ray Fluorescence
UCIL	Uranium Corporation of India Limited
UHV-MOT	Ultra-High Vacuum Magneto-Optical Trap
UKAS	United Kingdom Accreditation Services
UMRT&EH	Upgradation of Metal Reduction Technology & Effluent Handling
UNRC	Uranyl Nitrate Raffinate Cake
UOF	Uranium Oxide Facility
URP	Unique Radiolytic Product
USUSS	Under Sodium Ultrasonic Scanner
VCIIS	Vacuum Control Interlock and Information System
V-DBL	Visible Diagnostics Beamline
VECC	Variable Energy Cyclotron Centre
VFD	Variable Frequency Drive
VFU	Vertical Flux Unit
VRF	Variable Refrigerant Flow
VSI	Voltage Source Inverter
VSSP	Versatile Solvent Synthesis Pilot Plant
VTS	Vertical Test Stand
VVPAT	Voter Verifiable Paper Audit Trail Printers
WANO	World Association of Nuclear Operators
WHO	World Health Organization
WIP	Waste Immobilization Plant
WNA	World Nuclear Association
WSN	Wireless Sensor Networks
X-DBL	X-ray Diagnostics Beamline
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
XRR	X-Ray Reflectivity
YMD	Yellow Mosaic Disease
YMV	Yellow Mosaic Virus
ZDNO	Zirconium Di-Nitrate Oxide
ZIET	Zonal Institute of Education and Training



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