GOVERNMENT OF INDIA

DEPARTMENT OF ATOMIC ENERGY

ANNUAL REPORT
2016-17

सत्यमेव जयते

Government of India

Department of Atomic Energy

ANNUAL REPORT

2016-17

Front cover: Kudankulam Nuclear Power Project Unit-1 & 2

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

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

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

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

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

During the year 2016-17, 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

The Nuclear Power Corporation India Limited (NPCIL) is a dividend paying company with AAA credit rating by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. At present, NPCIL operates 21nuclear power reactors (including RAPS-1, which is under long shutdown and belongs to DAE) with a total installed capacity of 5780 MWe. In addition, the second unit of Kudankulam Nuclear Power Project (KKNPP-2, 1000 MWe LWR) in Tamilnadu is generating infirm power. It was synchronized to the Southern Grid for the first time on August 29, 2016 and is expected to commence commercial operation by the end of the current Financial Year 2016-17. The unit was dedicated to Indo-Russian partnership and Cooperation jointly by the Hon'ble Prime Minister of India and HE President of Russian Federation. First pair of indigenously designed 700 MWe Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (KAPP-3&4) followed by second pair at Rawatbhata in Rajasthan (RAPP-7&8) are under construction. NPCIL in all its endeavours is committed towards upgradation, continuous improvement in Quality Management, Quality Assurance/ surveillance, Pre-Service Inspection/ In-Service Inspection and interface with regulatory body.

Power Generation

During the Calendar Year 2016, NPCIL recorded highest ever power generation of 38781 Million Units (including 900 MUs infirm power from KKNPP-2) which was about 1.1 % higher than the generation of 38364 MUs in the last Calendar Year 2015.

During the Financial Year 2016-17, NPCIL has registered a total power generation of 29138MUs (including 900 MUs infirm power from KKNPP-2) till December 31, 2016. The expected power generation for the Financial Year 2016-17 is about 39500 MUs (including expected 2300 MUs infirm power from KKNPP-2).

During the Financial Year 2016-17, the overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 79% and 81%

respectively till December 31, 2016. In the previous year 2015-16, the overall PLF and AF were 75% and 77% respectively.

During the year 2016, KGS-3 achieved continuous run for more than a year (409 days). So far, this feat has been achieved 21 times by various reactors operated by NPCIL.

Projects under Commissioning

Kudankulam Nuclear Power Project (KKNPP) Unit-2 (1000 MWe LWR)

Kudankulam Nuclear Power Project Unit-1 & 2

The Unit-2 of Kudankulam Nuclear Power Project achieved its First Criticality on July 10, 2016. Various post-criticality tests and low power physics experiments were successfully completed. This unit was synchronized to Southern Grid for first time on August 29, 2016. Subsequently, reactor power was raised in stages and all the mandatory tests at various power levels were carried out as per requirement and generated 899.79 MU as infirm power till December 31, 2016. In January 2017, reactor power has been raised upto 100% power level for test operation. The Unit is expected to commence commercial operation by the end of FY 2016-17.

Projects under construction

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

In Unit-3, all main plant civil construction works were completed except Inner Containment (IC) and Outer Containment (OC) dome concreting. IC dome structure was put in place and preparation for concreting is continuing for Inner Containment (IC) dome. Various equipment/ components are being progressively delivered and their erection works are in progress. Welding of Steam Generator (SG) Reactor Header piping is in progress. Turbine Condenser tubing work has already been commenced and is in progress. Cumulative piping fabrication and erection of 143217 inch-dia and 215754 inch-meter respectively in common services piping and 145551 inch-dia and 77192 inch-meter in Primary Piping package are completed for Unit-3&4. The overall physical progress of the unit is about 84% as of end of December-2016.

In Unit-4, civil works are in progress. Concreting of IC wall Ring beam has been completed. All internal civil structure works are also completed. The overall physical progress of the unit is about 70%.

Kakrapar Atomic Power Project Unit 3 & 4

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

Civil and Mechanical works in various fronts are in progress. 400KV Switchyard has been charged and synchronized.

In Unit-7, major milestone “Installation of Calandria Tube” has been completed and installation of Coolant Tubes is in progress. The overall physical progress of the unit is about 69% as of end of December-2016.

Rajasthan Atomic Power Project -7&8

In Unit-8, End shields & Calandria have been lowered and aligned in Calandria Vault and welding is in progress. In Reactor Building (RB)-8, work for Inner Containment wall is in progress. The overall physical progress of the unit is about 57% as of end of December-2016.

Sanctioned Projects

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

Siting consent from AERB, Environmental Clearance (EC) and Coastal Regulation Zone (CRZ) clearance from MoEF, consent for establishment under Air act and Water act from TNPCB, approval for construction of Hydro Technical Structures (HTS) for KKNPP -3-6, AERB clearance for excavation of main plant buildings etc. exists. Excavation for Unit-3 pit and Unit-4 pit is completed. Excavation for other structures like tunnels and intercepting drain areas are under progress. Contracts have been signed with Atomstroyexport (ASE), Russian Federation (RF) for supply of Long Manufacturing Cycle (LMC) equipment & First Priority equipment, development of working documentation, supply of equipment and materials (BOP Phase-1) and supply of equipment and materials from Third Countries. First Priority Design Works (FPDW) contract signing with ASE, R.F.is completed. Application for AERB consent for First Pour of Concrete (FPC) is under review by AERB.

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

Administrative approval and Govt. financial sanction, MoEFCC clearance for plant site, siting consent from AERB and consent to establish from Haryana State Pollution Control Board exists. Land for the project has already been acquired. Order for transfer of land to NPCIL has been issued by Haryana Government for Residential Complex. Erection of meteorological tower, precast boundary wall erection, commissioning of construction power of 11 KV/415 V, internal access road (Phase-1) etc. are completed. Geotechnical investigations are completed and final report is generated. Ground improvement scheme for main plant and site administrative building is submitted and site mock-up trials are completed. Tendering activities are in progress for long delivery equipment/components, main plant engineering works, etc. Excavation clearance is under review by AERB. Work of Neighbourhood Development Programme (NDP) is also gaining momentum for the Project. Other pre-project activities are in progress

New Project / Sites

Various pre-project activities like Land Acquisition, Rehabilitation & Resettlement, Environmental studies, Site studies, Regulatory submissions, Public outreach, Techno commercial discussions, etc. are in various stages of progress for sites, having “In Principle” approval of the Govt., namely Jaitapur in Maharashtra, Chutka and Bhimpur in Madhya Pradesh, Mahi Banswara in Rajasthan, Mithi Virdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga Unit-5&6 in Karnataka and Haripur in West Bengal. Land is available at Jaitapur and Kaiga-5&6 sites. Land acquisition is in the advanced stage at Chutka and Mahi Banswara and same is in process for Kovvada. Commitment for water is yet to be confirmed by Madhya Pradesh State Government for Bhimpur site. At Mithi Virdi and Haripur, land is to be acquired.

Quality Assurance

Quality Assurance/Surveillance activities are being carried out expeditiously by NPCIL for projects and stations. Corporate reviews of operating stations have been conducted based on WANO guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO.

FRONT END FUEL CYCLE

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

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

Heavy Water Production

Heavy Water Board (HWB) has contributed successfully to the first stage of Nuclear Power Programme by producing Heavy Water for all Pressurized Heavy Water Reactors in a cost effective manner enabling the Department to provide nuclear power at an affordable cost to public. Presently, Heavy Water Board is not only self-sufficient in meeting the domestic demand of heavy water, but is also geared up to supply heavy water for the future PHWRs and AHWRs as per the envisioned nuclear power programme of DAE. The largest Heavy Water Plant in the world, HWP, Manuguru has completed 25 years of operation and surpassed 5 Million Kg production of nuclear grade heavy water during the period.

Over a period of time, HWB has emerged as the largest global producer and a trusted supplier of heavy water. HWB continued to nurture and facilitate R&D activities in the area of non-nuclear applications of deuterium and heavy water in life sciences, pharmaceuticals and technology. Many Indian companies and leading research institutions are now regularly sourcing heavy water from HWB instead of importing the same, for their research work and producing deuterated compounds as NMR solvents.

Performance of the Board during the period was excellent with respect to production, specific energy consumption, on stream factor and plant safety. As per the Annual Action Plan for the year 2016-17, major Turnaround of Exchange Unit-II of HWP, Manuguru was completed during the period including commissioning of the new DCS system. HWP, Thal has also completed Annual Turn Around during the period. The specific energy consumption at all the plants including the non-productive consumption during the planned shutdown period is less than the target. The overall specific energy consumption is the lowest ever figure achieved so far. This could be achieved mainly due to continual and meticulous review of the process parameters to ensure optimum levels of plant operation. Consequently, during the period Board could surpass the production target by more than 15.8% and also achieved 125.1% of overall capacity utilization.

Preliminary activities for restart of HWP, Tuticorin such as plant health assessment and design adequacy evaluation of plant structure under revised Seismic & Tsunami condition has been initiated.

The Heavy Water Board achieved more than 115% of targeted production for the financial year 2016-17 and the specific energy consumption was 27.9 (GJ/Kg D_2O).

Diversification Activities

After meeting the primary mandate, HWB has

made major progress on the extended mandate on development, demonstration and deployment of technologies for in-core and out of core material inputs for Indian Nuclear Power Program such as solvents for front and back end hydrometallurgical operations of nuclear fuel cycle; demonstrating Solvent Extraction technologies for nuclear hydrometallurgy; producing stable isotope like ^{10}B for Fast Breeder Reactors (FBR); production of nuclear grade Sodium for FBR's and production of ^{18}O for societal applications.

Solvent Technology

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

At HWP, Tuticorin, the diversified activities for development of technology for synthesis of new organo-phosphorus solvents in the Versatile Solvent Synthesis Pilot plant (VSSP) is in progress. The plant is in operation for synthesis of TiAP, D2EHPA II, DHOA and TAPO in campaign mode as scheduled. Small quantities of these novel solvents were supplied to BARC/NFC/IGCAR for R&D applications. HWB has initiated setting up of Solvent Production Plant (SPP) for industrial scale production of these solvents with an objective to achieve self-reliance. HWB is also planning to take up synthesis of some special solvents viz. DGA, Calixarene etc. based on collaborative efforts with DAE unit as requested by them.

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

Boron Enrichment

In consonance with the material input required for second stage of NPP based on FBRs, HWB, with its decades of experience of handling isotope separation process, under took initiatives like development, demonstration and deployment of indigenous technologies for production of enriched Boron. In order to support the progress of PFBR , HWB has successfully delivered the entire quantity of enriched Boron for its 1st core. India has marked a place in the world along with only few countries possessing such capability.

Sodium Metal

The operation of the 2000 Amp test cell for production of Sodium metal is continued to further fine tune the process and establish performance of cell components. Assimilation and analysis of the data from the trial operation is being done for improvement in the proposed industrial unit of 600 MTPA at Baroda.

Mineral Exploration and Mining

Atomic Minerals Directorate for Exploration and Research (AMD) continued the accelerated pace of exploration activities during the year by integrated, multi-disciplinary methodology and judicious utilization of man power with a focused approach on augmentation of uranium, thorium and rare metals. This resulted in the augmentation of additional uranium oxide (U_3O_8) reserve of over 15,011 tonnes in the areas of Andhra Pradesh, Meghalaya, Rajasthan and Jharkhand. The country's uranium reserve has been updated to 2,44,947 tonnes of Uranium Oxide (U_3O_8).

Significant uranium anomalies were located in Himachal Pradesh, Meghalaya, Madhya Pradesh, and Chhattisgarh. About 1,71,122.30 m reconnoitory, exploratory and evaluation drilling was carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of uranium and REE mineralization in the new promising areas. Significant mineralized intercepts/bands have been identified in boreholes drilled at Andhra Pradesh, Tamil Nadu, Jharkhand, Meghalaya, Rajasthan and Madhya Pradesh.

Exploratory mining site at Rohil uranium deposit, Sikar district, Rajasthan

Potential/significant blocks have also been identified at Rajasthan, Meghalaya, Andhra Pradesh, Karnataka and Madhya Pradesh.

Geochemical surveys (3,840 sq km) have been carried out in different parts of the country for delineating the target for detailed investigations. Ground geophysical surveys (719.35 sq km) have delineated conducting zones in Rajasthan and high chargeability zones in Jharkhand Karnataka and Madhya Pradesh. Airborne survey and remote sensing survey has also been carried out over 28,740 line km in parts of Rajasthan and Chhattisgarh.

Rare Metal and Rare Earth (RMRE) investigations have successfully located significant concentrations of RMRE along Chhattisgarh and Odisha.

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

The performance of all major units of the company during the year 2016-17 remained quite satisfactory. The Tummalapalle Uranium Project at Andhra Pradesh is nearing completion and sufficient ore has been stockpiled. The underground mine has achieved full production capacity. Re-dissolution System facility in the Plant has been successfully completed and implemented. Second stream of the Processing Plant has been made operational.

Exploratory mining activities by UCIL on behalf of AMD at Rohil Uranium Project located at Sikar district of Rajasthan has already been started. Decline development and portal excavation is in progress. Identification of water sources and preparation of 3D ore body modeling is in progress.

Pre project activities have been taken up at Gogi Uranium Project located at Yadgir district of Karnataka. Land acquisition has been completed (government land) except tailings pond area. Construction of Mine Water Treatment Plant is in progress.

UCIL intends to revive the processing of copper tailings at Musabani in Jharkhand for recovery of uranium bearing minerals under the project Musabani Uranium recovery Plant. Pre project activities have been initiated and baseline environmental studies have been completed.

UCIL have proposed to carry out a few de-bottlenecking activities in Singhbhum and Tummalapalle units. Tendering and work order are in progress for Debottlenecking of Singhbhum and Tummalapalle operations project in different units.

UCIL has outlined a plan for massive expansion of production potential in line with DAE's vision for self-sufficiency in production of Uranium in the next 15 years. This includes plan to maintain sustained supply from existing facilities, capacity expansion of some existing units and construction of new production centers in different parts of the country. Work has been initiated for exploratory mining project to be undertaken by UCIL on behalf of AMD at Rohil in Rajasthan, Gogi in Karnataka and Singridungri-Banadungri in Jharkhand.

The major achievements of IREL included the Sale Purchase Agreement with M/s Toyota Tsusho Corporation, Japan: Culminating from the Inter Government Agreement signed by the Government of India and Japan for co-operation in the field of rare earths. During the year 2016, IREL has supplied over 1,200 tons of RECL on dry metric ton basis to TREI. IREL

expects to supply substantially higher tonnage to TREI during the 2nd contract year.

To produce Samarium-Cobalt (Sm-Co) magnet for meeting national objectives, a Special Purpose Vehicle (SPV) has been developed. Production of Sm-Co metal & Magnet is based on technologies developed by BARC, Mumbai & DMRL, Hyderabad. Activities for firming up the investment, plant location etc. are under progress.

A MoU has been signed with BARC, Mumbai for setting up of a 5 Million Liters per Day (MLD) desalination plant at OSCOM, Odisha as a part of field applications of indigenous desalination technology in various DAE units.

Supply of Nuclear Grade Ammonium di-Uranate (NGADU) from new source i.e. the newly commissioned monazite processing plant at OSCOM, Odisha has been commenced.

Approval has been received for entering into production sharing contract viz. concession & profit sharing options with land owners having surface rights within IREL mining lease area with a view to mitigate the difficulties in sourcing land for raw material of the Southern operating units of IREL.

Patent application on 'Solvent extraction process for Rare Earths (RE) separation through partial reflux of RE in solvent' has been filed.

Large-scale leach circuit for H2SO4 processing of U ores was installed at TDPP, Jaduguda alongwith interconnecting piping lines. Studies on leaching of U from the Rohil-Ghateswar U ore were carried out. A hollow fibre liquid membrane technique was developed to separate rare earths from rare earth magnetic scrap (Nd:17%, Pr:5%, Dy:2.5%, Fe:75% and B:1%) in HNO3 using organophosphorus extractants D2EHPA and DNPPA.

Fuel Fabrication

Nuclear Fuel Complex (NFC) manufactures and supplies fuel bundles for Pressurised Heavy Water Reactors (PHWRs) and Boiling Water Reactors (BWRs) of NPCIL. Highest ever production of PHWR fuel bundles, Zirconium Oxide, Zirconium sponge and Niobium metal was achieved during the period.

All the tubes, components of Fuel Pins and hardware for subassemblies, $DDUO_2$ Blanket Pins, Enriched B_4C Absorber Pins, Sb_2O_3 Neutron Source Pins, various fabrication processes and equipment developments, etc., required for fabrication of 10 types of sub-assemblies, including their final assembly fabrication work (at IFSB, IGCAR) was completed for the First time in the Country and all these Subassemblies are stored in IFSB for further deliverying to BHAVINI. Three nos. of source sub-assemblies are awaiting AERB clearance for final assembly work to meet the commissioning schedule of 500 MWe PFBR.

Two new projects were proposed during MTA in addition to the 13 projects sanctioned during XII plan. Sanction was obtained for pre-project activities of NFC-7 proposed during MTA. Financial sanction is awaited for one project and revised sanction is awaited for two projects. These projects were launched to meet the fuel and zircaloy requirements of forthcoming 700 MWe PHWRs and 300 MWe AHWR, in addition to augmentation and modernisation of the present production facilities, in line with the demand from M/s NPCIL. In addition preliminary project report is under preparation for setting-up a project at proposed site of Kurnool to meet the requirements of 12 x 1000 MWe VVERs and 2 nos. of 500 MWe FBRs.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

All the fuel reprocessing plants performed at their designed capacities. Power Reactor Fuel

Reprocessing Plant-2 (PREFRE-2), Tarapur achieved designed throughput. Kalpakkam Reprocessing Plant (KARP) performed well. Advance Fuel Fabrication Facility (AFFF), Tarapur supplied MOX fuel to PFBR. Spent Fuel Storage Facility (SFSF), Tarapur and Kalpakkam were in operation. A solvent for selective recovery of Pu (IV) from lean sources (HLLW after Purex and different metallurgical waste) was synthesised.

The treatment of intermediate level liquid waste for isolation of radionuclides in the Waste Immobilization Plants (WIP), Tarapur and Kalpakkam created record by uninterrupted processing at the highest throughput. The Solid Waste Management Facility (SWMF) and low level liquid waste treatment plants in Tarapur and Kalpakkam performed satisfactorily to meet the DAE requirements. Spent resin cementation system for MAPS was commissioned in WIP, Kalpakkam. Entire legacy resin stored in MAPS was received and removed by fluidisation and successfully fixed in cement matrix. A 2000 Te Supercompactor for compaction of hull waste was designed, manufactured and tested.

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 In-Service Inspection system 'PRESAM 220' was developed for sag measurement of pressure tubes in 220 MWe PHWRs. Remotely operated Advanced Drive Machine is designed, commissioned and demonstrated in simulated reactor conditions for inspection of coolant channels of 540 MWe reactors. Detailed finite element analysis was carried out for accounting elastic-plastic and creep deformation for severe accident scenario of a large loss of coolant accident, loss of emergency core cooling system, moderator heat sink to ensure in vessel corium retention. An ultrasonic technique using an angle beam was developed to detect the presence of zirconium oxide nodules in pressure tubes of PHWR during in-service inspection. The structural integrity assessment of Reactor Pressure Vessel in presence of flaws discovered during in-service inspection of welds during the 24th Re-Fuelling Outage was performed for granting license to TAPS-2 power plant for further operation. A methodology was evolved for assessment of uncertainty in the sizing of flaws and their location with respect to the weld-centre line and the scanning surface. Required number of Control Blade assemblies for TAPS-1&2 were fabricated & supplied. A high temperature pyrohydrolysis (PH) system operating up to 1500°C for extracting halides and boron from several refractive materials, which cannot be pyrohydrolysed with the normal PH apparatus, has been indigenously designed and developed. A plant wide networked Radiation and Gas Monitoring System was designed, developed and delivered for Compact Light Water Reactor Project.

HEALTH SAFETY & ENVIRONMENT

A virtual environment model of LOCA Equipment Qualification Facility was developed in 3DVIA Studio Pro software tool for generating the human factor data for a typical postulated accident scenario. A solar powered geo-station comprising an indigenous radon monitor, soil probe and an accumulation chamber for prediction of earthquakes by detecting stress release from earth's crust prior to its occurrence through sub-soil radon perturbation were developed. Two units were installed in NIT, Rourkela and SGRC, Shillong. Global fingerprint comparison software was introduced to the National Occupational Dose Registry System of BARC for effective dose control and for tracking the movement of radiation worker within DAE units. 41 Environmental Radiation Monitors (ERMs) were installed taking the ERMs deployed to 462 under the Indian Environmental Radiation Monitoring Network (IERMON) programme. A two member team from BARC carried out radiation measurements around 'Bharati' station during the 35th Indian Scientific

Expedition to Antarctica. Environmental surveillance around nuclear facilities clearly indicated that the members of public at fence post received a dose of a small fraction of regulatory limit of 1000 µSv/y and negligible compared to the dose received by the public from natural sources (2400 µSv/y).

NPCIL has recorded about 451 reactor years of safe operation of reactors by the end of December 2016. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by AERB by following the principles of As Low as Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB.

NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At all operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001: 2004 and Occupational Health and Safety Management System (OHSMS) as per IS-18001: 2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

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

NUCLEAR POWER PROGRAMME: STAGE 2

FAST BREEDER REACTORS

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

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

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

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

Prototype Fast Breeder Reactor

All the commissioning activities are in progress and preparation for preheating of all primary and secondary systems are in advanced stage. The major jobs that have been completed during the year includes: commissioning of component handling flask & subsequent retraction of pump with flask, segmental trial pre-heating of sodium pipelines, pressure run down test of inflatable seals in rotatable plugs, commissioning of shutdown mechanism, completion of pre-service inspection of 10% tubes in seven steam generators and 100% of tubes in eighth steam

Overall View of PFBR

generator, demo operation of fuel handling machines for handling the dummy & bowed sub-assembly, trial leak testing of reactor containment building and reactor assembly etc. Presently, work is in progress for commencement of integrated pre-heating. This will be followed by sodium filling, fuel loading and first approach towards criticality.

Fast Breeder Test Reactor

During the period, Fast Breeder Test Reactor (FBTR) continued to play an important role in testing the fuels, structural materials and special neutron detectors for FBR programme. Reactor power was raised to 27.3MWt on 18thJuly for the first time and turbo generator was synchronized to grid generating a power of 5.8 MWe. Around 72 Nos. of Thoria subassemblies were loaded in the twelfth ring of the reactor core towards production of Uranium-233 after discharging steel subassemblies. Twenty fifth irradiation campaign is in progress since 30thJune. Recommendations of SARCOP including post Fukushima and seismic retrofits like construction of new diesel generator flood safe building were implemented.

FBR Fuels

U-Pu mixed carbide fuel pins were fabricated and supplied to the Fast Breeder Test Reactor (FBTR). A Neutron Multiplicity Counter (NMC) was developed for the estimation of Pu from as low as 30 mg up to kg level in sealed containments. Facilities for post-irradiation examination were augmented for examination of advanced fuels and structural materials. A new test reactor facility (FBTR-2) for continuing the material irradiation programmes beyond the life of present FBTR using metal fuel, is planned and the site was also identified. Preliminary layout for the plant was prepared in line with the experience from PFBR.

Fast Reactor Fuel Reprocessing

CORAL (Compact Reprocessing facility for Advanced fuels of Lead cells) continued to operate and reprocess the spent fuel of FBTR. One of the significant achievement was the in-situ replacement of degraded radiation shielding window for the first time with minimum man-REM expenditure. Pyro-chemical reprocessing of Uranium-Zirconium fuel (100 grams) in a hot cell facility was successfully demonstrated. Construction of the Fast Reactor Fuel Cycle Facility (FRFCF) and fabrication of major components for the same are gaining momentum.

FBR Related Technologies

The R&D activities for the fast reactors and associated fuel cycle included Numerical analysis of total instantaneous blockage single fuel subassembly; Investigation of sodium fire and hydrogen production following a core disruptive accident; Simulation of rapid voiding scenario under severe accident conditions in FBR; Design and development of Electromagnetic Pumps; Design and Development of Electromagnetic flow meters; Performance test of Diffusion Bonded Ultrasonic Transducer in Silicon oil; Qualification of mutual inductance type level probe using indigenously manufactured mineral insulated cables; Testing of gate valve shield plug; Indigenous development of 450NB sodium frozen seal butterfly valve; Numerical study on impurity precipitation in cold trap and its validation by experiment using surrogate solution; Sodium cooled pool hydraulic studies using large scale water model and

Experimental investigation of PFBR source pin wettability using water as test medium.

Future FBRs

A significant number of experimental facilities were commissioned during the current year, such as the large scale (5/8) water-model test facility for hydraulic studies and validation of design concepts for the future FBRs, facility based on travelling heater method for growing single crystals of CdZnTe (CZT) for application in room temperature semi-conductor radiation detectors and advanced dual beam ion irradiation facility for injecting helium, 1.7 MV Tandetron accelerator for irradiation by heavy ion beam etc.

Significant progress was made in the design of twin units of 600 MWe FBRs and conceptual design of major systems was completed incorporating the latest design standards. A processor based CPU card was developed for diversified real time computer systems for future FBRs in collaboration with ANURAG, DRDO.

Health, Safety & Environment

An indigenous fully-automated Waste Assay Computed Tomography (WACT), nested modelling system, for national, regional and local scale atmospheric dispersion studies and a decision support system for nuclear emergencies were also developed. Multi-purpose high-performance parallel computing cluster with 180 teraflops was commissioned.

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD personnel monitoring services, covering about 3000 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 750 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for about 140 occupational workers were also carried out.

In-situ/in-house testing of more than 110 HEPA filters was completed. Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated. Various samples around active facilities and other samples for low level counting and determination of the radioactivity from different institutions and industries were also catered to.

Radon measurements were carried out on natural samples. Gamma monitors calibration facility was commissioned.

Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Environment, industrial, fire and occupation health awareness programmes were also conducted successfully for employees.

NUCLEAR POWER PROGRAMME: STAGE 3

THORIUM BASED REACTORS

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

Advanced Heavy Water Reactor

Passive Containment Isolation System for AHWR was designed to prevent release of radioactivity into environment in the event of an accident. Models have been developed to simulate the wall and bulk condensation in presence of non-condensable gases and to simulate the typical post-LOCA steam laden atmosphere of the containment of a Nuclear Power Plant.

Other Thorium Reactor Systems

Preliminary safety analysis report for Molten Salt Breeder Reactor Developmental Facility (MSBRDF), Vizag was completed. Scheme for production of hafnium free anhydrous zirconium fluoride starting from anhydrous zirconium chloride was worked out. Procurement of zirconium fluoride for initial studies and X-ray Diffraction (XRD) examination of the salt was completed.

KAlpakkam MINI (KAMINI) Reactor

KAMINI reactor was licensed for operation till June 2020, after periodic safety review. It continued to support the testing of pyro devices for ISRO and also for activation analysis and irradiation of various samples.

Research Reactors

DHRUVA operated with a high level of safety upto 100 MWth at an availability factor of 72% and capacity factor 61% benefiting researchers from various academic institutions across the country. More than 700 samples were irradiated for radioisotope production. Neutron Radiography and Tomography Facility was commissioned in DHRUVA to meet imaging needs of BARC and other organizations such as ISRO. Construction of refurbished APSARA reactor pool, annex building, pump house and dump tank was complete. Preparation and review of preliminary safety analysis report, part-A and preliminary architectural drawings of the structures of the high flux research reactor have been completed.

ADVANCED TECHNOLOGIES

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

Accelerators

A single-cell 650 MHz (β=0.92) Superconducting Radio Frequency (SCRF) cavity has been fabricated, processed, and tested using facilities set up at RRCAT. RRCAT has initiated fabrication of HB 650 MHz (β=0.92) five-cell bare cavity. Design and fabrication of various cavity fabrication tooling and fixture like forming tooling, welding, and machining fixtures have been completed.

World's first multi-cell laser welded SCRF cavity (a 5-cell laser-welded SCRF cavity) has been fabricated at RRCAT. It is a very cost effective alternative to the conventional and expensive electron beam welding technology which is currently being used internationally for this application. The technology of laser welding of SCRF cavities has been granted international patents in USA and Japan.

5-cell laser welded superconducting radio frequency cavity

For the development of high voltage DC and pulse power supplies for IMS based explosive detection

system being developed at ECIL, compact high voltage pulsed supplies required for the drift tube of the IMS detector were developed by RRCAT. The proposal for technology transfer for these power supplies is in process.

Development of high stability, high power capacitor charging power supply to be used to charge pulsed power circuit capacitors of septum / kicker pulsers at a repetition rate of 25 Hz has been done. A 10 MeV electron linear accelerators (linac) with 5 kW power output in long duration has been developed for agricultural, medical and industrial applications.

The first signature of lasing at 34 µm wavelength has been successfully observed in the indigenously developed infra-red free electron laser (IR-FEL). End to end beam dynamics simulation studies for the 1 GeV H- injector linac for Indian Spallation Neutron Source was carried out. Studies of power threshold of ferrite and garnets for high power circulators were also carried out.

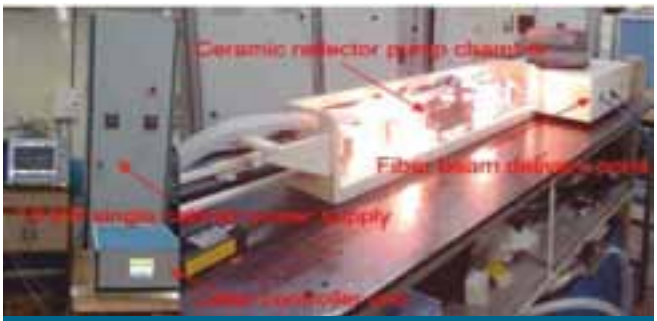
The Pelletron-Linac facility achieved 80% uptime by November, 2016 delivering various ion beams. A three-electrode Atmospheric Pressure Plasma Jet was developed for better, quicker and effective decontamination. Amidoamine functionalized multi-walled carbon nanotubes (MWCNT-AA) prepared by surface organic reactions on CNTs have shown higher uptake capacity (101 mg/g at pH 6) for Hg(II) ions compared to conventional sorbents and pristine CNTs. 99.9% pure BeO powder was produced in the Beryllium Facility, BARC. Specific shapes of high density BeO were supplied to ISRO for heat sink application in communication satellites. A dual power supply was designed and developed for Backward Wave Oscillator system. A 1 GW pulsed S band microwave source is designed and developed for microwave-plasma interaction studies in Institute of Plasma Research, Gandhinagar. A 500kV, 10kA, 100ns flash X-ray system with cable fed source was developed as an import substitute for ISRO. This system performs dynamic radiography of moving and deforming objects. Solar thermal technology based on beam up concept with various systems of 20 kW solar thermal test facility like heliostats, receiver system based on coupled natural circulation and air cooled condenser was demonstrated in BARC. The knowhow was transferred to BHEL and NTPC for detecting health of turbine blades in thermal power plants. A state of the art six degrees of freedom, 500Kg servo hydraulic shake table meeting IEEE 344 STD was developed and commissioned in BARC.

A Digital Holographic Microscope system was developed for imaging phase objects such as living cells which generally have only refractive index contrasts amongst their structures. High resolution seismic data recorder, which can be interfaced with broadband seismometer, for large dynamic range seismic signals with an accuracy of 1 msec was developed.

An important development of Superconducting RF (SRF) cavity for high intensity proton linear accelerator under the IIFC collaboration took place at VECC. A single-cell niobium cavity has been designed and developed in-house, with the help of Electron Beam Welding (EBW) facility at IUAC, New Delhi. The test result shows a remarkable achievement with a maximum accelerating gradient attained 34.5 MV/m, which the highest value achieved so far in the world, in case of LB650 cavity.

Laser Technology Development and Applications

An NdYAG laser system based on compact



A view of in-house developed 630 W average power pulsed Nd:YAG laser

ceramic reflector and single flash lamp pump chamber has been developed at RRCAT. The laser provides maximum pulse energy of up to 12 J in 10 ms pulse duration having laser beam diameter of 4 mm. A double-lamp ceramic reflector based pump chamber and NdYAG laser system providing a maximum average output power of 630 W and 13 kW peak power in ms time duration has been developed for laser cutting of irradiated FBTR components in hot cell at IGCAR.

RRCAT has designed and developed a prototype laser radiator unit, substitute for imported laser, for defence applications for laser guiding of a missile fired from a tank to hit a moving target. An all-fibre thulium-doped CW fibre laser (TDFL) has been developed with stable CW output power of 18 W centred at 1940 nm with sub-nanometre line width. These lasers have wide applications in material processing of metals and non-metals, surgery, defence, and space applications. A mode locked ytterbium (Yb) doped fibre laser producing a train of 500 fs pulses at 45 MHz repetition rate has also been developed. A lab model of frequency doubled narrow-line-width CW ytterbium-doped fibre laser emitting 5 W at 515 nm with narrow line width of ~0.07 nm has been developed for dye-pumping applications.

A table-top model of high power pulsed blue laser source operating precisely at 456 nm wavelength has been developed. The laser provides average output power of 1.2 W in pulses of duration 400 ns at 20 kHz repetition rate. Pulsed blue laser source precisely at 456 nm finds potential application for deep sea under water communication.

Blue laser under operation

A 2 kW RF-excited FAF (fast axial flow) CO2 laser with an all solid state modular RF power supply has been developed for material processing applications. The laser system is compact and reliable in operation with novel features such as power stability with better beam quality suitable for laser material processing applications. The laser is capable of operating in quasi-CW and pulse mode due to RF excitation.

Four engineered models of DPSS green lasers each delivering ~40 W of average power at 532 nm at 6.25 kHz repetition rate with less than 40 ns of pulse duration have been indigenously developed. The lasers incorporate all the major operational and safety features and exhibit excellent power, pulse, and beam pointing stability. The lasers have been delivered to BARC for resonance ionization experiments.

DPSS green laser under operation with fiber coupling

A MoU has been signed between RRCAT and NPCIL for development and deployment of remotely operable laser systems and advanced laser cutting techniques for refurbishment of nuclear reactors. In situ laser cutting of liner tube, end-fitting, bellow lip weld joint, and underwater cutting of PT stubs for Q-15 and N-6 coolant channels of KAPS-2 reactor was carried out for confirmation of presence of corrosion and nodules along with its post-irradiation examination data for future operation and en masse coolant channel replacement of KAPS-2 reactor. This cutting procedure

Mock-trial for laser cutting of bellow lip after removal of outboard end-fitting

was not possible by conventional mechanical methods due to space restrictions.

The other technologies developed at RRCAT for various applications included the development of distributed temperature monitoring system using in-house fabricated fibre Bragg grating (FBG) distributed sensors; Design and development of a Raman probe for measurement of artefact-free Raman spectra from (in-vivo) tissues; Raman spectroscopy and optical coherence tomography for investigating human oral mucosa; Off-confocal Raman spectroscopy (OCRS) for depth-sensitive measurements of layered turbid samples; Development of orthogonal polarization spectral imaging system; Ultrafast shadowgraphy using high harmonic generation (HHG) Source; Development of a magneto-optical trap for Rb atoms on atom-chip and Development of high average power laser marker.

Electronics & Instrumentation

The Electronics Corporation of India Limited (ECIL) continued to remain engaged in the design, development, manufacture, supply, installation and commissioning of electronic equipment for the Atomic Energy, Defence, Aerospace, Security, Information Technology and e-Governance sectors. Some of the new products introduced during the year were Development of prototype GEM foils required for

Plastic Scintillator based Portal Monitoring System (PMS)

VECC used in their modern advanced detectors; Laundry Monitoring System; SiPM / Scintillator based Detectors and development of Prototype plastic Scintillator based Portal Monitoring System (PMS)

BARC has developed an indigenous device called "ANU NISHTA" to ensure cyber security of Instrumentation and Control systems of Nuclear Power Plants. BARC and ECIL have developed an indigenous Ship Borne antenna Terminal for ISRO missions for tracking of re-entry modules and launch vehicles of ISRO's future manned space missions.

RADIOISOTOPES & RADIATION TECHNOLOGY AND THEIR APPLICATIONS

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

Radioisotopes are produced in the research reactors at Trombay, accelerator at Kolkata and the various nuclear power plants of NPCIL. During the report period, a wide variety of radioisotopes for medical, industrial and research applications were produced and supplied by BARC. The Board of Radiation and Isotope Technology (BRIT) produced and supplied a wide range of radioisotope products,

and radiation technology equipment for medical and industrial uses. BRIT's plants for radiation sterilization of medical products and radiation processing of spices and allied products continued to offer services to medical and agro-industry. Radiation technology based tools and techniques benefitted variety of industries and social sector.

Agriculture

Two new mustard seed varieties TM108-1 and TM2014, were developed by radiation-induced mutation in plant breeding. An advanced variety TRR-1 of the aromatic rice was developed through γ ray-induced mutation breeding.

Food Technology

Electron beam irradiation of rice and wheat seeds was done at RRCAT, using dual scattering system for obtaining the necessary low dose irradiation for BARC, Punjab Agricultural University, Ludhiana and Indira Gandhi Krishi Vishwavidyalaya, Raipur.

Processes for increasing shelf-life and reduce post-harvest losses of processed mango, banana, papaya and pineapple were developed. An indigenous technology for extending the shelf-life of litchi has been developed at BARC using Generally Recognized As Safe (GRAS) chemicals. A cost-effective process for the production of Xanthan gum was developed using a laboratory isolate of Xanthomonas campestris. A nontoxic, non-hazardous and safe bio-degradable oxocatalyzed polyolefin film was developed using electron beam/γ irradiation for food packaging application.

BARC-processed litchi even after 60 days

Nuclear Medicine and Healthcare

BRIT supplied 700 Ci of I-131 products in 22500 consignments to various hospitals in the form of capsules and solution for both, diagnostic and therapeutic purposes for thyroid disorders and treating thyroid cancer.

^{50}Ci of other therapeutic products such as ^{153}Sm, ^{177}Lu and ^{32}P for bone pain palliation were supplied to nuclear medicine hospitals up to December 2016. New ready-to-use radiopharmaceutical product, ^{177}Lu-DOTATATE injection developed, successfully tested on patients at RMC, BARC. RPC clearance is awaited for the product to launch it in market.

1282 consignments containing 455 Ci of ^{99}Mo for Technetium-99m Generators to obtain ^{99m}Tc at hospital end have been supplied to various hospitals in India.

More than 13829 consignments of Technetium-99m cold kits for imaging various organs have been supplied to nuclear medicine centres in India. Recertification and accreditation for 'cGMP-Pharma Products' by United Registrar of Systems was completed for the production of '^{99m}Tc-Radiopharmaceutical cold Kits' during the reported period. New product, ^{99m}Tc-cold kit developed by BRIT for preparation of ^{99m}Tc-Macro Aggregated Albumin (MAA) injection, useful for lung perfusion imaging has been approved by Radiopharmaceutical Committee (RPC), DAE. Radiopharmaceutical Committee (RPC) approval is also obtained for extension of shelf-life (expiry date) of Technetium-99m cold kits, DTPA, Phytate & MIBI injections, from existing 6 months to one year and

extension of expiry date for ^{99m}Tc-Sulphur Colloid cold kit from existing 100 days to six months.

New in-cell roof hanging and remote operated, decapping tool, for use of radioactive liquid vials, developed and installed in production plants.

Around 353 radiopharmaceutical samples and 36 ^{99}Mo-^{99m}Tc COLTECH Generators were routinely analysed and certified by QC during the report period.

RPC approval obtained for the following quality control procedures: (a) Alternate BET method for TCK cold kits analyses; (b) QC methods for new products to be launched by BRIT, such as, ^{177}Lu-DOTATATE; ^{99m}Tc-MAA cold kits and ^{99m}Tc-UBI.

GMP compliance achieved for batch manufacturing records of 12 TCK products.

Labelled compounds Programme of BRIT continued the synthesis and supply of a variety of ^{14}C, ^{3}H and ^{35}S-labelled products and various types of Tritium-Filled self luminous Sources (TFS). Since April 2016, more than 26000 TFS sources of various sizes and shapes were supplied to defence establishments.

Based on MoU between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers.

The Medical Cyclotron Facility (MCF) of BRIT continued the synthesis and supply of Positron Emitting Tomography (PET) radiotracers, the maximum being [F-18]-FDG. Other PET radiopharmaceuticals include [F-18]-NaF, [18F]-FLT, [18F]-FMISO and [F-18]-FET, which are produced in smaller scales.

[F-18]-Fluro Ethyl –L- Tyrosine ([18F]-FET) was cleared by Radiopharmaceutical Committee (RPC) for regular supply. This will be used for biopsy guidance and treatment planning of cerebral gliomas.

So far 263 Ci of F-18 FDG have been supplied to various hospitals in Mumbai for PET imaging upto December 2016.

Alternative Applications of Heavy Water

Realizing the potential requirements of Oxygen-18 having application in nuclear medicine and bio-chemical research i.e. in PET scanning and Metabolic studies, HWP, Manuguru has successfully commissioned the first indigenously developed Oxygen-18 water production plant.

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 Institute Council of Agricultural Research, Indian Veterinary Research Institute, Institute of Plasma Research, TIFR etc., have shown their interest in this area and HWB has supplied small quantities of heavy water to support their R&D jobs.

As part of developmental activities on non-nuclear uses of Heavy Water, methods for synthesizing deuterated NMR solvents have been developed at HWP, Baroda in laboratory scale. As part of MoU signed between HWB & BRIT, BRIT is marketing these solvents to various reputed research institutes in the country.

Cancer Diagnostics & Treatment Services

TMC prides itself in providing multidisciplinary treatment to all cancer patients irrespective of their socioeconomic strata. Cancer treatment were administered based on established protocols to reduce variance and promote quality for improved outcomes. A concerted effort has been made through the National Cancer Grid to educate caregivers in all participating centres to adopt protocol based treatment. Surgery remained the bedrock of treatment for solid tumours. Approximately, 6500 major surgical procedures including minimal invasive and Robotic Surgeries were

performed during the year. The full-fledged Medical Oncology & Radiation Oncology Departments treated patients solely or in conjunction with their Surgery counterparts. Special facilities for Haematological Malignancies including a Bone Marrow Transplantation Unit; State of the Art facilities for Intensity Modulated Radio Therapy (IMRT) and Image Guided Radio Therapy (IGRT) were available. The establishment of a Proton Beam Therapy at ACTREC will enhance the capability to give high precision radiotherapy especially in children.

Industrial Applications of Radioisotopes & Radiation

At BRIT, nine teletherapy sources (CTS) of ^{60}Co containing activity in the range of 164 and 226 RMM were supplied to different cancer hospitals in India and abroad. 69 Nos. of sealed sources containing Cs-137 with a total activity of 16474 Ci were loaded into 6 units of Blood Irradiator 2000. Eighty eight Irradiator sources of industrial grade in eight consignments with total activity of 14, 38, 169 Ci (1438 kCi) were supplied to nearly eight radiation processing plants within the country. Another 675 kCi of activity is planned to be sent to three processing plants within India and one to Sri Lanka. A total of 749 numbers (with total activity of 33, 987 Ci) of ^{192}Ir & nine numbers of ^{60}Co Radiography sources containing 255 Ci of activity were supplied to NDT users. Another 400 sources with activity 16000 Ci of ^{192}Ir and five numbers with activity of 150 Ci of ^{60}Co is expected to be supplied upto March 2017.

One consignment each of Sc-46 and Cs-137 Custom Made Reference sources (CMR) of 6.9 Ci and 970 mCi respectively were also supplied upto December 2016. Another fifteen Cs-137 CMR sources with 6500 mCi is planned to be supplied soon. Three numbers of Co-60 CMR with total activity of 427mCi were supplied till December 2016, while another five sources with 500mCi is planned to be supplied in March 2017. Licence for operation of Integrated Facility for Radiation Technology (IFRT) has been obtained from AERB and for the first time sealed sources were fabricated and handled at IFRT, Vashi.

BARC continued its support to the Indian industry for troubleshooting, measurement of hydrodynamic parameters, flow visualization and design evaluation in industrial process systems using radiotracer techniques. Radiotracer based thin layer activation technique was applied to estimate the wear of automobile disc gear material in the presence of lubricants. The first large scale facility to hygienise sewage sludge using Radiation Technology is expected to be operational by August 2017. A polyurethane based foam modified through γ radiation grafting technique has been developed to separate oil/water from layered as well as from emulsified oil/water mixture. Dual energy x-ray baggage scanning system was indigenously developed.

Radiation Processing

About 5860 Cubic meters of medical supplies have been sterilized using gamma radiation processing at ISOMED, BRIT upto December 2016. About 3985 MT of spices and other products like herbal raw material, pet feed, color powder etc. were processed during the reported time period. NABL accreditation for calibration of dosimetry laboratory of RPP, Vashi was continued after the initial surveillance audit during this period. Dose rate certification was provided to eight blood irradiators and four gamma chambers which were supplied to various cancer hospitals and research universities respectively. BRIT signed four MoU's for setting up Gamma Radiation Processing Plants for disinfestations, shelf-life extension of food products and sterilization applications of healthcare products, each with M/s Suzaina Foods Pvt. Ltd. at Kundh, Chikli District, Navsari, Gujarat, M/s KGS Agrotech Pvt. Ltd. at Saiwad, Jaipur, Rajasthan, M/s. Gaur Chemtech, Rohini, Delhi and M/s. Pinnacle Therapeutics Pvt. Ltd., Vadodra, Gujarat.

At BARC, 169 batches of radiochemicals of activity 2940 Ci (109 TBq) consisting of radioisotopes ^{99}Mo, ^{131}I , ^{177}Lu , ^{153}Sm, ^{32}P, ^{125}I and ^{51}Cr were processed and supplied to BRIT for the formulation of radiopharmaceuticals. 676 laboratory reference sources and 178 custom-made special sources were commercially supplied to various users through BRIT. 249 ^{125}I sources were supplied for ocular and prostate brachytherapy. Radiopharmaceutical Committee (RPC) of DAE approved the supply of indigenously developed ^{68}Ge / ^{68}Ga generator, ^{131}I-Lipiodol and kit based formulation of ^{188}Re-HEDP injection for radionuclide therapy of hepatocellular carcinoma.

Radiation Technology based Equipment & Services

100 Radiography Cameras, ROLI-2 model were supplied to various NDT users within India and services were provided for 658 numbers of BRIT and imported radiography cameras. Two Blood Irradiators – 2000 (BI-2000) units with Cs-137 source were supplied to hospitals in India. One Gamma Chamber – 5000 unit have been supplied to Crop Research Unit, Research Directorate Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Kolkata for research purposes. A specialized anthropomorphic head and neck dosimetry audit phantom was designed and developed for credentialing advanced radiotherapy techniques.

Water Purification, Water Desalination & Isotope Hydrology

Isotope hydrological investigation was initiated in Ranchi urban area to understand the mechanism of groundwater recharge. BARC developed the know-how for preparation of thin-film composite based sea water reverse osmosis membrane for desalination of highly saline/sea water.

BASIC & APPLIED RESEARCH

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

Mathematics & Computational Sciences

At TIFR, research has been carried out in the fields of Algebra and Algebraic Geometry, Differential Geometry, Number Theory and Combinatorics, partial differential equations and stochastic differential equations. The School Of Technology and Computer Science (STCS) has pursued the study of important topics in the areas of computer science as well as systems science. Number theory, Algebra and Geometry and Analysis are the broad heads under which important contributions have come from HRI. New results have been obtained in the area of zero-sum problems with weights. At IMSc, the work related to lattice Boltzmann methods for fluid flow computation has led to a start-up company. The School of Mathematical Sciences at the National Institute Education of Science & Research (NISER) has worked on mathematical programmes

Physics

Mechanical structure of MACE telescope is nearing completion. A facility for the design and fabrication of neutron super mirrors has been established. Different types of devices based on scintillator crystals have been developed. TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) is used to search for VHE photons from various galactic and extra-galactic sources. Thin film coatings of Polytetrafluoroethylene (PTFE) over glass were developed by RF magnetron sputtering for application as super-hydrophobic/oleophobic, antireflection and protective coatings. In-situ X-ray diffraction on Lithium metatitanate (LTO) and lithium metazirconate (LZO)

were studied under high pressure to explore their possible application in thermonuclear reactors. Superconductivity in a crystalline high entropy equi-atomic composition alloy (Hf-Ti-Ta-Nb-V) was observed for the first time. ANUINDRA ASIC has been developed, fabricated and tested for front-end readout of the proposed silicon tungsten calorimeter (FoCAL) as part of ALICE upgrade for High Energy Physics experiments at CERN.

At TIFR, one of the major achievement was the successful launch of AstroSat satellite carrying five science payloads on board. The discovery of superconductivity in a high quality single crystal of Bismuth at 0.00053 K with a critical magnetic field of 0.000005 Tesla. TIFR has significantly contributed to the CMS experiment going on at the Large Hadron Collider (LHC) by analysing data to confirm the presence of the standard model Higgs boson which was discovered earlier.

At VECC, among the important experimental results from nuclear physics research, the study of cluster correlation in the binary breakup of ^{24,25}Mg, level density parameter in A~210 region, isospin mixing in ^{32}S are the most significant ones. Two important detection systems related to gamma ray spectroscopy have been developed as a part of the 'Advanced Nuclear Physics Research' project.

IOP focussed on the research in the fields of theoretical and experimental condensed matter physics, theoretical high energy physics and string theory, theoretical nuclear physics, ultra-relativistic heavy-ion collisions and cosmology, quantum information and experimental high energy nuclear physics.

Synchrotrons and their Applications

The synchrotron radiation sources, Indus-1 and Indus-2 at RRCAT were operated in round-the-clock mode as a national facility. The beam availability to the users was more than 7200 hours for Indus-1 and more than 5200 hours for Indus-2. The undulators U1 and U2 installed in 2015 in Indus-2 were successfully operated at enhanced beam currents in excess of 150 mA. The third insertion device, namely, the APPLE-2 undulator was commissioned this year with demonstration of enhancement in brilliance. A number of optimization steps were employed to re-establish operation of Indus-2 at 200 mA with reduced vertical aperture of vacuum chamber at the APPLE-2 undulator location. The machine was run at 2.5 GeV, 200 mA in user mode. Four injection kicker ceramic chambers of Indus-2 ring were replaced with new upgraded chambers which has led to a significant improvement in vacuum and hence the beam life time.

The Advanced Plane Polarized Light Emitter (APPLE-2) undulator installed in Indus-2 last year was commissioned. The effect of undulator action on the orbit stability with low beam current (5 mA) at 2.5 GeV was studied. No significant distortion of the orbit during magnet pole gap and phase movement was found. Indus-2 was operated at higher current (2.5 GeV, 100 mA) with vertical jaw movement of APPLE-2 up to the minimum pole gap. There was no significant change in beam life time and temperature of vacuum chamber.

Design, development, and installation of an upgraded version of fluorescent type Beam Profile Monitor (BPM) for Indus-2 was carried out. The upgraded BPMs have been designed for fail safe operation, improved actuation and guiding to reduce the force required for actuation, and provision of positioning and referencing with global and local coordinates. Further, upgraded Beam Position Indicators (BPIs) were designed, developed, and installed in LS-1, SS-1 and SS-8 straight sections of Indus-2 ring, replacing the old devices. This upgraded version of BPI has improved design features like high frequency compatible 50Ω impedance SMA feedthrough, and NdYAG laser welded coaxial electrode sub-assembly. Software development for bunch-by-bunch betatron tune measurement has been carried out to obtain the

Beam Profile Monitor installed in Indus-2 ring

information about betatron tune of individual electron bunches in Indus-2.

Performance improvement of the cooling tower water loop of the Low Conductivity Water (LCW) plant has been achieved through introduction of online weak acid cation polisher and dosing of calculated quantity of sulfuric acid to the cooling tower to control water chemistry.

The effect of residual gas molecules in Indus-2 storage ring on the gas bremsstrahlung dose rate was studied. The dose rate was found to be 3 times lower than estimated by assuming same gas composition as air at atmospheric pressure, which is the conventional practice world over.

In Indus-2, the shielding evaluation for undulator based beamline hutch was carried out using FLUKA Monte Carlo code and the shield requirement was optimized. An aluminium prototype broadband kicker RF cavity for Longitudinal Multi-Bunch Feedback System (LMBFS) for Indus-2 has been designed, fabricated and tested.

Four modified, upgraded ceramic vacuum chambers for kickers in Indus-2 have been installed in Indus-2. This has improved the average vacuum of the Indus-2 ring and increased the beam life time to more than 30 hours at 100 mA and 2.5 GeV. The average

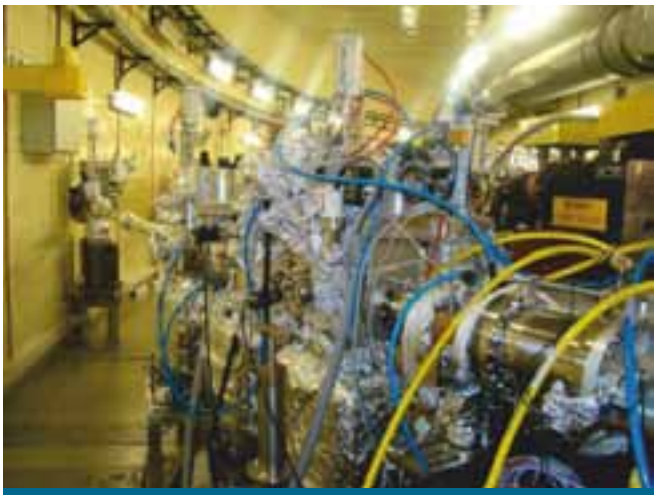
Half cell of kicker RF cavity

vacuum in the ring is now 3 x 10^{-10} mbar as compared to 9 x 10^{-10} mbar with the old ceramic chambers.

Design and development of an upgraded pulsed injection thin septum magnet with better field homogeneity (1x10^{-3}) and reduced stray fields outside the septum has been carried out for Indus-2. This will result in improved injection efficiency.

More than 600 user experiments were carried out at the Indus-1 and Indus-2 beamlines in the calendar year 2016, leading to about 100 publications in peer reviewed international journals.

Significant efforts have been put in towards the development of new beamlines and their related facilities. These include the installation of the radiation shielding hutch of the Engineering applications beamline, installation of the monochromator of the ARPES beamline, procurement of the gratings and the other optical components for the ARPES beamline etc. The front end for Indus-2 soft x-ray beamline (BL-26) has been installed and tested and vacuum of the order of 10^{-9} mbar has been achieved. Some of the components like pre-mask, water cooled beam viewer, scanning wire monitor etc. of the undulator U-3 based X-ray magnetic circular dichroism beamline (BL-20) front end have been designed, indigenously fabricated and installed in



Front end part installed in BL-5 AMOS beamline

Indus-2. A part of the front-ends for AMOS beamline (BL-5) on U-1 undulator and ARPES beamline (BL-10) on U-2 undulator have been installed. The remaining components of these front ends like water-cooled shutters, safety shutters, water-cooled masks, beam viewer and vacuum chambers are designed, fabricated and tested for 1x10-9 mbar vacuum.

A computer-controlled flow setup to enable in situ time-resolved X-ray Absorption Spectroscopy in the Energy Dispersive EXAFS beamline BL-08 in INDUS-2 was developed to study reactions under special experimental conditions. Toroidal Spectrometer was developed for the Angle Resolved Photo Electron Spectroscopy (ARPES)/PEEM.

Fusion and Other Plasma Technologies

The Facilitation Center for Industrial Plasma Technology (FCIPT) has contributed significantly towards exploiting various plasma phenomena for potential societal benefits through short term projects and technology transfers to various industries. In an another significant development, Remote Handling and Robotics Technology Development (RHRTD) group has realized low cost solution for Virtual Reality (VR) facility in the laboratory. In long term societal benefit category, fusion plasma activity dominates and in this direction, assembly work of upgraded version of first Indian tokamak, Aditya is completed. In Tokamak (SST-1)

Radical plasma nitriding system developed in FCIPT

project, experimental campaign XVIII had obtained Tokamak plasma discharges where plasma currents are in in excess of 112.5 kA in a central field of 1.5T with plasma density ~ 0.8- 1.0 x 10^{13} cm^{-3} and electron temperature in excess of 200 eV are obtained. Plan of indigenizing the technology available elsewhere either by collaboration through participation in the experiments or through fundamental developments is continued. The Guwahati campus named Center for Plasma Physics, has contributed strongly through programs

Chemistry

Several benzene-centred tripodal diglycolamide (DGAs) and DGA-dendrimers were synthesized for the first time and evaluated for their efficacy in actinide separation. A high performance liquid chromatographic method using α-hydroxyl isobutyric acid as an eluent was established to separate different oxidation states of Pu such as Pu(III), Pu(IV) and Pu(VI) from each other. At TIFR, a novel functionalised

nanomaterial for carbon dioxide capture was developed, which has superior capture capacity and stability over conventional materials. Fluorescent and magnetic resonance imaging sensors for biologically essential molecules and ions were designed and developed.

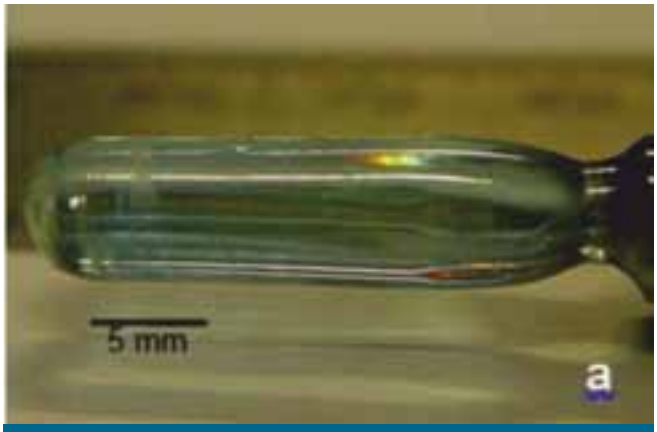
Biology

At TIFR, some of the crucial studies include role of Cholestrol in fighting pathogens; role of proteins to control fat metabolism in the liver; dynamics of a cytoskeletal protein; role of a transcription factor (Lhx2) in determining neuronal development; control mechanisms that regulate insulin secretion; malarial parasite biology; Pathogenic Mutations etc. A non-toxic herbal radioprotector BRP, developed at the centre provided 80-82% survival to mice against whole body γ-irradiation (8.5 Gy). A natural wound-healing formulation PB has been developed using an Indian herb. A novel product of BinA alone has been synthesized by BinA modification to kill the larvae of Culex and Anopheles mosquitoes and control of the diseases borne by them. A protocol for biofilm formation has been developed at BARC using an Indian cyanobacterium, Nostoc muscorum. At SINP, the widely prevalent diseases such as leukemia, Alzheimer's and the Prion diseases are being investigated for gaining insights into the diseases.

Materials Science

The various research activities undertaken at RRCAT on material science included the study of the temperature and magnetic field dependence of heat capacity of two superconducting skutterudite compounds LaPt4Ge12 and PrPt4Ge12; Large magnetoresistance and magnetocaloric effect in TbFe2Al10; Surface oxides and their role on the optical response of high-purity niobium used in the superconducting radio frequency cavities; Giant magnetocaloric effect near room temperature in Mn–Co–Ge alloy; Interesting magnetic properties observed in rare earth intermetallic ferromagnet NdRu2; Establishing an analogy between resistive transition in type-II superconductor with viscous flow of disordered solids; Testing of Pt-CA catalyst for D/H isotope exchange under bi-thermal condition; Magneto-photoluminescence a tool for the investigation of quantum structures; Invisibility in Nanoscale Effect on Optical Limiting; Role of plasmon resonance on quantum dot photo-luminescence; Theory and Computational Activities; Light-induced synthesis of silver nanoparticles with tunable plasmonic response; Fabrication of polymer based photo-voltaic cells and Understanding the effect of Anti Phase Domains (APD) in GaP/Si by Raman and AFM microscopy study.

Several high quality single crystals were grown by different techniques for various applications. These include single crystals of Nd doped $GdVO_4$ for laser host applications and Ce doped Lithium Tetra Borate (LTB) for Thermos Luminescence (TL) dosimetry. Further, rare-earth doped transparent ceramics for laser-host (Nd doped YAG/Y_2O_3 and Yb,Tb co-doped Y_2O_3) and scintillation (Ce doped YAG) applications have been fabricated by nano-powder technique and subsequent



Single crystal of NdGdVO4

vacuum sintering.

An electropolishing technology was developed to polish SuperNi42 (Ni:Cr:Mo::57:42:1) alloy fuel tube of LWR for fabrication of ECT (Eddy Current Testing) standard in fuel fabrication (IF3, BARC) by etching wall

thickness uniformly. UO2 coated electrodes were supplied for fabrication of Fission counters for detecting neutrons in various reactors.

At IGCAR, thin films of $Pr_{0.6}Sr_{0.4}MnO_3$ were prepared on oriented single crystalline $SrTiO_3$ and $LaAlO_3$ substrates using pulsed laser deposition. Proton irradiation studies on pure Ti and Ti-6Al-4V alloy and Proton irradiation studies on Al and Al5083 alloy were carried out at VECC.

Cancer Research

The ACTREC facility at Kharghar, Navi Mumbai continued to provide the facilities for Basic/Clinical/Translational Research. The emphasis was laid on therapies which can work well in the local context and are cost effective.

International Research Collaborations

As a part of the in-kind contribution to Facility for Antiproton and Ion Research (FAIR), Darmstadt, Germany, the first converter, a two-quadrant converter has been developed based on the design and prototyping provided by RRCAT. The converter has qualified factory acceptance tests and has been delivered to FAIR for site acceptance tests. RRCAT has successfully developed, tested and supplied two high power WR 2300 copper coated stainless steel power couplers for CERN's Linac-4 project. RRCAT scientists participated in the commissioning of the accelerating structures and the beam diagnostics for the Linac 4. The Linac-4 has been commissioned by CERN and accelerated H- ions to the rated energy of 160 MeV.

One of the WR 2300 copper coated stainless steel power couplers installed with the CCDTL accelerating structure of linac-4 tunnel at CERN

The Super Critical Water cooled Reactor (SCWR) is one of the six reactors considered in the Generation IV International Forum for safer and financially attractive reactors of the future. In order to accurately predict heat transfer characteristic of supercritical fluid a rectangular uniform diameter, Supercritical pressure natural circulation loop (SPNCL) is being operated at BARC.

The important development of Superconducting RF (SRF) cavity for high intensity proton linear accelerator under the IIFC collaboration took place at VECC. The Institute of Physics (IOP) remained actively involved in the International Collaborations with CERN (Switzerland), BNL (USA), ANL (USA), GSI (Germany), and other laboratories abroad. At TIFR, the CMS Experiment collected data from proton-proton collisions at a centre of mass energy of 13 TeV at the Large Hadron collider (LHC). SINP made critical hardware contributions to ALICE Collaboration which have been fabricated indigenously.

ITER-Project

Six segments of Base section of the Cryostat manufactured by L&T, Hazira, is undergoing welding operations for final assembly at ITER site in France. About 600 neutron shielding block are delivered to Europe and Korea. A novel concept of “pipe-in-pipe” developed to accommodate thermal expansion in buried pipes. Tritium Extraction System (TES), important in realizing Test Blanket Module (TBM) development in ITER, consisting of He Purge gas System (HPS) and a scale down HPS system was installed for concept demonstration.

Base section of Cryostat, manufactured by L&T

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. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research. The synchrotron radiation sources at RRCAT, Indus-1 and Indus-2 were operated round the clock as a national facility for the Synchrotron Radiation (SR) user community.

Human Resource Development And Knowledge Management

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a deemed to be University aided by DAE continued to nurture the academic programmes of eleven premier institutions of the DAE under a single umbrella making it a vast research and faculty resources within DAE available for students.

Training

While the academic programme of the 59th batch of BARC was continuing, screening examination for 9 engineering and 5 science disciplines for the 60th batch was organized successfully at 62 venues in 45 cities. This year Nuclear Engineering was added as 9th engineering discipline. Summer training and academic projects for BE/B.Tech/M.Tech/ ME/Engg Diploma/MSc/MCA students from all over the country were conducted. During January –December, 2016, 1606 students from different institutes visited BARC for training/project. Scientific information resources are being upgraded to provide seamless access of information to scientists and engineers in BARC and other DAE institutions.

The BARC Training School at IGCAR successfully completed its tenth year and young qualified scientists and engineers were placed in various Units of DAE. In the current batch, 36 Trainee Scientific Officers are undergoing training. As a constituent institution under Homi Bhabha National Institute, IGCAR has 153 research scholars pursuing their doctoral programmes.

Human Resources Development activities at RRCAT continued to impart training to trainee scientific officers of the BARC Training School at RRCAT and research scholars pursuing their Ph.D. degree under the framework of HBNI. Additionally every year about 130 M.Tech. and M.Sc. students from various universities and engineering collages were provided an opportunity to carry out then six month / one year project at RRCAT towards partial fulfilment of their degrees.

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

maintained across NPCIL.

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

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

Sponsored Research

Promotion of Extra-mural Research in Nuclear Science

Besides funding research projects, BRNS continued to provide the financial assistance to organize symposia/ conferences/ workshops on topics of relevance to the programmes of DAE. BRNS also awarded projects to young scientists to initiate them in a career of research and Dr. K. S. Krishnan Research Associateship to identify and encourage highly talented young scientists and technologists. The DAE Graduate Fellowship Scheme (DGFS) was provided 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 were also offered. The Homi Bhabha Chair sponsored by BRNS was instituted to avail the honourable services of Scientists and Technologists who have distinguished themselves at national and international levels.

Promotion of Mathematics

NBHM has been in charge of the Mathematics Olympiad activity for talented young students at higher secondary (the plus two) level. The 57th International mathematical Olympiad (IMO) 2016 was held at Hong Kong where the six-member Indian team secured 1 Silver and 5 Bronze Medals at the IMO-2016. The 5th European Girls Mathematical Olympiad (EGMO) 2016 was held at Bușteni, Romania where the two-member Indian team secured One Bronze Medals at EGMO-2016. NBHM continued to conduct the Madhava Mathematical Competition for the undergraduate students. NBHM gave grants to various mathematical centres engaged in activities of promoting higher mathematics.

Olympiad Programme

The Olympiad programme was conducted successfully with all 25 students trained at HBCSE securing medals, including 11 gold medals at international Olympiads. Over 200 teachers participated in various Olympiad related Exposure and Resource Generation camps.

Information Technology Application Development

Various software applications were developed and deployed in an endeavour to push E-Governance at RRCAT. These include digital signature based casual entry permit, material gate pass management etc. RRCAT web site was upgraded to latest platforms and webpages for CHSS beneficiaries, suppliers and pensioners were also added. A vehicle movement monitoring system based on UHF technology has been deployed at Guard House security. Integration of Kshitij-4 high performance computing cluster with centralized resources was accomplished and it was released to users for regular use.

As part of addressing the large-scale computational requirement, a multi-purpose parallel high-performance computing cluster, delivering a sustained numerical performance of 180 Teraflops was commissioned at IGCAR.

NPCIL has implemented many major IT enabled work processes in the area of Maintenance

Management, Material Management and Work Management in NPPs, Human Resource and Finance management and continuously improving the software applications based on the feedback from user community.

TECHNOLOGY TRANSFER

At BARC, the knowhow for detecting operating health of turbine blades in thermal power plants to BHEL & NTPC has been transferred. The technology of He MS Leak Detector was successfully demonstrated and is ready for transfer to industry. Incubation MOU for the development of Residual Gas Analyzer was signed with L&T. An incubation technology for an oral BRP formulation is being transferred to a private Indian entrepreneur. The know-how for preparation of Thin-Film Composite (TFC) based Sea Water Reverse Osmosis (SWRO) membrane capable of desalination of highly saline /sea water has been transferred. At IPR, the technologies "Atmospheric pressure plasma jet technology"; "Metal oxide nano powder production technology"; "Plasma Pyrolysis technology for organic waste" and "Atmospheric pressure inline plasma processing technology" has been transferred to private firms.

Collaborative Programmes

At BARC, a collaborative experiment on laser interaction with foam targets was undertaken. Air-worthiness qualification and Safety of Flight Tests (SOFT) have been completed in the collaborative development of indigenous Seekers by BARC and ECIL

Intellectual Property Rights

DAE-IPR Cell constituted by the Department, works as a nodal agency for all Intellectual Property Rights (IPR) related matters including filing of patents within India and abroad for all the Units including Public Sector Undertakings and Autonomous Institutions under DAE. During the financial year 2016-17, five DAE-IPR cell meetings were held. DAE filed seventeen new patent applications which includes; two application under PCT (Patent Co-operation Treaty), five in India, four in USA, three in Europe and one each in Australia, Canada & Japan. During this period, eleven of the previously filed patents have been granted to the Department. These includes; six in USA, four in India and one in Europe.

PUBLIC SECTOR UNDERTAKINGS (Financial Performance)

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

Nuclear Power Corporation of India Ltd.

The expected net Profit After Tax (PAT) for the year 2016-17 is about ₹ 2180 Cr Crore. The net profit after tax for previous Financial Year 2015-16 was ₹ 2707 Cr Crore. NPCIL bonds continued to be rated at AAA (Highest Safety) by CRISIL and CARE.

Uranium Corporation of India Ltd.

The performance of all major units of the company during the year 2015-16 remained quite satisfactory. The total income of the Company during the year 2015-16 was ₹ 1024.63 crore as against ₹ 890.24 crore in the previous year. The Company has registered a Profit Before Tax of ₹ 158.06 crore in the year 2015-16 as against ₹ 11.33 crore in the previous year. Performance of the Company in terms of MoU signed with DAE is expected to be "Good" for the year 2015-16 (Check year).

Indian Rare Earths Ltd.

During the year 2016-17, the Gross Sales

Turnover anticipated is ₹ 459.94 crore (provisional) against ₹ 362.36 crore of previous year. Anticipated PBT (Profit Before Tax) in 2016-17 is ₹ 30.67 crore (provisional) compared to PBT of ₹ 111.23 crore in 2015-16.

Electronics Corporation of India Ltd.

Against the MoU target of ₹ 1650 crore for production and net sales, the Company achieved a production of ₹ 863.20 crore and a net sales of ₹ 850.07 crore up to December 2016.

OTHER ACTIVITIES

International Relations

India is a founding member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA), continued to take active part in policy management and programmes of the IAEA. India was represented on a number of IAEA Committees, including those on safety, safeguards, nuclear radiation, nuclear engineering and application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings etc., and offered the services of its experts under the IAEA Technical Cooperation programme in a number of fields. India made contributions towards Innovative Nuclear Reactors and Fuel Cycles (INPRO), Technical Cooperation Fund (TCF) and Regular Budget of the IAEA. India actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combat Nuclear Terrorism, and India's own Global Centre for Nuclear Energy Partnership (GCNEP). Cooperation at the multilateral level in peaceful uses of nuclear energy and advancement of nuclear S&T was also promoted through active participation in the European Organisation for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER), and the Nuclear Energy Agency of OECD. India became an Associate Member of CERN on January 16, 2017. NPCIL continued to participate in various programmes of World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), Institute of Nuclear Power Operations (INPO) and World Nuclear Association (WNA) to enhance the safety and reliability of its nuclear power plants.

Science Research Council

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

Barc-safety Council

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

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

Crisis Management Group

The Crisis Management Group (CMG), a standing Committee of senior officials of the Department of Atomic Energy (DAE), is responsible for coordinating the Department's emergency preparedness and response activities to any radiation emergency in the public domain.

The CMG continued to provide its expertise in various forums in the field of nuclear / radiological emergency management at both National and International levels.

Vigilance

To ensure effective functioning of the vigilance machinery a senior officer in each of the Constituent Unit and Aided Institution of the Department has been designated as part time Vigilance Officer/Chief Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time CVOs discharges these responsibilities. The vigilance functions were continued at DAE headquarters. The vigilance week was observed during the year. NPCIL has taken number of initiatives and adopted innovative methods in spreading awareness and imparting knowledge to employees. Vigilance seminars, interactive sessions at various sites and HQs are regularly organized. A new initiative of organizing 'Outreach programmes in Schools & Colleges' was taken by NPCIL as per directives of Central Vigilance Commission (CVC).

Scientific Information Resource Management

The Scientific Information Resource Division (SIRD), BARC has been upgraded / equipped with the state-of art facilities and technology infrastructure to provide seamless access to information to BARC scientists and engineers in their day-today R&D activities and also extends its facilities to other DAE institutions. The SIRC of DAE Secretariat continued to provide the library & information services. The publications of various reports, periodicals, brochures etc. were also continued.

Public Awareness

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

During the year, DAE participated in the 104th Indian Science Congress held at S.V. University, Tirupati; The exhibition held in collaboration with Nehru Science Centre (NSC), Mumbai; Govt. Achievements and Schemes Expo' and concurrent show` Food &

Visitors at DAE pavilion during the 104th Indian Science Congress, Tirupati

Technology Expo-2016' held at Pragati Maidan, New Delhi; A two day seminar on `Applications of Radioisotopes and Radiation Technology' in `Industries, Agriculture & Healthcare was held at Amity University, Noida; The 20th National Science Exhibition with the theme `Vision of India for a New Era' was held during August 10-14, 2016 at Kolkata; Bharat Utsav 2016 held at Hyderabad, Telangana; India-IAEA Exhibition India-IAEA Joint Partnership in Peaceful Uses of Atomic Energy' during the 60th Regular Session of the IAEA General Conference held at Vienna, Austria; The 8th edition of India Nuclear Energy Summit 2016 at the Nehru Centre, Worli, Mumbai; the `Agrovision' agriculture summit held at Nagpur; National Metallurgist Day (NMD) organized by Indian Institute of Metals was held at IIT Kanpur; a two day Seminar organized by National Association for Applications of Radioisotopes & Radiation in Industry NAARRI at Thapar

University; A workshop cum Expo on Rural Technology & Innovations was organized by Centre for Studies of Popular Science at Shahjanpur, UP; Indian International Science Festival 2016 organized by Ministry of Science & Technology and Earth Sciences and Vijnana Bharati at New Delhi; A seminar on Peaceful Uses of Atomic Energy organised by United Schools Organizations of India and an exhibition organised by the Goa Science Centre, a grand festival of Science & Technology called Science Fiesta.

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

NPCIL has also been partnering with several expert agencies like National Council of Science Museums, Regional Science and Technology Centers, PR agencies, Department of Science and Technology etc. to enhance public awareness. NPCIL has set up permanent nuclear galleries at Science Centres in Mumbai, New Delhi and Chennai. NPCIL is also in the process of setting up of nuclear galleries at other science centres across the country to showcase beneficial aspects of nuclear energy in phased manner. In the smaller cities miniature galleries are also planned in large numbers to promote nuclear energy.

Social Welfare

Corporate Social Responsibility

From the inception of nuclear power programme in the county, various units of NPCIL have been implementing social welfare activities for the benefit of local population living within 16 Kilo meter radius of plant site. With issuance of Department of Public Enterprises (DPE) guidelines on CSR for Central Public Sector Enterprises (CPSEs) in 2011 and enactment of the Companies Act 2013, NPCIL has started structured programme as per the act. Under CSR programme, NPCIL is taking up the activities in the five identified thrust areas of education, healthcare, infrastructure development, skill development and sustainable development.

Swachh Bharat Mission

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

As a part of Swachh Bharat Mission, during this year, total 1478 toilets and 244 urinals have been constructed in nearby villages and schools by NPCIL and construction of another 30 toilets are expected to be completed by March 2017. In addition to this, contribution amounting to ₹ 17 Cr. to Swachh Bharat Kosh and ₹ 17 Cr. for Clean Ganga Fund is also being deposited to the concerned Government body.

Employee's Welfare

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

Right To Information Act (rti) Compliance

The Right to Information Act of Government of India which came into force on 12th October 2005 has been implemented at DAE and all its constituent units.

The provisions contained in RTI Act, 2005 were fully complied by DAE and its constituent units. The RTI applications and appeals received at DAE and its constituent units were promptly attended.

Awards & Prizes

NPCIL and its sites won several awards in areas of safety and performance, public outreach activities, CSR and Official Language. During the year 2016-17, UCIL has received a few accolades for its outstanding activities in different domains. The AMD officers were conferred with Life Time Achievement Award. ECIL has been awarded the prestigious 41st ELCINA EFY (Electronics Industries Association of India-Electronics for You) Award for excellence in Electronics in Research & Development. The HWP, Kota has received DAE's Group achievement award for installation and commissioning of Sodium Sulphate Crystallizer. The scientists from TIFR have won prestigious national awards during this period.

CHAPTER 1

Kudankulam Nuclear Power Project Unit-1 & 2

NUCLEAR POWER PROGRAMME STAGE-1

Rajasthan Atomic Power Project - 7&8

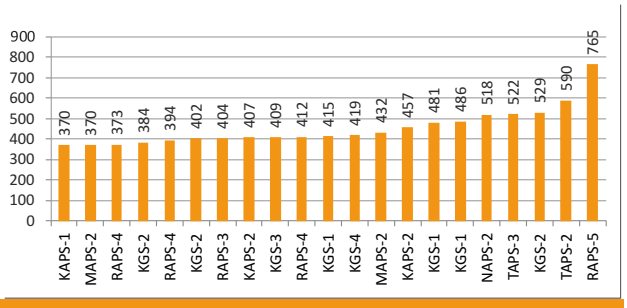
PRESSURISED HEAVY WATER REACTORS (PHWRs) & LIGHT WATER REACTORS (LWRs)

Nuclear Power Corporation of India Limited (NPCIL), formed in 1987, is a Public Sector Enterprise under the administrative control of Department of Atomic Energy (DAE). NPCIL is a dividend-paying company with an AAA credit rating by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. At present, NPCIL operates 21 nuclear power reactors (including RAPS-1, which is under long shutdown and belongs to DAE) with an installed capacity of 5780 MW. In addition, the second unit of Kudankulam Nuclear Power Project (KKNPP-2, 1000 MW LWR) in Tamilnadu is generating infirm power. It was synchronized to the Southern Grid for the first time on August 29, 2016 and is expected to commence commercial operation by the end of the current Financial Year 2016-17. The unit was dedicated to Indo-Russian Friendship and Cooperation jointly by the Hon'ble Prime Minister of India and HE President of Russian Federation. The first pair of indigenously designed 700 MW Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (KAPP-3&4) followed by the second pair at Rawatbhata in Rajasthan (RAPP-7&8) are under construction. NPCIL in all its endeavors is committed towards upgradation, continuous improvement in Quality Management, Quality Assurance/ surveillance, Pre-Service Inspection/ In-Service Inspection and interface with regulatory body.

Operating Reactors

During the Calendar Year 2016, NPCIL recorded highest ever generation of 38781MUs (including 900 MUs infirm power from KKNPP-2) which was about 1.1 % higher than the generation of 38364 MUs in the last Calendar Year 2015.

During the Financial Year 2016-17, NPCIL has registered generation of 29138 MUs (including 900 MUs infirm power from KKNPP-2) till December 31, 2016. The expected generation for the Financial Year 2016-17 is about 39500 MUs (including expected 2300 MUs infirm power from KKNPP-2).



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

The overall Plant Load Factor (PLF) and Availability Factor (AF) for all the reactors in operation were 79% and 81% respectively till December 31, 2016 during the Financial Year 2016-17. In the previous year 2015-16, the overall PLF and AF were 75% and 77% respectively.

During the year 2016, KGS-3 achieved continuous run for more than a year (409 days). So far, this feat has been achieved 21 times by various reactors operated by NPCIL.

Thirteen reactors of NPCIL viz. TAPS-1&2, RAPS-1&2, RAPS-3&4, RAPS-5&6, NAPS-1&2, KAPS-1&2 and KKNPP-1, with total installed capacity of 3380 MW, are under IAEA safeguards and operating on imported fuel. Eight reactors viz. MAPS-1&2, TAPS-3&4, KGS-1&2 and KGS-3&4, with total installed capacity 2400 MW, are operating on domestic fuel.

KAPS Unit-1&2 are under shutdown since March 2016 and July 2015 respectively for coolant channels health assessment. Subsequently, these units have been taken in project mode from August 2016 for En-masse Coolant Channels Replacement (EMCCR) & En-masse Feeders Replacement (EMFR). Various activities including procurement of components are in progress.

Projects under Commissioning

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

KKNPP Unit-1 & 2

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 Russia and India. The power generated from the project (2x1000 MWe) shall be fed to Tamilnadu and other beneficiary states in the Southern Grid. Unit-1 has been put into commercial operation with effect from December 31, 2014. Unit-2 is in final stage of commissioning. After satisfactory review, AERB granted clearance for First Approach to Criticality in June 2016. Unit-2 achieved its First Criticality on July 10, 2016. Various post-criticality tests and low power physics experiments were successfully completed. Subsequently, reactor power was raised to 30%, 50% & 75% of Nominal Power in stages and all the mandatory tests at various power levels were carried out as per requirement. Unit-2 was synchronized to Southern Grid for first time on August 29, 2016 at 30% Nominal Power Level. Since then Unit-2 has generated about 900 MUs (million kWh) as in-firm power till December 31, 2016. In January 2017, reactor power has been raised to 100% power level for test operation. The Unit is expected to commence commercial operation by the end of Financial Year 2016-17.

CMD, NPCIL on occasion first Criticality of KKNPP-2

Projects under Construction

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

KAPP-3&4

The construction activities of Kakrapar Atomic Power Project-3&4, India's first indigenously designed Nuclear Power Reactor of 700 MWe series, are presently in full swing along with commissioning of electrical and Common Service systems.

Header-Boiler pipe welding in progress in KAPP-3

In Unit-3, various common service systems viz. firewater system, chilled water system & service water system equipment erection & associated piping works has been completed and ready for system commissioning. Also 70% of circuit hydro test in Common Services piping system has been completed. Various equipment/ components are being progressively delivered and their erection works are in progress. Critical path activity of Feeder erection job shall commence in the month of March-2017. The preceding job of feeder erection i.e. header boiler piping is in progress. All main plant civil construction works are completed except Inner Containment (IC) and Outer Containment (OC) dome concreting. Finishing works of all major buildings are also nearing completion. Inner Containment (IC) dome structure has been lifted as single unit of 365 MT to the Reactor Building (RB) ring beam, which is a major milestone of the project, also a first of a kind activity in Indian nuclear history. Turbine Condensers fabrication job is nearing completion and tubes installation is in full swing and is likely to complete by April-2017. The HP and LP turbine erection works is in progress. Test charge of Start-Up Transformer (SUT) was completed in the month of Sep 2015. Class-IV, Class-III & Class-II switchgear/MCC along with associated transformers pre-commissioning has been independently completed. Various commissioning activities have commenced. The project is having constraint of delay in equipment/ components supply/erection by various vendors.

In Unit-4, Reactor Building internal structures including SG vaults, Inner Containment wall and ring beam construction completed. Also, fabrication of IC dome structure was completed. All eight Reactor Headers erection is completed in FM Vault. Major equipment's such as Pressurizer, ECCS accumulator and PDHRS tank erection is in progress. Coolant channel end fitting pre-assembly completed. Preparation for Calandria Tube rolling in FM Vault is in progress.

Overall physical progress of KAPP-3 and KAPP-4 are 84% and 70% respectively as of end December 2016.

Equipment/ components of KAPP-3&4 such as one Steam Generator, one Pressurizer, one Bleed Condenser, 5 Reactor Headers, one Low Pressure Heater (LP Heater), one Shut Down Cooler (SDC), 384 Bearing sleeves, 6 Condensate Extraction Pumps (CEP), 2 Main Boiler Feed Pumps and various quantities of valves and fittings, etc. were dispatched to site.

KAPP-3&4 has won AERB environment protection award for the year 2015.

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

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

RAPP-7&8

Coolant Channels installation in progress in RAPP-7

In Unit-7, major milestone "Installation of Calandria Tubes" has been successfully completed. Subsequently, installation of Coolant Tubes is in progress and is likely to be completed by March 2017. In Reactor Building (RB)-7, erection of liner panels of ring beam, which is a part of Inner Containment dome is completed and preparation for concreting work is in progress. Construction of Steam Generator Vaults is also in progress. In Reactor Auxiliary Building (RAB)-7, concreting of 100M slab is completed & work for 105M El slab is in progress. Construction of Turbine Building, Annexe Building, Control Building, etc. are in progress.

In Unit-8, End Shields & Calandria have been lowered and aligned in Calandria Vault and welding is in progress. In Reactor building (RB)-8, work for 6th tier of Inner Containment wall is in progress and concreting of 109M El slab up to 50% is completed.

Construction of Safety Related Pump House, Safety Related Electrical House, Fire Water Pump House, Chlorination Plant is in progress. Civil construction of Plant Water Pump House &DM Water Plant are nearing completion. Construction of four Natural Draft Cooling Towers (NDCT) and four Induced Draft Cooling Towers (IDCT) is going on. 400KV Switchyard, Sujalpur-I and Sujalpur-II lines along with line reactors have been charged and synchronized.

Progressive delivery and erection of piping and various equipment are in progress. Equipment/components of RAPP-7&8 such as 2 Steam Generators, one Reactor Header , Main Steam Isolation Valves(MSIV) [8 large & 16 small valves], 474 bearing sleeves, one Moderator Heat Exchanger, one Main Air Lock (MAL) & Auxiliary Air lock (AAL) Bellows Assembly and various quantities of valves and fittings, etc. were dispatched to site.

RAPP Unit-7&8 has won - SARVASHRESHTHA SURAKSHA PURASKAR (Golden Trophy) for the year-2016 from National Safety Council of India.

Sanctioned Projects

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

Kudankulam Nuclear Power Project, Units - 3&4, which is an expansion program of Units - 1&2, located in Tirunelveli district of Tamilnadu, is being implemented with co-operation from Russian Federation (RF) within the framework of the Inter-Governmental Agreement signed between Russian Federation and Republic of India in December 2008. General Frame Work Agreement (GFA) for setting up of KKNPP Units-3&4 has been signed with M/s. Atomstroyexport (ASE) and made effective in December 2014.Major contracts for supplies and services from Russian Federation and third countries are signed with M/s. ASE.

All statutory clearances including Ministry of Environment, Forest and Climate Change (MoEFCC), Coastal Regulation Zone (CRZ), Tamil Nadu Pollution Control Board (TNPCB), Tamil Nadu Maritime Board (TNMB) and siting & excavation clearance from Atomic Energy Regulatory Board (AERB) are in place. Application along with requisite documents seeking consent for First Pour of Concrete (FPC) have been submitted to AERB and are under review by AERB.

Excavation work started in February 2016 and excavation for Units -3 & 4 pits has been completed. Excavation for other structures like tunnels and intercepting drain area is under progress. Tendering works for Main plant civil works and for construction of Hydro-technical structures for Units-3 to 6 are under progress. Construction of Project Office Complex (POC), construction of external services such as water supply system, sewage disposal network & fire fighting services, construction of road and development of area around POC & punching gate, construction of rain water harvesting facilities in various buildings and construction of in & out punch building have been completed. Tendering works for design and

CHAPTER 1

Laying of Foundation concrete of KNNPP-3&4 witnessed by Hon. Prime Minister of India and HE President of Russian Federation

construction of covered warehouses with toilet block at CMM complex and civil foundation works for warehouse complex are under progress.

Foundation concrete was placed on October 15, 2016, witnessed by Hon Prime Minister of India and HE President of Russian Federation.

Manufacturing of equipment/components under contract "Supply of Long Manufacturing Cycle Equipment & First Priority Equipment (LMCE & FPE)" have been commenced in Russian Federation (RF). First consignment of doors was shipped from RF in March 2016 and till date five consignments consisting of around 500 nos. doors have arrived at Tuticorin port, India. Sixth consignment consisting of 24 nos. doors has departed from Russian port. First priority work contract signed with M/s. ASE is completed. The scope of the above contract includes design of hydro-technical structures, changes of Units-3&4 w.r.t. Units-1&2, layout finalization, interface documents, excavation drawings & raft foundation drawings for main plant etc. Submission of working documentation packages under Working Documentation contract signed with M/s. ASE, RF consisting of design, construction and erection documentation has commenced.

Tendering activities for Engineering, Procurement and Construction (EPC) package (Common Services), Electrical Switchyard package for Balance of Plant & procurement of first priority mechanical equipment and components (Indian scope of supply in Russian design buildings) are under progress. Purchase order has been placed for first priority large sized Stainless Steel (SS) tanks.

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

Land for the project has been acquired. Consent from Haryana Pollution Control Board and environmental clearance from MoEF has been obtained. Administrative approval and financial sanction for the project has been accorded by Government of India. Siting consent from AERB has also been obtained.

Field studies pertaining to Geotechnical, Geophysical, Metrological, Seismological and Hydrological parameters have been completed. Mock-up for ground improvement work is in advanced stage of completion. Most of the reports have been submitted to the regulators for obtaining excavation consent. Tender for package-1 Main Plant Civil work i.e. for excavation and ground improvement is floated and its award is expected by March 2017. Ordering of long delivery equipment is in the pipeline.

Many infrastructural works at site are getting a final shape now. Work of Permanent property boundary wall is completed and that for Site Management building is going to start shortly. Meteorological Tower is under erection. MEQ stations are installed. Deep borehole logging is completed. Internal access road at site is made. Construction water and dewatering tank is made ready. 11 KV/415 V construction power is

commissioned. Award of work for 33 KV/415 V power supply is in progress. Project Site Office equipped with advanced I.T. infrastructure with videoconferencing facility is made functional.

Work of Neighbourhood Development Programme (NDP) is also gaining momentum for the Project. Sanitation issues of nearby schools are being addressed by construction of boys' and girls' toilet blocks. 10 out of 20 toilet blocks are completed. Aiding equipment have been distributed to physically challenged persons of local area under MoU with ALIMCO (Artificial Limbs Manufacturing Corporation of India). Skill development, women empowerment etc. are being addressed in a progressive manner.

New / Expansion Sites

Various pre-project activities like land acquisition, R&R, environmental studies, site studies (to the extent possible, wherever access is there), regulatory submissions, public outreach, techno-commercial discussions, etc. are in various stages of progress for sites, having “In Principle” approval of the Govt., namely Jaitapur in Maharashtra, Chutka and Bhimpur in Madhya Pradesh, Mahi Banswara in Rajasthan, Mithi Virdi in Gujarat, Kovvada in Andhra Pradesh, Kaiga Unit-5&6 in Karnataka and Haripur in West Bengal.

At Jaitapur, land is acquired and MoEF and CRZ Clearances are available. Techno-commercial discussions with EDF (Électricité de France), France are in progress.

Land is already available for Kaiga-5&6. MoEFCC has approved Terms of Reference (TOR) for Environmental Clearance and EIA study is initiated.

Land acquisition is in the advanced stage at Chutka. EIA study is completed, public hearing is completed and MoEF clearance is awaited. Studies for AERB siting clearance are in progress.

In respect of Mahi Banswara, land acquisition is in the advanced stage, EIA study is completed and public hearing is planned. Studies for AERB siting clearance are in progress.

Commitment for water is yet to be confirmed by Madhya Pradesh State Government for Bhimpur site.

At Kovvada, activities for land acquisition are in process. NPCIL has deposited part amount as advance towards compensation for Land and Landed assets and R&R Package as per request by the Andhra Pradesh Government. Public Hearings regarding SIA was organized in December 2016, the final SIA Report has been submitted and the Expert Appraisal Committee has submitted its recommendations to District Collector, Srikakulam.

At Mithi Virdi, land is to be acquired. CRZ clearance available. Environmental Impact Assessment (EIA) studies completed and is under review by MoEFCC.

At Haripur, land acquisition is contingent to initiative by State Govt.

Quality Assurance

NPCIL, in all its endeavours, is committed towards upgradation and continuous improvement in Quality Management, Quality Assurance, Quality Surveillance, Pre-service Inspection/In-service Inspection and interface with regulatory body. Quality Assurance/Surveillance activities have been carried out expeditiously for projects and stations. Pre-service/In-service Inspection of stations has been completed successfully. Corporate QA audits of projects i.e. KAPP-3&4 and RAPP-7&8 have been completed in a planned way. Corporate reviews of operating stations have been conducted based on WANO guidelines. NPCIL continued to provide QA consultancy services to BARC, BHAVINI and DRDO. Directorate of Engineering, Directorate of Quality Assurance, Directorate of Procurement, Directorate of Reactor Safety & Analysis, Directorate of Health, Safety & Environment, Directorate of HR

(Knowledge Management Functions) are ISO: 9001 certified. Surveillance/Re-certification audits of these Directorates by the certifying body have been successfully completed.

FRONT-END FUEL CYCLE

Heavy Water Production

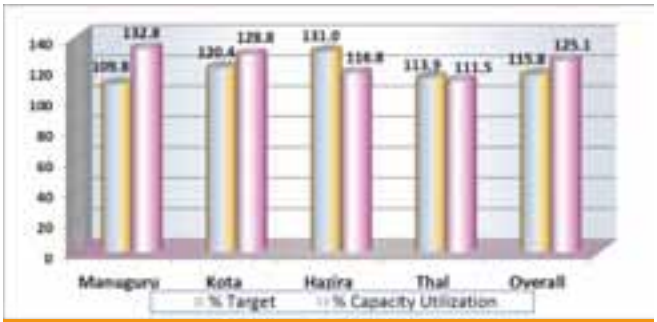
The Heavy Water Board (HWB), a constituent unit of DAE in its Industries Sector contributes to the first stage of Indian Nuclear Power Programme by producing Heavy Water for all Pressurized Heavy Water Reactors (PHWRs) in a cost effective manner, enabling the Department to provide nuclear power at an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

Performance of the Board during the period was excellent w.r.t. production, specific energy consumption, on stream factor and plant safety. As per the Annual Action Plan for the year 2016-17, major Turnaround of Exchange Unit-II of HWP, Manuguru was completed during the period including commissioning of the new DCS system. HWP, Thal has also completed Annual Turn Around during the period. The specific energy consumption at all the plants including the non-productive consumption during the planned shutdown period is less than the target. The overall specific energy consumption is the lowest ever figure achieved so far. This could be achieved mainly due to continual and meticulous review of the process parameters to ensure optimum levels of plant operation. Consequently, during the period Board could surpass the production target by more than 15.8% and also achieved 125.1% of overall capacity utilization.

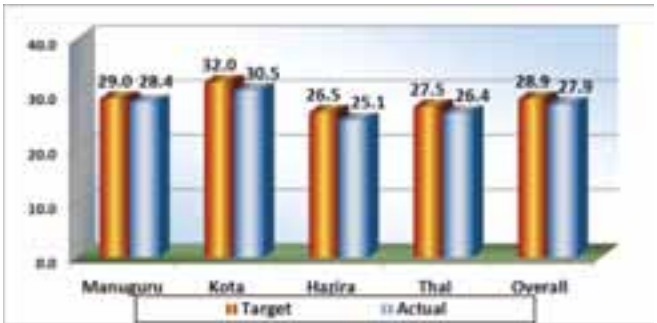
Preliminary activities for restart of HWP, Tuticorin such as plant health assessment and design adequacy evaluation of plant structure under revised Seismic & Tsunami condition has been initiated.

The Heavy Water Board achieved more than 115% of targeted production for the financial year 2016-17 and the specific energy consumption was 27.9 (GJ/Kg D2O).

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



% Production Target & Capacity Utilization



Specific Energy Consumption (Gj/Kg) During 2016-17

Heavy Water Plant, Manuguru

The performance of HWP, Manuguru during the year 2016-17 was excellent achieving 110% of target production and on stream factor of 0.98 excluding MTA period.

XU-II had come back into operation from 05.05.2016, after successful completion of DCS-PLC commissioning & MTA-2016, 12 days ahead of schedule. Installation & commissioning completed for both XUs & Utilities (XU-I in June 2015, DCS for utilities completed during March, 2016 and in May 2016 for XU-II)

At Captive Power Plant, TGs are being operated with extractions meeting the full plant steam and power requirements. Power export to TSTRANSCO was carried out as per the availability of coal stock and agreement with PTC, 27.45 MU power export to TSTRANSCO during the period.

Auxiliary Steam Turbine (TG-4) was in regular operation and 20.84 MU.

Specific energy consumption remained low at 28.4 GJ/kg in spite of plant shut down taken for installation of DCS for Exchange Unit-1I and Utilities.

For utilisation of waste heat / low grade heat to generate refrigeration, Hot Water Vapor Absorption Refrigeration machines are being procured and Mist Cooling System (MCS) is commissioned. Procurement of VAR machines is under progress. Feed chillers have been received at site and installation will be taken up in XU-II.

12 MWp Solar P V Cell at Heavy Water Plant, Manuguru

The 12 MWp Solar Photo Voltaic Power Plant commissioned in June 2015 as mandated under Renewable Power Purchase Obligation is operating satisfactorily.

Presently BEP is not in operation since January 2015 as DAE's requirement is already fulfilled. Elemental Boron Plant for production of Elemental Boron is being operated on sustained basis.

Heavy Water Plant, Kota

The performance of HWP, Kota was excellent achieving 120% of target production and 128.8% capacity utilization. Exchange Unit effluent is being cooled through Mist Cooling System and being utilized for generation of boiler feed water, make-up of cooling tower , back wash of sand filter and in-house gardening. Sodium Sulphate Crystallizer has been installed & commissioned and producing marketable sodium sulphate crystals from the effluent Sodium sulphate solution. Seismic requalification jobs have been carried out like, installation of Waste Stripper friction dampeners designed, developed and supplied by BARC, flare stack strengthening and painting, H_2S Storage tank foundation strengthening. Enhanced fire mitigation system being implemented at site includes manually operated water monitors and mayur nozzles.

Heavy Water Plant, Hazira

The performance of HWP, Hazira was excellent achieving 131 % of target production and 116.8% capacity utilization. To avoid loss of heavy water in the Burner unit a back end unit was installed to transfer Deuterium from rich ammonia to DM Water. Several innovative modifications were carried out including replacement of packing and increasing the height of the column.

Heavy Water Plant,Thal

The performance of HWP, Thal was very good achieving 113.9 % of target production and 111.5% capacity utilization. The plant has carried out the Annual Turn Around activities during the period. Real time data of CO/CO2 in feed gas from RCF's Methanator outlet analyzer is provided to HWP control room for effective monitoring and control. This has resulted reduction in CO/CO2 ingress in the feed synthesis gas enabling smooth operation of the plant.

As a measure toward energy saving 200 numbers lights have been replaced by 20W LED lights resulting in significant reduction in energy consumption towards plant internal lighting. Installation of VFD for pumps and installation of additional Air Pre-heater in Main Cracker-B helped in energy economy.

Heavy Water Plant, Baroda

ATA on both TBP Plant and the Potassium Metal Plant was completed and the plants have achieved the target production during the period.

As per directive of AEC, decommissioning of the heavy water plant has been initiated. A few identified equipment, instruments/components and transmission cables were sent to HWP, Tuticorin for meeting the requirement during re-start-up. a few vessels of main plant and front end units have been suitably converted for product storage.

As a part of developmental activity on alternate uses of heavy water, deuterated NMR solvents viz.; Chloroform-d, DMSO-d6, Acetone-d6 & Acetonitrite-d3, Benzene-d6 and D_2SO_4 are being synthesized in laboratory scale using conventional and innovative processes. D-Compounds like $CDCl_3$ and Dimethyl Sulphoxide-d6 were marketed by BRIT.

D-labelled compounds produced at HWP Baroda and marketed by BRIT

Sodium Test Cell at HWP, Baroda

In the Sodium metal plant, fine tuning the process and establishing performance of 2000 Amp test cell is continued. Detailed analysis of the operational data was done and the same was incorporated into the design and engineering of the proposed industrial scale plant of 600 MTPA at Baroda. The refurbishment of the cell has been taken up and curing of the cell refractory is completed. Validation of analytical procedure for carbon estimation in Sodium metal is completed.

Meanwhile, a unit for purification of NG grade sodium & fabrication of 24 KA single (4 electrodes) cell is being planned against expenditure of ₹ 2 Cr.

Heavy Water Plant, Tuticorin

At HWP, Tuticorin, the diversified activities for development of technology for synthesis of new organo-phosphorus solvents in the Versatile Solvent Synthesis Pilot plant (VSSP) is in progress. The plant is in operation for synthesis of TiAP and D2EHPA II in campaign mode as scheduled. 10 Kg of DHOA produced was dispatched to meet requirement of RED, BARC. One kg of TiAP was supplied to TDP, RCF Mumbai for their experimental work.

To cater to the requirement of new generation solvents in the nuclear fuel cycle of NPP, sanction has been received to set up an Industrial scale Solvent Production Plant at HWP, Tuticorin for production of five

solvents, namely TiAP, DHOA, D2EHPA II, TBP & TOPO. Actions have been initiated and basic engineering has been completed. Siting & Construction consent is received from AERB subject to statutory consent. Environmental clearance has been received and application made for Air & Water Consent from TNPCB.

AEC has cleared re-startup of Heavy Water Plant, Tuticorin subject to availability of natural gas supply and renewal of agreement with SPIC. Financial sanction from DAE is awaited. Meanwhile DPR for Tuticorin re-start up is prepared & submitted to DAE. Fitness and corrosion survey of major equipment & structure of the main plant were carried out and report submitted. Design adequacy study of plant structure is in progress with BARC experts under revised Seismic & Tsunami condition. Technical documents for procurement, overhaul and maintenance outsourcing is being prepared. Since naphtha would be replaced by natural gas as feed material of M/s SPIC, it is planned to replace existing burners designed for naphtha as fuel, with the burners of HWP, Baroda with due modification of fixing block.

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

Heavy Water Plant, Talcher

At HWP, Talcher, the production facilities for D2EHPA and TBP were operated continuously to meet the target production. 33000 kg of TBP were dispatched to NFC and units at Kalpakkam during the report period.

At the R&D pilot plant facility, synthesis of TOPO was taken up and target production of TOPO has been achieved. Quality of product was as per Benchmark. Integrated effluent treatment plant was operated for treating effluent from VSPP and TBP facilities.

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

Technology Demonstration Plant (TDP) is now being operated in "close loop" for refinement of technology & processes prior to industrial deployment. After completion of technology demonstration at RCF, the land provided for TDP is expected to be cleared and handed over back to RCF. It is now proposed that a Solvent Extraction Plant (SXP) can be set up at HWP, Tuticorin taking phosphoric acid from M/s Greenstar Fertilizers Ltd., (GFL) for continuing technology up-gradation and RM production of 25 MT of RM (U_3O_8) per annum at an estimated capital cost of ₹ 150 crore. The SXP will be laid out over 15 acres of land available at HWP, Tuticorin and is proposed to be operated by HWB. Most of the equipment & machinery, electrical & Instrumentation system, structural steel etc. is proposed to be shifted from TDP to HWP, Tuticorin.

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 2016-17, the integrated multi-disciplinary approach adopted for uranium exploration with substantial inputs of radiometric, geological, ground and heliborne geophysical, geochemical surveys and drilling

(Departmental and Contract), have resulted in augmentation of in-situ reserve by 15,011 tonnes of U_3O_8 (XII plan period: 69,937tU_3O_8; Country's total U reserve: 2,44,947t U_3O_8).

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

In addition, pegmatite belts of Chhattisgarh, Odisha and Karnataka have been explored for rare metals and rare earths and sand bodies of coastal stretches have been explored for heavy minerals for augmentation of resources of the country respectively.

The laboratories at AMD Headquarters and in Regional Headquarters are equipped with state-of-the-art instruments and every effort was made to utilize them to full capacity. All the laboratories contributed actively by providing speedy analytical support to the ongoing exploration programme.

Some of the significant achievements are summarised below:

Uranium Investigations

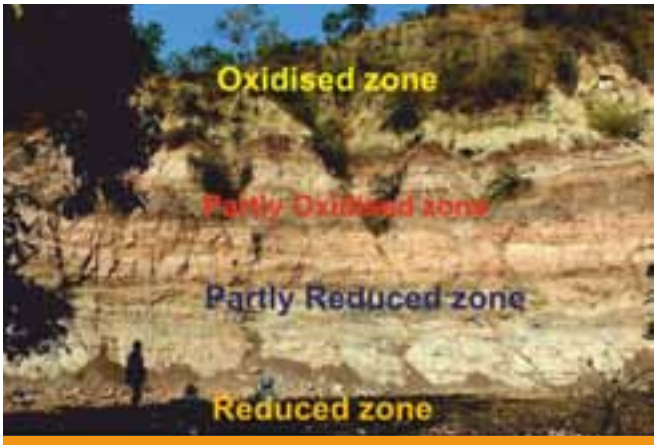
Ground radiometric surveys

Reconnaissance (5,432sq km) and detailed (282.75sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

Siwalik Group, Una district, Himachal Pradesh: Sandstone at Gwalsar-Parah.

Mahadek basin, East Khasi Hills district, Meghalaya: Sandstone at Laitduh.

Motur Formation, Satpura Gondwana basin, Betul district, Madhya Pradesh: Sandstone at Dharangmau.



Field Photograph of Dharangmau area, Betul district, Madhya Pradesh

Betul Crystalline complex, Chhindwara district, Madhya Pradesh: Brecciated quartz reef / vein in pink granite near Bijori, Bhuli, Khudharadhana, Setparas and Sajba.

Bortalao Formation, Rajnandgaon district, Chhattisgarh: Gritty sandstone and conglomerate of Bortalao Formation along Kolarghat-Kauhapani-Gandhinagar, Bortalao-Khampura-Burhanchhapar-Aledand and Nawatola-Ramatola-Kolarbhatti tracts.

Geochemical Surveys

Geochemical surveys (3,840sq km) have indicated upto 392ppb U in palaeochannels of Ghaggar river between Suratgarh and Anupgarh in Sri Ganganagar district and upto 7284ppb U in Ranns of Barmer and Jalore districts, Rajasthan and upto 70ppb U from Khetri-Kolihan and Jasrapur-Kharkhara sectors in Jhunjhunu district. Calcrete samples collected from Loha and Padihara areas, Churu district, Rajasthan analysed upto 279ppm and 104ppm respectively.

Ground Geophysical surveys

Ground geophysical surveys have been carried out in parts of Singhbhum Shear Zone, Jharkhand; Gani – Kalva Fault zone, Andhra Pradesh; Dharmapuri Shear Zone, Tamil Nadu; Bhima basin, Karnataka; North Delhi Fold Belt, Haryana and Rajasthan, Saraswati Palaeochannel, Rajasthan and Satpura Gondwana basin Madhya Pradesh. High conducting zones associated

with low magnetic signature delineated in Gorir – Modi – Nalpura, Jhunjhunu district, Rajasthan and high chargeability zones delineated in Sankadih, Saraikela-Kharswan district, Jharkhand, Bagholi-Jodhpura, Jhunjhunu district, Rajasthan, Kanchankayi, Yadgir district, Karnataka and Dharangmau-Kachhar, Betul district, Madhya Pradesh.

Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 28,740 line km in parts of Aravalli Fold Belt, Rajasthan and Chhattisgarh basin, Chhattisgarh.

Processing of EM, magnetic and radiometric heliborne geophysical data of Dungarpur Block in Aravalli Fold Belt, Rajasthan has resulted in the identification of eleven potential target zones around Undwala, East of Tartai & Chhoti Mandli, Lasara, Bachi-fala & Sarangi, Parsola, north of Parsola, East of Manpur, North of Bhabrana, South of Jambura, Pavati-Burel and Salumber.

Data processing in Chhattisgarh Block has resulted in delineation of fractures/faults and basic bodies within the basement complex. The basin–basement contact has been demarcated due to conducting lithology just above the unconformity. Detailed study around Chitakhol area delineated the basement configuration and about a maximum of 700m sediment thickness estimated in the deeper part of the basin.

Ground validation of heliborne geophysical anomalies identified uranium mineralisation upto 0.63% U3O8 in North Delhi Fold Belt at Buchara, Sikar district, Rajasthan. Gamma-ray logging indicated radioactivity in three borewells in Buchara area out of which one borewell recorded significant radioactivity.

Three prominent zones of uranium mineralisation (upto 0.041% U_3O_8) are identified in Singhbhum Shear Zone along (i) Chirugora - Kudada, (ii) Baramdra - Sidheswar Pahar and (iii) Purnapani - Dhobani tracts, East Singhbhum district, Jharkhand. Boreholes have been planned to probe the subsurface continuity of mineralization.

Exploration by Drilling

A total of 1,71,122.30m (Departmental: 84,446.60m and Contract: 86,675.70m) reconnoitory, exploratory and evaluation drilling has been carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of mineralisation in the new promising areas.

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

Tummalapalle sector, Kadapa district, Andhra Pradesh: Hangwall lode in Rachakuntapalle Deeper block and in Gidankivaripalle block in Vempalle dolostone.

Rohil and its extensions, Sikar district, Rajasthan: Albitite zones in Rohil Central western extension, Gumansingh ki Dhani, Narsinghpuri and Jahaz areas.

Wahkut and Kulang, South West Khasi Hills district,

Exploratory mining site at Rohil uranium deposit, Sikar district, Rajasthan

Meghalaya: Lower Mahadek sandstone at Wahkut and Kulang blocks (Nongjri Plateau).

Kanchankayi, Yadgir district, Karnataka: Associated with brecciated limestone in a similar geological setup

as that of Gogi uranium deposit.

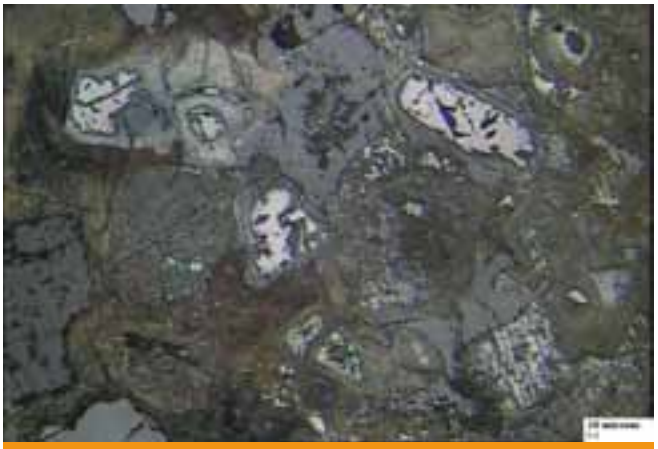
Devri, Surajpur district, Chhattisgarh: Associated with brecciated granite, grey granite and granite- gneiss in Devri, which is situated between Dumhath and Jajawal uranium deposits.

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

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

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

In addition to the above, the potential / significant blocks have also been identified for sub-surface exploration at Dharangmau-Kachhar, Betul district, Madhya Pradesh; Jamalpur, Jhunjhunu district and Karoi, Narsinghpuri, Sikar district, Rajasthan; Rambas, Begapur-Sareli ki Dhani, Mahendragarh district, Haryana; Kamaguttapalli, Nagaripalli, Kadapa district, Andhra Pradesh; Suldhal – Gujanal block, Belgaum district, Karnataka; Rasimalai, Vellore district, Tamil Nadu; Bangurdih, Banaykela, Mahalimurup, Gurulpada, Seraikella –Kharsawan district, Jharkhand.



Photomicrograph showing discrete Uraninite in arenite, Dharangmau area, Betul district, Madhya Pradesh

Exploratory Mining

Uranium Resources

AMD has established an additional reserve of 15,011t uranium oxide (U_3O_8) as detailed below:

- 13,139t U_3O_8 established in Tummalapalle and its extensions, Kadapa district, Andhra Pradesh.
- 955t U_3O_8 at Banadungri-Singridungri, East Singhbhum district, Jharkhand.
- 337t U_3O_8 at Bangurdih, Saraikela-Kharswan district, Jharkhand.
- 315t U_3O_8 in Wahkut, South West Khasi Hills district, Meghalaya.
- 258t U_3O_8 at Rohil, Sikar district, Rajasthan.

The country's uranium reserve has been updated to 2,44,947t U_3O_8 as on 31.10.2016.

Rare metal and rare earths investigations

Reconnaissance (1190sq km) and detailed (19.70sq km) surveys have been carried out for identification and evaluation of Rare Metal and Rare Earth resources in Chhattisgarh, Odisha, Rajasthan, Karnataka and Telangana.

Additional reserve of 3,743kg of columbite-tantalite was estimated in pegmatites at Jangapara, Jharsuguda district, Odisha; Jogiyani, Balrampur district, Chhattisgarh; Kawadgaon, Dantewada district, Chhattisgarh and at Marlagalla, Mandya district, Karnataka. 27.26t xenotime bearing heavy mineral concentrate was estimated in Kasijore nala, Jashpur district, Chhattisgarh.

Production of columbite-tantalite (3,022kg), beryl (900kg) as by-product and xenotime concentrate (6,550kg) was achieved at Pandikimal and Jangapara unit, Jharsuguda district, Odisha; Bodenar unit, Bastar district, Chhattisgarh; Allapatna-Marlagalla sector, Mandya district, Karnataka and at Siri River, Jashpur district, Chhattisgarh.

A total of 2,336m drilling has been carried out for RMRE in Dantala, Phulan and Ramaniya areas of Siwana Ring Complex, Barmer district, Rajasthan. Cores of samples from the boreholes analysed high REE (ΣREE 7,590ppm) and Nb (708ppm) contents. Preliminary estimation of ore reserves at Dantala, Siwana Ring Complex, Rajasthan have shown 81,035 tonnes REE at an avg. grade of 0.523% along with avg. 0.06% Nb_2O_5 in a small area of 0.20 sq km.

In addition, preliminary estimation of ore reserves at Ambadongar, Chhota Udepur district, Gujarat have shown 1,39,397 tonnes total REE at an average grade of 1.16% over a small area of 0.04 sq km.

Beach Sand and Offshore Investigations

Survey (Reconnaissance- 335.68sq km and detailed- 14.38sq km) and prospecting (drilling, sampling and evaluation) were continued along the coastal tracts of Andhra Pradesh, Odisha, Kerala, and Tamil Nadu to establish additional beach sand heavy mineral resources.

Beach sand drilling operations

Exploration/Evaluation

Conrad bunka drilling by the Directorate through 1,759 boreholes with a cumulative depth of 10,895.35m has been carried out and 8,562 samples have been generated.

Sonic drilling, on contract, has been continued at Neendakara – Kayamkulam sector (Chavara Major deposit), Kollam district, Kerala to evaluate deeper horizons (>12m) and a total of 5,114m drilling has been carried out in 110 boreholes and 5,112 samples have been generated.

10,493 samples constituting individual, composite and mineralogical types were processed and analysed for resource evaluation.

The following potential heavy mineral zones have been delineated:

Two new inland sand bodies with THM content upto 48.10% (Avg. 10.03%) along Haripuram – Parisavaripalem – Nakshatranagar - Kottapalem coast, Guntur district, Andhra Pradesh.

Metturu - Bhavanapadu tract, Srikakulam district, Andhra Pradesh with upto 22.87% (Avg. 7.49%) THM concentration.

In the berm Zone of Hope Island, Kakinada spit, East Godavari district, Andhra Pradesh with rich concentration of heavies up to 30%.

Field photograph of heavy mineral concentration in berm zone, Hope Island, Andhra Pradesh

Oppilan-Valinokkam coast, Ramanathapuram district, Tamil Nadu with THM concentration up to 10%.

Reports Generation

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

Resources

The country's total heavy mineral resource now stands at 1,064.79 mt which include ilmenite 593.50mt, rutile 31.35mt, monazite 11.93 mt, zircon 33.71mt, garnet 168.33mt and sillimanite225.97 mt. Survey, exploration and evaluation are in progress to augment these BSM minerals.

Mining & Mineral Processing

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

Uranium Corporation of India Ltd. (UCIL) is engaged in uranium ore mining and processing since 1967. The performance of all major units of the company during the year 2015-16 remained quite satisfactory. The Tummalapalle Uranium Project at Andhra Pradesh is nearing completion and sufficient ore has been stockpiled. The underground mine has achieved full production capacity. Re-dissolution System facility in the Plant has been successfully completed and implemented. Second stream of the Processing Plant has been made operational.

Exploratory mining activities by UCIL on behalf of AMD at Rohil Uranium Project located at Sikar district of Rajasthan has already started. Decline development and portal excavation is in progress. Identification of water sources and preparation of 3D ore body modeling is in progress.

Pre project activities have been taken up at Gogi Uranium Project located at Yadgir district of Karnataka. Land acquisition has been completed (government land) except tailings pond area. Construction of Mine Water Treatment Plant is in progress.

UCIL intends to revive the processing of copper tailings at Musabani in Jharkhand for recovery of uranium bearing minerals under the project Musabani Uranium recovery Plant. Pre project activities have been initiated and baseline environmental studies have been completed.

To maintain the present performance level of the mines and plants in a sustained manner, UCIL has proposed to carry out a few de-bottlenecking activities in Singhbhum and Tummalapalle units. Tendering and work order are in progress for Debottlenecking of Singhbhum and Tummalapalle operations project in different units.

UCIL has outlined a plan for massive expansion of production potential in line with DAE's vision for self-sufficiency in production of Uranium in the next 15 years. This includes plan to maintain sustained supply from existing facilities, capacity expansion of some existing units and construction of new production centers in different parts of the country. Work has been initiated for exploratory mining project to be undertaken by UCIL on behalf of AMD at Rohil in Rajasthan, Gogi in Karnataka and Singridungri-Banadungri in Jharkhand.

The major achievements of IREL included the Sale Purchase Agreement with M/s Toyota Tsusho Corporation, Japan: Culminating from the Inter Government Agreement signed by the Government of

India and Japan for co-operation in the field of rare earths, Indian Rare Earths Ltd. signed sale purchase agreement (SPA) with M/s Toyota Tsusho Corporation, Japan and their subsidiary M/s Toyotsu Rare Earths India Pvt. Ltd., Vizag (TREI) on 9th December 2015 for supply of Rare Earths Chloride (RECL) being produced at Monazite Processing Plant (MoPP) at IREL's OSCOM unit in Odisha to TREI for value addition purpose. During the year 2016, IREL has supplied over 1,200 tons of RECL on dry metric ton basis to TREI. IREL expects to supply substantially higher tonnage to TREI during the 2nd contract year.

To produce samarium-cobalt (Sm-Co) magnet for meeting national objectives, a Special Purpose Vehicle (SPV) has been formed. Production of Sm-Co metal & Magnet is based on technologies developed by BARC, Mumbai & DMRL, Hyderabad. Activities for firming up the investment, plant location etc. is under progress.

A MoU has been signed with BARC, Mumbai for setting up of a 5 Million Liters per Day (MLD) desalination plant at OSCOM, Odisha as part of field applications of indigenous desalination technology in DAE units.

Supply of Nuclear Grade Ammonium di-Uranate (NGADU) from new source i.e. the newly commissioned monazite processing plant at OSCOM, Odisha commenced.

Approval has been received for entering into production sharing contract viz. concession & profit sharing options with land owners having surface rights within IREL mining lease area with a view to mitigate the difficulties in sourcing land for raw material of the Southern operating units of IREL.

Patent on 'Solvent extraction process for Rare Earths (RE) separation through partial reflux of RE in solvent' has been filed.

Development of Finite Element Method (FEM) based analysis for earth pressures using Cemented Paste Backfill (CPB) for supporting underground stope was carried out by BARC for exploring CPB for tailings disposal at Tummalapalle Mines. A single excavated stope in the footwall lode keeping the hangwall lode undisturbed has been considered. All finite element models are analyzed based on non-linear elasto-plastic behaviour of rock materials. Results of finite element analysis have been obtained in terms of displacements, principal stresses and effective plastic strain along the rib pillar and bottom of the roof. For each numerical model, principal stresses and displacements are calculated from each model separately. These values are calculated along pre-decided linear paths in the models. The location of these paths was selected to highlight those regions of the model, which are most relevant to the property being measured. FEM studies suggest that close to 100% filling will be required to prevent yielding of pillars and hanging wall rock. It is clear that as the depth of mine increases, intensity of yielding or failure of pillars also increases and hence pillar stitching from sides may be required before backfilling operation is commenced. Steps for on-site testing of the findings is in progress.

Subsequent to identification and development of conditions for dissolution of Rare Earths (REE) from fly-ash generated at lignite coal-fired thermal power plant at Neyveli, Tamil Nadu, studies were taken up to understand the deportment of REE in various phases constituting the fly-ash to improve overall process efficiency and to precipitate dissolved rare earths in purified form.

The Total Rare Earths (TREE) content in the sample coded TS/II was 0.216% with Lighter REE (LREE) of 0.145%; Medium REE (MREE) of 0.0235% and Heavy REE (HREE) of 0.0472%. Sequential chemical extraction studies indicated that 55% of the TREEs are ion-exchangeable followed by 30% TREEs which are Fe-bound. Both the fractions released REE into leach solution during H_2SO_4 leaching but co-precipitation issues limited the overall REE recovery to 60%. The

precipitation and purification of dissolved REE in leach solution was carried out by a combination of solvent extraction – HCl stripping – oxalate precipitation – calcination process. This process gave overall enrichment of TREE by 750 times.

Erection of large-scale leach circuit for H2SO4 processing of U ores at TDPP, Jaduguda and insulation of these units along with interconnecting piping lines has been completed. Field instrumentation installation and calibration of various equipment and synchronization with digital panels and documentation for safety clearance is in progress.

Studies on leaching of U from the Rohil-Ghateswar U ore was carried out. U content (U_3O_8) of the feed was 0.18% and the sulphur assay was 7%. The sulphides are iron minerals with minor amounts of sulphides of Cu (0.15%) and Mo (0.04%). The sulphides were selectively separated by froth flotation losing only 10% of U values in the float. 90 – 95% of U values were leached from the flotation sink at 50 - 60^0 C under atmospheric leaching conditions in 6 h contact time at pH 1.5.

Investigations on grindability and vacuum filtration of Tummalapalle U ore using reagent solution as aqueous phase were carried out. The target grind size was 85 – 88% passing 74µm in exclusively in carbonate – sulphate media. The chemical composition of the reagent solution was Na_2CO_3 – 88g/L, Na_2SO_4 – 35 g/L. Comparison of the grinding kinetics have indicated that longer time, about 8 – 10 minutes is necessary for getting equivalent grind when the aqueous medium is carbonate and sulfate. Rate of filtration with similar filter cloth as used in the plant was 700 kg/h-m^2 with 14% cake moisture and 8 mm cake thickness. The rate of filtration in plain water was about 750 kg/h-m^2. An important feature noticed was dissolution of U to the extent of about 25 ppm when the ore is ground in presence of reagent solution while the same with plain water was about 50 ppb.

Different samples from stopes & levels of Narwapahar and benches of Bandhurang U mines were received for determination of Bonds Work Index (BWI) for grinding. BWI for Narwapahar samples varied 14 - 19 kWh/metric ton and that of Bandhurang samples is in the range of 12.3 - 15.3 kWh/metric ton.

A Hollow Fibre Liquid Membrane (HFLM) technique was developed to separate rare earths from rare earths based magnetic scrap material (Nd:17%, Pr:5%, Dy:2.5%, Fe:75% and B:1%) in HNO3 using organophosphorus extractants D2EHPA and DNPPA. Feasibility of the technique was established in continuous operation mode under optimized process variables by processing 25 L of 5 g/L rare earths leach liquor of magnetic scrap. 120 gm of rare earths values were obtained with a recovery of more than 99%.

Crude Sodium Diuranate (CSDU) obtained during processing of secondary source of U contains impurities such as iron (10%) and rare earths (5%). A counter current solvent extraction process employing the combination of neutral extractants comprising of TBP (0.8M) and DHOA (0.2M) was developed to process CSDU-nitric acid leach solution. U was selectively extracted into organic phase while impurities including rare earths remained in the aqueous phase. U was recovered by precipitating the strip solution with ammonia in the presence of a complexing agent as yellow cake (Ammonium Diuranate, ADU) of required nuclear grade purity.

The nuclear grade yellow cake and impure CSDU

Scheme of retrofitting for process tank using Friction Dampers

To qualify the process tanks for seismic loads, innovative friction dampers were suggested to HWP. The double sliding friction dampers were designed, fabricated and tested before deploying them on the process tanks. This resulted in qualifying the process tank for earthquake motion.

Evaluation of alternative extractants (TiAP, TEHP) for direct dissolution and supercritical fluid extraction of U from solid matrices were carried out. Direct supercritical fluid CO_2 dissolution and extraction of U from crude Sodium Diuranate (SDU) has been carried out using adducts of alkyl phosphates and nitric acid. Straight chain extractant Tri-Butyl Phosphate (TBP) and branched chain extractants, Tri-Isoamyl Phosphate (TiAP) and Tri-Ethyl Hexyl Phosphate (TEHP) show different U extraction and purification behaviour. Structure of the alkyl phosphates and the acidity of the corresponding adduct phase influence direct dissolution and supercritical fluid extraction of U from crude SDU. U extraction efficiency obtained by TBP, TiAP and TEHP are 84, 84 and 81% respectively.

Nuclear Fuel Fabrication

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

PHWR fuel

NFC has successfully 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/SU received from M/s UCIL was converted into 19 element and 37 element fuel bundles for meeting the requirement of Out of Safeguard (OSG) reactors.

NFC has achieved production of 1038.45 MT of PHWR fuel bundles in the financial year till December, 2016 (highest ever production for this period).

Production of 65 BWR fuel assemblies was achieved during the year till December, 2016 and target of 100 assemblies would be completed during the financial year 2016-17.

Developmental works in fuel plants

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

Introduction of cooling loop in dissolution

In order to control the reaction temperature and avoid any runaway reaction during UOC dissolution, cooling water input was conceptualized and introduced. After reaching a set temperature during the process, steam inlet into the unit will be cut off and beyond further increase in temperature, circulation of cooling

water will be enabled. The new cooling water flow and steam flow are precisely monitored and regulated by SCADA system. This development has led to reduction of batch time by approximately 50%.

Development and implementation of high concentration Uranyl nitrate feed in slurry unit

In view of increasing production and productivity, it was imperative to increase solvent extraction capacity. Accordingly, an innovative plan of increasing feed concentration from 300 to 400 gUpl was implemented. The above modification has resulted in increase of extraction capacity by 32%. The existing slurry unit is designed to handle 250lph with Uranium concentration of 300gpl. It would limit the output from the unit to only 75 Kg/hr of Uranium. In order to meet 90MT of production per month, slurry unit output has to be increased to 140Kg/hr. Which means increasing the capacity of the unit by around 100%. This is possible only with increase of concentration gradient in the unit by providing sufficient Organic to Aqueous (O/A) ratio. In order to maintain same O/A ratio at 350 lph of feed with concentration of 400gpl, would substantially increase the organic flow rate. With increase in these flow streams, ratio shifts the operating line away from equilibrium line as the slope decreases from 17 to 14 degrees. Accordingly, the feed entry is modified and introduced in the third stage of the unit and organic is introduced in two stages. This development resulted in achieving 90MT per month with the same unit.

Design, development and in-house fabrication of coalascers in Mixer Settler

An innovative and unique concept of coalascers were designed and introduced in each chamber of mixer settler to achieve laminar flow and increase the stripping capacity in solvent extraction. Performance of this is excellent and initial results are encouraging. Existing mixer settler-II can give only output Uranium at a rate of 28Kg/hr whereas the requirement from this unit is around 70Kg/hr. The step of re-extraction is more

Coalescer

Coalescers placed inside Mixer Settler-2

difficult than extraction in view of difficulties in coalescense. A conventional design suffers from 30 to 40% compromise in area of settling due to "back mixing"; wherein organic from bottom of the settler moves in counter direction with aqueous settled from top layers. In general different kinds of packings with different patterns and materials are provided in the settler to increase settling area. On the contrary, the problem of back mixing is addressed by an innovative and unique concept of introducing coalescers in each settler chamber of box type mixer settler.. The organic and aqueous flows are stream lined and do not encounter in each other. This increased throughput of the unit to 70 Kg/hr.

Introduction of new end settler in slurry unit

A 2KL tank is installed in place of old end settler with provision for auto drain of aqueous solution thus decreasing the organic gradient in the unit. This

development resulted in hands free operation and facilitated for separation of only entrained aqueous and to increase throughput of slurry unit.

Introduction of level transmitters in powder collection bunkers

For the first time in the plant, the level sensing concept in powder handling bunkers is introduced and installed in ADU bunkers. Often the problem of choking of Turbo discharge observed due to excess filling of ADU bunker. This results in air borne activity and operational interventions which limit the output from the section. This problem is successfully solved by introducing a level sensor in the bunker by not compromising on the structural supports at turbo dryer and rotary furnaces. This modification helped in increased radiological safety and safe operation of the section in the plant.

Increase of production capacity in stabilization unit

Process parameters of stabilization operation are optimized thereby increasing the feed rate from 130kg/hr to 180 kg/hr without affecting the powder quality. This has also reduced the batch time by around 1 hr. The powder produced with the modified parameters is performing satisfactorily during pelletizing.

Shifting of high temperature sintering furnaces

In order to produce more pellets through UOC to UO_2 route two sintering furnaces were shifted in as it is condition and commissioned. Two very high capacity sintering furnaces weighing around 20Te were shifted along with refractory bricks and heating elements which are very fragile in nature. After modelling and simulation a special lifting structure was designed, fabricated and load tested in-house. This has resulted in shortening the commissioning time by at least 45 days.

Lifting structure along with the furnace

Introduction of Element Weighing System

In order to ensure stack weight in PHWR fuel pin, an independent element weighing system has been installed for 100% element weighing after end cap welding operation. This has improved the reliability in the PHWR fuel production line.

Introduction of split packing ring

More robust and reliable split packing ring has been implemented in place of single-piece packing ring. This has improved the safety of fuel packing during transportation to reactor sites.

Introduction of an Online U_3O_8 particulate matter collection system

A gravity settling chamber (having provision for temperature control) was installed in the path of the exhaust gases for on-line collection of U_3O_8 particulate matter at the reduction furnace exhaust. The entrained particulate matter from the exhaust gases gets settled and collected in the gravity settling chamber. This modification eliminates the manual collection of wet sludge from the scrubber. Due to the above, once-through recovery of the plant increased by about 2%.

Reduction in generation of UNRC

UNR treatment by second cycle of solvent extraction is re-established with UNR generated from MDU. The parameters were fine tuned to operate 5 nos. of cross-flow stages instead of earlier 6 nos. of stages. This resulted in reduction in quantity of treated solvent

and subsequently reduced load on solvent treatment. The generation of wash solutions reduced by about 15 %. By this route the plant successfully produced 50MT UO_2 which resulted in avoiding generation of 38MT of UNRC.

Treatment of Lean Solvent

Solvent treatment trials with oxalic acid solution was carried out on plant-scale which had encouraging results These trials gave a breakthrough in treated solvent having 'U' concentration < 0.1gpl. This process modification resulted in the reduction in quantity of aqueous wash solution generation by about 30%. Also, there was a reduction in time required for solvent treatment by 67% compared to treatment with soda solution.

Cooling water system modification in reduction and stabilization furnaces

The water cooling system of rotary reduction and stabilization furnaces was modified which has facilitated the increase in feed rates of furnaces without affecting the powder quality. It has resulted in 20% and 50% increase in output from reduction and stabilization furnaces respectively.

Production of Axial Blanket Pellets for PFBR

NFC has successfully fabricated very small diameter pellets of 6mm using innovative die design. The present hydraulic press tooling was modified where in three punch system was designed and developed in place of single punch system for each die sleeve.

Punch and die set for diluent pellet production

Modification in powder transfer system in roll compactor and final compaction press enclosure has reduced average air borne activity from 0.25 Bq/m^3 to less than 0.20 Bq/m^3 with no sample above DAC limit.

Plant has taken up the repair work of costly, imported used molybdenum components. This repair work has saved Rs 48 lakhs worth in foreign exchange.

Vibratory bowl feeder was successful developed and implemented in center-less grinder to feed sintered UO_2 pellets which are fragile in nature into the grinding machine. This has eliminated manual pellet discharging operation at sintering operation and greatly helped in reduction of radiation exposure to the working personnel.

Introduction of RAPISCAN X-ray Machine

100% scanning of fuel elements using RAPISCAN X-ray machine has been introduced subsequent to end cap welding operation to ensure UO_2 pellet stack in PHWR fuel pins.

RAPISCAN X-ray machine

Automatic tube feeding cum butting system for de-burring machine

Equipment Development & Automation section has developed an automatic tube feeding cum butting system for production of fuel tubes. This system is having an electrically operated vibrator to break the bridging / jamming of tubes in the tubes basket.

Development of Software for Incorporation of critical Interlocks on Spacer Pad Welding Machines

Interlocks were provided for critical parameters such as Mandrel, Chuck & Electrode Pressures, Spacer Pick up Vacuum, Argon Flow & Weld Current on Spacer pad welding machines for ensuring the weld quality. The machine availability and productivity have been improved after incorporation of these interlocks.

Structural Materials & Components

Zirconium activities

Zirconium Oxide Plant has achieved the highest ever production of 505.23 MT of nuclear grade Zirconium dioxide during the period from April 2016 to December 2016 surpassing the previous record of 452.39 MT during the same period. This increase in productivity could be achieved through extraction and recycle of Zirconium values from scrub Raffinate (a process intermediate stream).

In-house fabrication and installation of 500 mm diameter Zircaloy scrubber along with two stage dust separator for scrubbing of exhaust gases coming out of rotary calcination furnace. This scrubbing system has facilitated reduction in concentration of oxides of sulphur and nitrogen in the off gases.

Developed and implemented extraction of Zirconium from scrub raffinate. The extract was mixed with extract generated from the main slurry extraction unit, thereby increasing once through recovery and enhancing productivity.

Developed a process for conversion of acidic silt into usable product & discussed with private firms for the same. As a result, disposal of acidic silt could be initiated @50MT/month at a sale price of ₹ 2241/MT, against zero disposal previously in spite of sale orders @ ₹ 777/MT, that had led to accumulation of silt to about 1700MT in 3 years.

Production of 369.1 MT of Reactor grade Zirconium sponge is achieved from April to December, 2016. As part of 1.5 MT zirconium sponge batch Technology demonstration units major equipments have been received and erection and testing of 1.5 T batch reduction furnace is completed. 7th Magnesio-thermic reduction unit is successfully commissioned in reduction section of Zirconium Sponge Plant with modified temperature profile and control systems. Modified feed hoper in oxide chlorinator to improve briquettes distribution in the reactor bed. This has helped in improving productivity and chlorine utilization. Modified temperature profile for vacuum distillation operation to minimise losses & optimize the distillation time. Intermediate stage shredder (250 mm size) is successfully commissioned in sponge handling. Introduction of intermediate stage shredder has substantially reduced the sponge processing time & manpower requirement for the job, apart from replacing hydraulic press (3 units) operations.

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 materials were carried out.

Developmental works

SuperNi rods of 8mm and 16 mm were developed in coordination with BARC and first lot was supplied in August, 2016.

In-house fabrication of Honing Machine

A Honing machine for honing of 7.5 meter long coolant tubes in one stroke was conceived, designed and fabricated in-house. The use of new machine has resulted in de-bottlenecking the Coolant tubes

production process and has the following merits over the existing facility:

- The equipment facilitates honing of long tubes from one end itself, which has drastically increased recovery & offered better quality.
- Increase in productivity due to reduction of setting time of tubes by 50% coupled with single stroke.

Eccentricity at the ends was major demerit of horizontal honing of long tubes and same was overcome with this equipment by addition of suitable features to the machine. The entire project was completed within a short span of three months.

In house Design and Fabrication of Hydro Testing Equipment for low wall high OD tubes

Zr-1% Nb, 60mm OD x0.8 mm WT x 1.2m long tubes used for defence application were required to be hydro tested. The equipment was designed and developed successfully, which has addressed the problems related to testing of thin wall and high OD tubes.

The set-up consists of one fixed sealing head and other pneumatically operated moving head. Fast pre-fill and slow pressure ramp which was one of the major requirements is achieved by a hydraulic system powered by 3-plunger pump with flow by-pass arrangement. The work was completed in shortest possible time and led to timely supply of tubes.

Development of sealing system for High Pressure Roll actuating cylinder of straightening Machine

Frequent failure of oil seal of the roll actuating cylinder resulted in loss of oil and decreased reliability. Further, difficulty in accessing of the seal increased the downtime of the machine. Development of new sealing arrangement for piston rod of the High Pressure Roll actuating cylinder has not only led to increased availability, but it has also resulted in avoiding wastage of hydraulic oil. This work has resulted in increased productivity and reliability of the unit.

Rectification of 361 KN-m capacity braking system of 150 VMR Pilger Mill

150 VMR Pilger Mill is more than 30 year old and is one of the critical facilities, used for production of Coolant and Calandria tubes and no substitute of the same is available for production. The rectification of failed braking system was challenging, owing to the following reasons:

- The procedure for assembly / disassembly was not available in the manufacturers' manual.
- The 361 KN-m capacity brake is a bulky unit, Ø 1.4 m x 0.25 m long, weighing around 3 Tonnes.
- The unit is shrink fitted centrally on 4m long drive shaft.

In the absence of procedure for dismantling / assembly of the unit, the entire procedure and fabrication of jigs/fixtures was developed in-house. The shaft was kept over hanged by designing and fabricating jigs and supports for disassembling and assembling, which is carried out at 1200 bar.

Copper embedded Niobium rods were extruded in preparation of super conductor elements for BARC. One CRPM 65 Pilger Mill and one CPM 32 Mill each were received through import from two different companies and erection and commissioning was carried out in-house. Two capsule carrier bundles have been manufactured and delivered to RED, BARC and presently are undergoing pressure tests at BARC.

Reactivity Mechanisms

Development of reactivity mechanism

assemblies for 700 MWe PHWRs such as Poison Injection Unit, Vertical flux monitoring assemblies (VFU) and Horizontal flux monitoring assemblies (HFU). Load test arrangement of HFU & VFU assemblies was modified in-house by developing necessary gauges and fitting in-house to accomplish loading of two assemblies simultaneously, enhancing significant increase in test output.

In-house development of fixtures for pneumatic pressure test and helium leak test of HFU and VFU assemblies to ensure compliance with respect to assembly integrity, functional requirement and leak tightness in the order of 10-8 standard cc per sec.

One number of startup counter assembly of about 12 m long required on urgent basis for KAPS site was successfully qualified meeting all the stringent specification requirement with respect to integrity and leak tightness. 12 nos. of Cobalt absorber assemblies were qualified for 220MWe PHWRs. These assemblies were qualified with respect to Helium leak test, Radiography & Load test at 500 Kg. 104 nos. of PRP Water Pin Assemblies were successfully qualified and delivered to PRP, BARC meeting the extremely stringent requirement with respect to ultrasonic test, radiography & liquid penetrant examination of weld joint. Development of 3 nos. of dummy cobalt assemblies for 700 MWe PHWRs was carried out.

Special Materials

Produced & supplied 100 kg of micron size zirconium metal powder to meet requirement of Defence & Space departments. Antimony trioxide filled SS capsules have been produced and supplied to meet the second core requirement of neutron source sub assembly of PFBR. Production and supply of special grade high purity Niobium oxide and Zirconium oxide for AFD, BARC. Supplied various high purity materials such as POCl3, selenium, tellurium, antimony oxide and etc. on market demand. Supplied low RRR grade Niobium sheet of 650 x 550 x 5.8 mm to RRCAT for accelerator programme.

Advanced Melting & Machining Facility

Advanced Melting & Machining Facility under Project was sanctioned under XI plan project for indigenous development of Electron Beam Gun and various components to facilitate melting of zirconium, niobium, hafnium, molybdenum and its alloys.Procurement of electron beam melting plant envisaged under the project will enable direct utilization of scrap and off-grade materials for melting, refining and consolidation into ingots of Zr, Nb, Ti, Hf, Mo etc. and its alloys.300 kW EB melting furnace was indigenously developed as an import substitute embargo item at substantially lesser cost of the imported equipment.

The technology of Electron beam melting furnace is multidisciplinary in nature and in Indian scenario EBMF of similar capacity has not been developed so far. In the background of design expertise available with BARC and operational experience of NFC, Electron Beam melting furnace was designed jointly by NFC and BARC to develop the technology by involving indigenous manufacturers. Scope of this project was to indigenously build a high power EBMF, test for proper functioning of EB gun to the required power levels, gas loads, and also to assess for proper functioning of mechanical systems like charge feeders (rod and granules), ingot retraction systems for casting upto 280mm dia. on industrial scale for manufacturing of refractory metal ingots weighing about one ton.

Design and fabrication of the complete system involving EB gun, HV power supply, controls, vacuum system, installation and operation, cold and hot testing, trials and full-scale melting operation is completed. The furnace has been erected at NFC and is under commissioning.

This facility will also be used for the production of high purity reactive and refractory metals and their alloys such as niobium (RRR grade), titanium, hafnium, molybdenum etc. to fulfil requirements of atomic energy, defence and aerospace applications

EBMF- Front view

EBMF- Rear view

Commercial activities

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

SSTP has established the critical facilities for operations such as U Bending, with bend radius 2.3 x OD followed by heat treatment of bend region required for D_2O heat exchanger.

During the period from April - December 2016, SSTP has manufactured and supplied critical products which include 643 nos. of Incoloy 800 U-bend tubes for Moderator Heat Exchanger of upcoming 700 MWe PHWRs, 9765 nos. of SS-D9 grade Fuel clad tubes for Prototype Fast Breeder Reactor (PFBR), 800 nos. of SS304L poison tubes to TAPS, PT 7m tubes to BHEL and SS304L pipes to FRFCF project etc.

Developmental works in SSTP

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

Development of manufacturing process of Ti-Al-Zr (Titan-24) Tube for Defence Nuclear Application

Ti-Al-Zr (Titan-24) a titanium base alloy is one of the important materials, used for Defence Nuclear Application and made first time in the country as import substitute. The manufacturing process of these tubes are first time established successfully at NFC. During developmental process plant has optimized the production process such as pass schedule and heat treatment process parameters to meet all the desired mechanical, chemical, metallurgical properties with specified NDT requirement of UT and Eddy current testing against stringent ultrasonic defect standard of 3% WT.

The tubes produced at the plant were characterized w.r.to texture, corrosion, mechanical properties at room temperature & high temperature and also microstructure evaluation. The above properties are found to be superior and uniform in nature. The trial lot produced with established process parameters yielded recovery of more than 80%. Now plant is ready for taking up bulk production to meet the requirement.

Projects

Green field Projects of NFC

NFC-Kota

NFC-Kota, Rawatbhata, Rajasthan, a green field project, is being established to produce 500 tpy of UO_2 Pellets and 65 tpy of Zircaloy Products to meet the fuel

requirement of four 700 MWe PHWRs viz., RAPP 7&8 and Kakrapar 3&4.

Water Bound Macdam (WBM) road work and 15 kms out of 21 kms bitumen carpet work, 10 kms of drain work is completed. Construction of raw water reservoir, 9 nos. out of 12nos. watch tower, structural erection of 4nos. sheds for site office & stores are completed & finishing works are in progress. Construction work for main gate & material entry gate are in progress. Equipment for construction power have been received at site and erection work is in progress. Recommendations for placement of order for Plant civil works is approved by High Power Committee and action is on for procurement of long delivery equipment. An overall progress of 10.9% was achieved in the project till December, 2016.

Other sanctioned projects of NFC

Some of the major equipment like Tube reducing mill for 63mm dia tubes, automated fuel bundle inspection system, shredder machine for cutting of sponge and control system for reduction unit were commissioned and put in production line.

Receipt of Indigenously developed Electron Beam Melting gun & furnace at NFC, Hyderabad with 100 KW gun in September, 2016. Presently erection & commissioning is in progress.

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

As NFC plans to expand the facilities at Hyderabad and Kota, requirement of NFC 5 & 6 earlier proposed during XII plan for production of fuel & Zircaloy components is being revised.

The project proposed at Kota (NFC-4) for production of 100 tpy Zircaloy components will have to be taken up at a later date in line with the progress of Nuclear Power programme.

The projects proposed for AHWR Fuel Cluster Fabrication (FCFF-AHWR) and Zircaloy Structural Tubes & Component fabrication (ZF-AHWR) will be taken up at a later date to match with the schedule of AHWR programme.

In view of the revised requirements from NPCIL and availability of forging facility at Ishapore, need for the project proposed for Radial forging of ingots/ blanks (RFF) does not exist.

Projects proposed during MTA

NFC-7: The project is proposed to set-up a 400 tpy Zirconium Sponge Plant to cater to the zircaloy requirements of 16 x 700 MWe PHWRs being planned by NPCIL up to 2032 in various phases. Presently, sanction for taking up pre project activities was obtained in September,2016.

Augmentation of Amenities and Infrastructure at NFC (AAIS): The project is proposed to augment the existing amenities and infrastructural facilities at NFC, Hyderabad and Zirconium Complex, Pazhayakayal. The proposal for the same under consideration at DAE.

Other Green field Projects of NFC

NFC-Kurnool: Setting up of 300 tpy of VVER Fuel Fabrication Facility along with a Zircaloy Fabrication Facility of 75 tpy capacity for producing fuel tubes and other components to meet the requirements of 12 x 1000 MWe VVERs and setting up of a Stainless Steel Tube plant of 400 tpy capacity to cater to the requirements of 2 nos. of 500 MWe FBRs was proposed

at Kurnool site offered by AP Government, in place of the earlier proposal for setting up of NFC 5 & 6. Presently preliminary project report is under preparation.

Zirconium Complex

Zirconium Complex (ZC), Pazhayakayal, Tuticorin, Tamil Nadu is set up to produce 250 MT per annum of nuclear reactor grade Zirconium Sponge starting from washed and dried frit (crude zirconium hydroxide). Zirconium Complex was commissioned in November 2009 and regular production activities for both zirconium oxide and zirconium sponge continued since then. 399.4 MT of nuclear pure zirconium oxide and 194.485 MT of zirconium sponge were produced during the year till December, 2016.

Technology Demonstration Unit – 1.5 Ton Batch Zirconium Sponge

Technology Demonstration Units for 1.5 Ton Batch Zirconium Sponge are being installed to carry out demonstration trials. Construction clearance from AERB is received and structural modification works are completed. Process equipments and hardware have been received.

Reduction Furnace has been installed and tested. The units are expected to be commissioned by the end of March 2017.

Desalination Plant at Zirconium Complex

Desalination Plant with two streams each of capacity 30 m^3 per hour of product water is being set up at Zirconium Complex at a sanctioned capital cost of 20 Crores. Activities w.r.t sea water intake and outflow systems are completed. Intake Pump installation & commissioning is in progress. W.r.to the desalination plant major civil works are completed, erection of equipment completed, instrumentation hook up under progress. One stream has been commissioned in manual mode. Work on second stream is in progress w.r.t mechanical and instrumentation works.

Magnesium Recycling Technology Development & Demonstration Facility

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

Detailed engineering is in progress. Siting and construction consent from AERB was received on 19.07.2016. Civil construction works for main plant building is in progress. Retendering for melting furnaces, cables, transformers and electrical panels is taken up. Tenders are under preparation for various equipment systems / materials.

Melt shop

During this period, Melt shop has achieved production output of about 511 Tons of various Zirconium alloy ingots viz. double melted Zircaloy-4, Zircaloy-2, triple melted Zircaloy-4, Zr-1%Nb and Quadruple melted Zr-2.5%Nb. Melting of Zr-0.2%Nb, Zr-5%Nb and Zr-20%Nb alloys required for BARC was completed.

BACK END FUEL CYCLE

Fuel Reprocessing

All the operating plants performed very well at their designed capacities. Power Reactor Fuel Reprocessing Plant-2 (PREFRE-2), Tarapur has maintained its excellent performance and achieved the designed throughput. Kalpakkam Reprocessing Plant (KARP) continued to perform very well. Advance Fuel Fabrication Facility (AFFF) at Tarapur continued to

Construction of Raft of one front end block at INRP Tarapur

Sub-system of ADFTS

supply fuel to PFBR. Spent Fuel Storage Facility (SFSF) at Tarapur and Kalpakkam were in operation. Civil construction of Integrated Nuclear Recycle Plant (INRP) at Tarapur is in progress. The excavation work for four major front end blocks is completed and construction of raft is progressing well. Automated Direct Fuel Transfer System (ADFTS) for INRP has been designed and developed for the first time for remote transfer of the spent fuel bundles from spent fuel storage pool to dissolver cell for its direct feed to spent fuel chopper. The ADFTS has been installed at the component test facility at Tarapur and is being tested.

Installation of mechanical, electrical, I&C and materials handling equipment are completed and commissioning of Additional Spent Fuel Storage Facility (ASFSF) at Tarapur is in full swing.

Operation of Kalpakkam Reprocessing Plant (KARP) continued and performed very well. Fabrication and supply of MOX fuel to PFBR at Kalpakkam continued in Advance Fuel Fabrication Facility (AFFF) at Tarapur. The capacity of fabrication of fuel at AFFF has been increased by installation of a new fabrication line which will be commissioned shortly.

After a thorough decontamination of the plant, replacement of 3 failed evaporators with associated piping work was completed. Replacement of about 500 nos. of manually operated steam and air sparger valves in Operating Gallery with air actuated valves was completed for process operations. 2 nos. of 50-year old Stack Fans were replaced. About 15 m^3 of High Level Liquid Waste was transferred to WIP for Cs pencil production.

Plutonium Plant, Trombay

In-house heat exchanger was dismantled for de-scaling and was refitted saving substantial cost. A centrifuge-decanter system was commissioned at Low Level Liquid Waste Delay Tank for collection and disposal of accumulated muck. Structural repairs and painting were done for the 135m RCC stack. In the Power Reactor Thoria Reprocessing Facility (PRTRF), after the successful processing of two batches of irradiated thoria-rods, pre-commissioning activities of Waste Tank Farm was completed. In Metallurgical Waste Processing Facility (MWPF), five batches were processed successfully.

An Experimentation and Equipment Test Facility (EETF) for testing of large size columns for high throughput reprocessing plant has been set up at

Experimental Facility for Column Testing, Trombay

Trombay and commissioning trials are in progress. Lab scale recovery of U from Silicide Fuel expected from High Flux Research Reactor was established using a feed composition of reference burn up for 80,000 MWD/Te, 10 y cooling. Stripping took 3 stages with recovery of more than 99.95% and decontamination factor was more than 10^3.

An engineering scale prototype of hull-rinser based on spiral elevator concept has been developed for rinsing hull pieces discharged from Continuous Rotary Dissolver. Vibration induced in spiral flutes causes elevation of the hulls in a spiral path, finally get discharged at the top. The vibrating hulls get rinsed in the process. About 1,200 simulated trials were completed.

Removal of dissolved organics using pulsed column as a diluent-wash equipment was demonstrated, bringing down TBP upto 40ppm in treated aqueous phase. Preparation of Ag-loaded mordenite has been carried out on 1 kg batch scale for trapping of I2 vapours arising from Dissolver off Gas (DOG). The material has been tested extensively over 3 weeks. I2 removal efficiency of more than 90% was demonstrated.

A Test Facility was established for estimating protection factors for various particulate respirators used (half face mask, full face mask and powered air purifying respirators) in back end fuel cycle facilities to prevent any intake of radionuclides. The setup consists of an upper waist human dummy (mannequin) placed inside a glass test chamber. Respirator under test is placed on the dummy and air flow of 20 lpm (equivalent to average breathing rate) is established through the respirator using air suction pump. Particle measurements are carried out before and after the respirator using optical particle counters to determine the protection factors and select an appropriate respirator for a particular job.

A facility has also been established to test various filter media such as micro glass fiber for HEPA filter, HEPA plus carbon granules filter, HEPA cartridge filter, electrostatic filter, microdot filter and disposable masks for their filtration efficiency and pressure drop against airborne radioactive contaminants in nuclear facilities.

Facility for testing of (a) Respirators (b) Particulate Filter Media

Development of a new Cs(I) Ion Selective Electrode (ISE) with various alkyl bridged Calix[4]arene crown-6 compounds was taken up. The best response was observed with 1,3 cyclo tetradecyloxy calix[4]arene crown 6 compound. Studies carried out to optimize the membrane composition showed that membrane containing Dioctyl Sebacate (DOS) as a plasticizer and potassium tetrakis (perchlorophenyl) borate (KTpClPB) as anion additive gave best response for Cs(I). Optimised Cs(I) ISE gave Nernst response over the concentration range 10-7 to 10-2 M of Cs(I) and has very good selectivity for Cs(I) over various alkali, alkaline earth and transition meta ions.

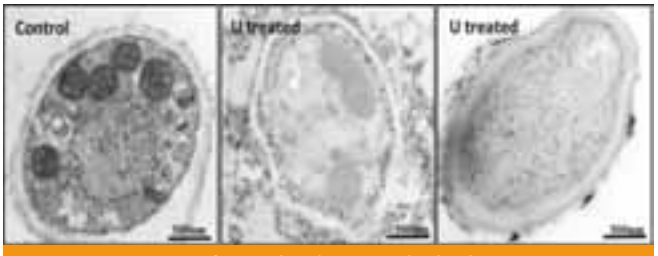
Studies were also carried out to develop an all solid contact Cs(I) ISE employing polyaniline as a transducer. Employing developed ISE Cs(I), content was determined in high level simulated waste solution and Cs(I) spiked tap water samples.

Synthesis of a solvent for selective recovery of Pu(IV) from lean sources (HLLW after Purex and different metallurgical waste) was accomplished. A traiarylpyridine–based diamide was rationally designed and synthesized for sequestering Pu(IV) ions from a mixture of diverse types of metal ions.

The molecule can be used both for solvent extraction and membrane separation. A new class of oxadicarboxamides (OBDAs) also showed high selectivity for separation of Am(III) and/ or Pu(IV) ions. Chemically grafted benzo-15-crown-5-based-resin for separation of Li isotopes and an anion exchanger for separation of Mo and Ru oxometalates from HNO3 medium were developed.

A γ radiation and metal tolerant bacterial strain, Serratia marcescens isolated from the U-rich deposits could efficiently bioprecipitate U ions in presence of β-glycerophosphate as the substrate, under acidic, neutral or alkaline conditions. Even a high dose (1.6 kGy) of ionizing radiation did not compromise its superior U precipitation ability.

Marine yeast, Yarrowia lipolytica was found to sequester 50% of uranyl ions within 24 h of exposure to 50 µM uranyl carbonate with a loading capacity of 37.51 mg U/g biomass. TEM images demonstrated intracellular electron dense needle-like fibrils of U deposits along with sizeable fraction of extracellular U deposits on the cell wall.



TEM images of control and U-treated Y. lipolytica yeast

Air Pulsed Columns are used extensively in nuclear fuel cycle. Computational Fluid Dynamics (CFD) models for prediction of hydrodynamic aspects like holdup, drop size and axial dispersion in Pulsed Sieve Plate Columns (PSPC) were validated using published and in-house experimental data. Experiments were carried out in pulsed columns of varying diameters up to 6 inch. Axial dispersion model based code was written for predicting mass transfer in PSPCs and validated with reported data for U and Pu extraction in a 2 inch column. Similar studies are in progress for modelling of Pulsed Disc and Doughnut Columns (PDDC). Two-phase CFD model of PDDC to predict dispersed phase holdup was validated using in-house experimental data generated in 3 inch column and was found to be better than empirical correlations reported in literature.

Waste Management

The treatment of Intermediate level Liquid Waste (ILW) for isolation of radionuclides created an operational record in the Waste Immobilization Plants (WIP) at Tarapur and Kalpakkam by processing ILW in an uninterrupted manner at the best throughput, thus continuously reducing the liquid waste inventory. The Solid Waste Management Facility (SWMF) and low level liquid waste treatment plants performed satisfactorily to meet the requirements of DAE facilities at Tarapur and Kalpakkam. In Waste Immobilization Plant (WIP) at Kalpakkam, the spent resin cementation system for MAPS has been commissioned and the entire legacy resin stored in MAPS was received, removed by fluidisation and fixed in cement matrix successfully. Ozonation studies in laboratory as well as pilot plant

VWSF Phase–I: Thermal Vaults

scale completed for treating the Di Butyl Phosphate (DBP) bearing ILW.

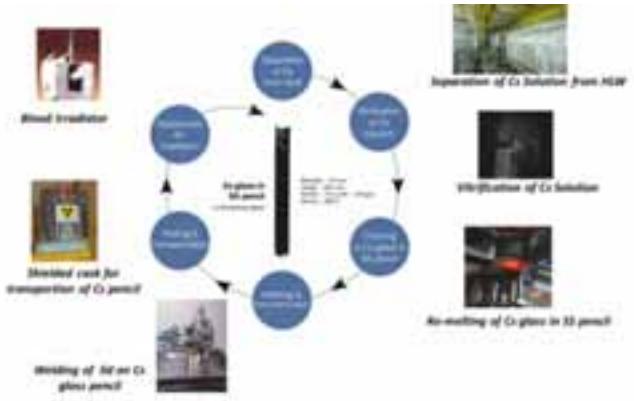
Construction of the Phase-I of Vitrified Waste Storage Facility (VWSF) comprising of the thermal vault and RCC stack has been completed and the phase-2 construction of superstructure is progressing well.

Design, manufacture and shop testing of a 2000 Te Supercompactor (high tonnage hydraulic press) for compaction of hull waste to achieve significant volume reduction through remote operation and maintenance has been completed. Compaction is done in steps in pre-programmed manner using PLC based operation. The installation of the Supercompactor is in progress in the component test facility at Tarapur. Centralised Waste Management Facility continued to provide waste management services to various units of DAE at Kalpakkam while maintaining the discharges/disposals well within the authorised limits. Several batches of Tc-99 bearing liquid waste from WIP was successfully treated using single/two stage chemical precipitation method developed at CWMF.

The Melt Densification System was installed and commissioned at the Centralised Waste Management Facility (CWMF), Kalpakkam for the volume reduction of contaminated polythene waste. Its operations are automated using a Programmable Logic Controller. As the volume reduction is achieved by heating the material to its melting point, the Volume Reduction Factor (VRF) in the system is higher than compaction. Also, the radionuclides are immobilized within the densified waste product resulting in excellent leach resistance.

Melt Densification System at CWMF, Kalpakkam

Continuing with the operational implementation of the concept of "wealth from waste", around 40,000Ci of Cs was separated selectively by use of the in-house developed calyx crown-6 solution from High Level Wastes and eventually immobilized in vitreous matrix on engineering scale. 56 Nos. of Cs pencils at 1.7Ci/gm delivered to BRIT.



Cs-137 Glass Pencil from High Level Waste, WIP (Trombay)

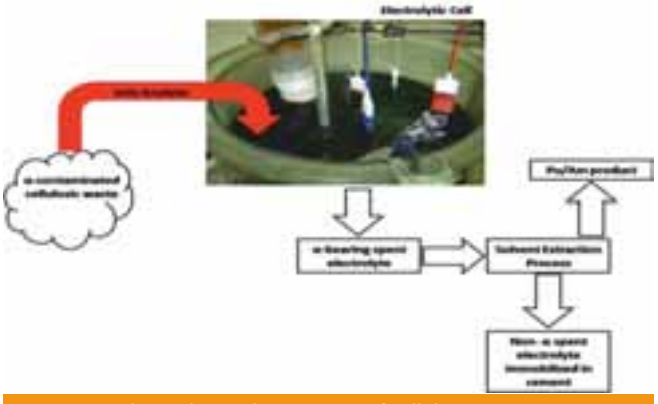
Multi-step solvent extraction process was employed for the separation of high specific activity ^{90}Sr from PUREX-HLLW. High purity ^{90}Sr nitrate product of 1Ci having activity of 100Ci/L could be recovered. This activity was used to separate carrier-free ^{90}Y in acetic acid medium using two stage supported liquid membrane generator system developed in-house.

Implementation of the three-stage process, processing High Level Legacy Wastes generated from reprocessing continued. These waste contain problematic sulphates along with high inactive salt load. This philosophy of partitioning has changed our perception of radio-active wastes into one resource material. This system was operated continuously during this period for treatment of 30,000 lit of legacy high level waste.

About 400 m3 of solid waste was managed safely. Around 1 lakh Kg of protective wears were decontaminated and recycled to users. 13,420 kg of high active components from DHRUVA was safely

processed and recycled. Effluent Treatment Plant is mandated to receive/collect, treat and dispose of Low Level radioactive Liquid Waste (LLLW) generated from various plants and laboratories in Trombay. A large quantity of LLLW was safely managed by Chemical Treatment, Ion Exchange and Reverse Osmosis.

Process development for management of α-bearing cellulosic wastes including lab-coats, swipes, tissue papers etc. has been completed. The process involves Ag++ mediated electrochemical oxidation of α-bearing cellulose in 8M HNO_3. A process for the recovery of actinides from acidic solution has also been developed. After extensive trials, coating of PVDF on SS vessels has been finalized as material of construction for plant scale adoption.



Electrochemical Destruction of Cellulosic Wastes

A pilot scale facility of processing capacity 10 lit (1kg) tissue paper per batch per day is under final stage of completion. The facility is being installed at WIP, Trombay.

An indigenous development of Induction Skull Melting (ISM) technology having many important applications in frontier areas was taken up. The ISM facility has a water-cooled segmented copper crucible with in-situ casting module, induction heating power supply system, cooling water recirculation system, vacuum chamber with vacuum delivery system and associated instrumentation & control units. The facility was successfully tested for melting and homogenizing different metals and alloys. Safety review of the facility for regular operation has been completed.

Direct vitrification of alkaline ILLW from FRP, Fast Reactor Fuel Cycle Facility (FRFCF), Kalpakkam is a promising alternate with several advantages over cementation. Vitrified product is superior in durability, leads to an improved volume reduction (50%) for ILLW. Higher temperature (1200°C) experimentation showed additional 25 % waste loading for a throughput of 30 lph.

R&D efforts have been directed towards downstream processing of separated alpha contents in Actinide Separation Demonstration Facility (ASDF), Tarapur to study and demonstrate the subsequent precipitation step in shielded glove box at ASDF, Tarapur. Experimental evaluation of the precipitation process on laboratory (active) scale and engineering (inactive) scale carried out and demonstrated the quantitative recovery and conversion (> 99%) of Rare Earths (used as surrogates for actinides) is feasible. These steps are being implemented down-stream processing facility at ASDF, Tarapur.

Ion exchange treatment of Intermediate Level Liquid Waste (ILLW) at WIP, Tarapur & Kalpakkam resulted in Tc rich Low Level Liquid Waste (LLLW).The generated LLLW is treated by chemical precipitation, prior to environmental discharge. Towards the development of a better process (w.r.t. TcDF) and minimal secondary waste generation, a novel nano-sorbent has been developed for the removal of Tc from LLLW. This process is under review of international patent committee.

Developmental work on Selective Catalytic Reduction (SCR) catalyst was taken up for abatement of NOx arising from reprocessing and vitrification of gas streams. $V_2O_5 - TiO_2$ and $V_2O_5 - WO_3 - TiO_2$ catalysts supported on low cost alumino-silicate water filter candles were prepared, demonstrated reduction of inlet NOx from 2000 ppm to background levels. A 2kg trial setup has been made.

Radiation stability of borosilicate glasses was

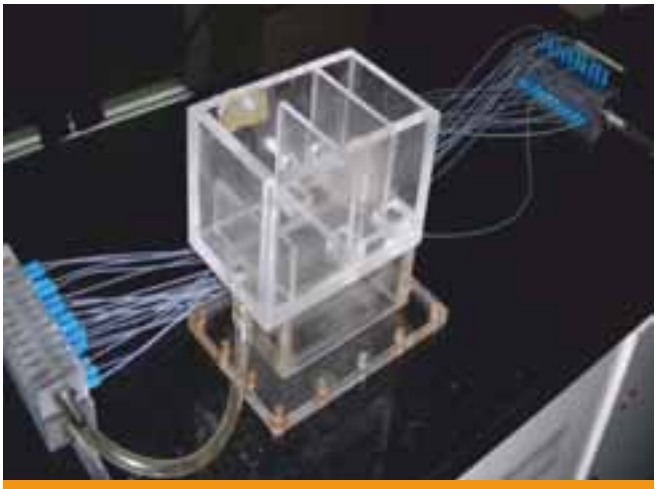
studied simulating 5,000 years of storage of vitrified HLW, containing 0.5Ci/g of ^{241}Am, under the Indo-UK and Indo-French projects. Composition-dependence on radiation damage was examined using in-pile irradiation and ion bombardment techniques. Studies showed glasses having high B_2O_3 and low Na_2O contents are least radiation stable. Al_2O_3 or ZnO in glasses improved chemical durability and radiation stability.

An engineering scale glove-box-based setup comprising of processing steps; dismantling, cutting, source removal, source material processing and management of hazardous secondary wastes was installed at WIP. Process steps were successfully carried out meeting all radiological and industrial safety aspects.

Design of two Solid Radioactive Waste Disposal Modules (SWDMs) completed with improved stability and seismic safety for accommodating wastes for 8-10 yrs with surface dose of 10 -15 mR/hr.

Nature of interface and mechanism of 'TBP associated uranyl' crossing under neutral and acidic conditions was studied using molecular dynamic simulations. The study provides compelling evidence of experimentally observed reorganization of interfacial complexes at the interface and their structural reformation during extraction. Study makes evident the TBP-induced charge redistribution of uranyl complexes during migration from the interface to the bulk organic phase, which contributes to drive uranyl complexes with diverse TBP and acid stoichiometry. The present study provides insights and quantitative investigations on the extraction of species at the liquid–liquid interface.

Process intensification using micro-structured devices were demonstrated for carrying out chemical reactions. Synthesis of monodispersed gold nanoparticles having particle size less than 5 nm required for radiopharmaceutical applications and Pd nanoparticles having size in the range of 7-10 nm



Stage Micromixer-settler for solvent extraction at 10 LPH

required for catalytic hydrogenation reactions in preparation of crown ethers were synthesized. Solvent-free continuous synthesis of ionic liquid 1,3-dimethylimidazolium dimethyl phosphate {[DMIM]DMP} having application in waste heat recovery and continuous synthesis of Tributyl Phosphate (TBP) in micro-reactor was demonstrated.

Multi-stage microfluidic solvent extraction using micromixer-settler was demonstrated. More than 90% extraction of U from lean stream (500 ppm uranium) was achieved in two counter-current stages.

Sr selective ligand Ditert-butyl DCH18C6 applicable in paraffinic diluent with high selectivity (>50) for recovery of Sr from acidic high level nuclear waste was synthesized. Synthesis of Ditert butyl DB18C6, precursor of Ditert-butyl DCH18C6, was demonstrated in 1 mol/batch basis at a yield of 10% having a purity of more than 90%. Synthesis of pure ditert-butyl DCH18C6 by hydrogenation of the intermediate DTBDB18C6 has been successfully achieved in lab scale and evaluation has been done with active solution with satisfactory result.

Direct thermal denitration of uranyl nitrate to uranium oxide powder has been demonstrated in 150 NB fluidized bed reactor which is scaled up version of previous 80 NB reactor. The reactor was operated using U_3O_8 as starting bed material and with a feed rate of 2 – 3lph. The reactor was operated in round the clock shift

and continuous smooth operation was established. During the operation, online regeneration of filter candles was successfully tested using blow back air pulse. UO_3 particles in the size range 10-15 microns were collected from the filter housing.

Safety Performance of Reactors

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

During the year 2016-17, following major activities were completed:

A computer based system, Symptom based Intervention Guidelines Management System (SIGMAS) has been developed, verified and tested for implementation of symptom based event handling scheme for 540 MWe PHWRs. This system is an operator aid designed to supplement existing event based Emergency Operating Procedures and will facilitate the operator to handle the transient or accident condition in a safe and effective manner.

As a step further towards improvement in handling of off-site radiological emergencies, Decision Support System has been implemented at NAPS. This system will help in identifying the affected area and assist the emergency managers for deciding the implementation of proper countermeasures in advance to avert the dose to the public thus resulting in minimizing the effects of accidents in public domain

Analysis for qualification of Containment Filtered Venting System (CFVS) for Indian PHWRs was completed and the design of CFVS for retrofitting in operating stations was finalized. Design Basis Reports (DBRs) of respective stations have been submitted to AERB. This system will ensure containment integrity in case of containment pressurization during severe accident conditions. CFVS design for 700 MWe has also been finalized in line with operating stations.

Calculations on performance of Passive Catalytic Recombiner Devices (PCRD) were completed for various tests performed at Hydrogen Recombiner Test Facility (HRTF) at Tarapur site. It was observed that PCRD located at bottom performed better than top and PCRD located near the wall gave little reduced hydrogen removal rate as compared to PCRD located centrally. Further PCRD with additional chimney fitted in the housing resulted in enhanced hydrogen removal rate. Design of PCRD was finalized in view of the above observations.

To assess the importance of the various components and human actions during shut down state, Level-1 PSA for MAPS was extended to include Shutdown and Low Power states to have an integrated model of the safety. This study helps in assessing the risk of core damage arising due to maintenance activities and gives better insight in the planning of shutdown maintenance jobs and acts as an additional operator aid for improving reactor safety during unit shutdown.

External flood Probabilistic Safety Assessment (PSA) of Madras Atomic Power Station (MAPS) was performed with the objective of identifying potential risk from significant event sequences following flood. The plant response to flood sources viz. rainfall, storm surge and tsunami showed that adequate levels of safety have been provided in MAPS and risk due to flood is bare minimum.

NPCIL participated in OECD (Organization for Economic Cooperation and Development) consortium programme jointly with BARC to gain insight of thermal hydraulic safety issue that constitutes the Advanced Thermal hydraulic Test Loop for Accident Simulation (ATLAS) experimental programme. Both pre-test and post-test analysis for benchmark exercise based on the ATLAS A5.1 test, which was organized in the framework of the OECD-ATLAS project. Experimental data of small

break Loss of Coolant Accident (LOCA) were compared with predicted results in blind calculation phase. The NPCIL results were found to be close to the experimental data thus bringing out the prediction capability of NPCIL Thermal Hydraulic computer codes.

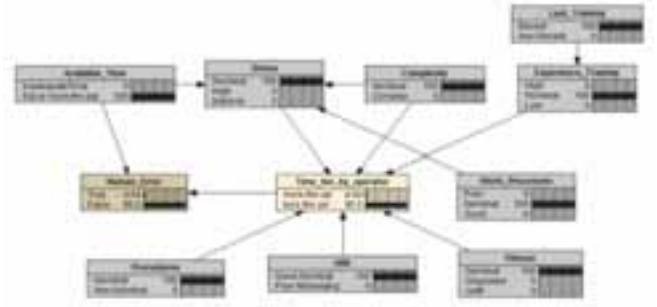
Annulus Gas Monitoring System detailed modelling was taken up for all Nuclear Power Plants, this included experiments to validate computational model. From the analysis efficacy of the system to capture leak at very low rate was established in recirculation mode. The calculation for containment response was made by using NPC containment thermal hydraulic code PACSR (Post Accident Containment System Response), and the results were found to be close to the observed pressure and temperature.

A detailed analysis for tsunami and storm surge estimation using latest state-of-the-art Computational Fluid Dynamics (CFD) approach was carried out for KKNPP-3&4. It was found that the estimated safe grade level due to tsunami and storm surge is well below the adopted grade level.

HEALTH, SAFETY AND ENVIRONMENT

Human Reliability Analysis (HRA) is an accepted methodology to assess the performance of human operator by identifying the human errors and quantifying their likelihood in terms of Human Error Probability (HEP). As a pilot study, a virtual environment (VE) model of LOCA (Loss of Coolant Accident) Equipment Qualification Facility was developed in 3DVIA Studio Pro software tool for generating the human factor (HF) data for a typical postulated accident scenario. Multi Attribute Utility Theory (MAUT) was applied on seven widely used HRA techniques based on the HF data obtained from human operator experiments conducted on virtual model of LOCA facility to rank HRA methods. Standardized Plant Analysis Risk HRA (SPAR-H) technique was found to be the most suitable HRA technique and the Bayesian Network (BN) model of SPAR-H for HEP estimation is

Virtual Environment LOCA Equipment Qualification facility



BN model for SPAR-H

shown in figure. Virtual simulator has an advantage over real simulator that can be easily modified to generate HF data for advanced plants during their design stage itself.

A portable Thyroid monitor and a Whole Body Monitor for in-vivo monitoring of general public and radiation workers for the detection of ^{131}I deposited in thyroid and other γ emitters like ^{137}Cs, ^{60}Co in whole body have been developed. The systems are easily transportable for field use during nuclear emergency.

Portable whole body monitor and thyroid monitor

Cerenkov counting technique was standardized for detection of ^{32}P in bioassay samples by studying various experimental parameters like vial material, volume of sample, molarity of ammonia, weight of Ammonium Molybdo Phosphate (AMP) precipitate formed and presence of colour and turbidity which have influence in Cerenkov counting efficiency as indicated by Triple to Double Coincidence Ratio (TDCR).

Internal exposure via ingestion to populations residing in High Background Radiation Areas (HBRAs) of India where the Th content in the soil is high due to presence of Th rich monazite ore, is estimated by the Dietary exposure assessment. Neutron Activation Analysis (NAA) was standardized for estimation of Th in the Duplicate Diet Samples (DDS) and dietary components.

The naturally occurring radon gas emanating from rocks and soil is one of the potential earthquake precursors. Results of diffusio-advection radon transport model have shown that a very low carrier gas velocity (µm/s) due to pre-seismic stress release can result in very significant changes in radon emission prior to earthquake events.

Based on this, a solar powered geo-station comprising of an indigenous radon monitor, soil probe and an accumulation chamber has been developed. 2 units have been installed at NIT, Rourkela and SGRC, Shillong as a part of feasibility study for detecting stress release from earth crust prior to earthquake events through sub-soil radon perturbation. Initial results are encouraging wherein at least five earthquake events in North-East Corridor of Indian Tectonic Plate Boundary have been correlated to radon anomalies occurring about 20-40 hours prior to the event depending upon the distance of monitoring site from the epicenter. This study has highlighted the need to establish a network of multi-parametric monitoring stations to address the challenging task of earthquake prediction.

Solar powered geo-gas (222Rn & 220Rn) monitoring station

Map showing monitoring location and various earthquake events within Indian Tectonic Plate Boundary

National Occupational Dose Registry System (NODRS) of BARC with a database of 6,26,875 radiation workers maintains and updates occupational dose data of all monitored radiation workers in India. The networked version has been expanded to cover 55 laboratories/ Health Physics Units of 7 NPPs and 8 other DAE units. System facilitates online allotment of personal numbers to new radiation workers, online updation of dose data, linking of dose records and online availability of dose history of existing radiation

Online display of Global Finger Print matching results

workers. Recently, Global fingerprint comparison software has been introduced in the system. A new radiation worker registering with NODRS is searched using his fingerprint and when the match is found, his personal details along with the dose history are displayed. This feature is very helpful in effective dose control as well as tracking the radiation worker movement within DAE units.

Under the Indian Environmental Radiation Monitoring Network (IERMON) programme, 41 Environmental Radiation Monitors (ERMs) were installed raising the strength of ERMs deployed in the country to 462.

IERMON Installations at Andaman and Nicobar Islands

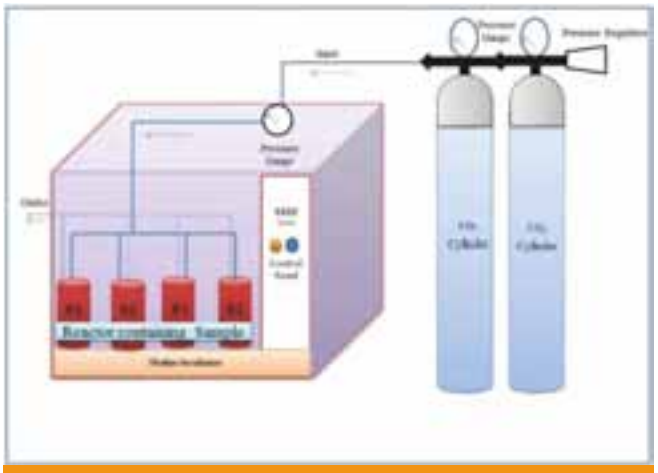
BARC provided consultancy service to National Thermal Power Corporation (NTPC) Ltd. to carry out radiological survey around NTPC's Thermal Power Plants. The study covers pre-operational radiological survey of three plants under construction and six operational plants within a period of 1 year. Survey

Deployment of radon monitoring passive device

Water sample collection from local source

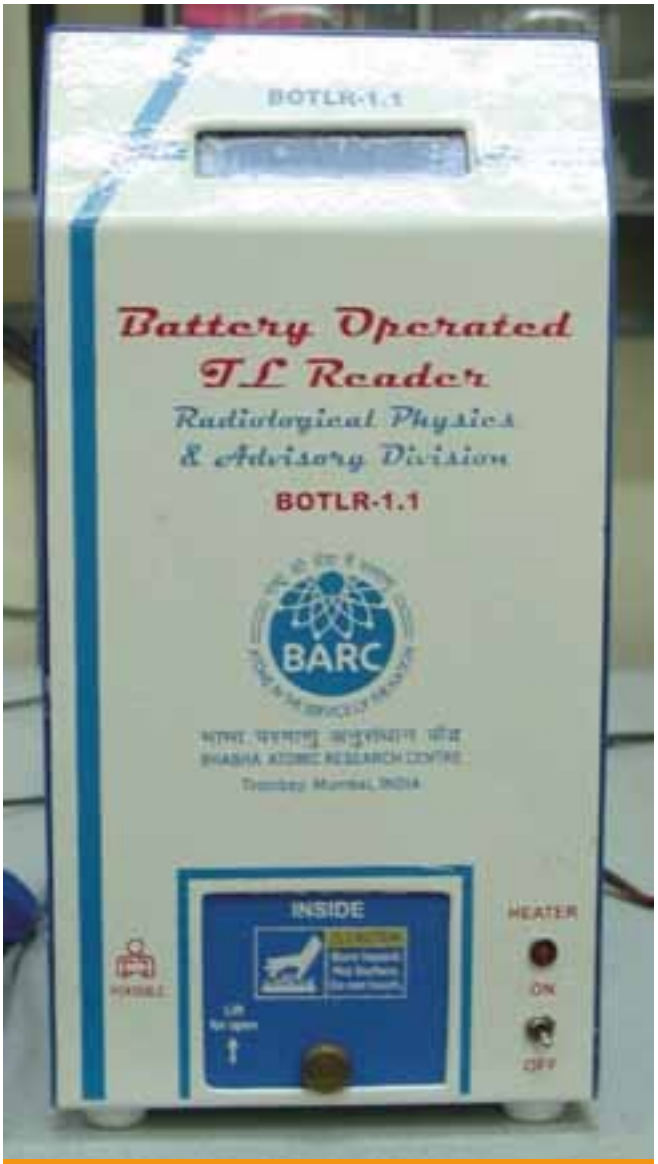
includes monitoring of γ radiation and radon and thoron in plant premises, surrounding villages and township areas, measurement of natural radionuclide levels (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb & ^{40}K) in soil, fly ash, ground and surface water, locally grown vegetables, drinking water in nearby villages and township.

A batch experiment of CO_2 infiltration under closed conditions was conducted on mineral (U Ore)-water system to understand how increased CO_2 concentration affects mobility and speciation of U and change in water chemistry due to CO_2 infiltration. After the exposure to CO_2, water pH declined rapidly and again rebound and achieved equilibrium by the end of the experiment. Speciation of U at mineral-water interface changed from $(UO_2)_2CO_3(OH)_3$- to carbonate (UO_2CO_3), fluoride (UO_2F^+) and sulfate (UO_2SO_4) complexes. Results of this study provide input for



Experimental Setup

designing of engineering barriers for long term storage of U containing wastes.



Battery operated TL system (BOLTR-1) with a Glow curve

A light weight portable Battery Operated TL Reader [BOTLR-1] has been developed which has a power requirement of as low as 5 Watt DC. The reader is capable of recording 25 TL glow curves at a heating rate of 5 K/s to 400°C with 4 AA size re-chargeable Ni-MH (2500 mAh) batteries. The reader has demonstrated six decades of dose linearity with a minimum measurable dose of 5 Gy for $CaSO_4$:Dy based TL dosimeter with an in-field dose reproducibility within ± 6 %. This development has opened up new opportunities of carrying out TL dosimetry beyond the confines of laboratory and is particularly attractive for nuclear emergencies/forensic applications.

A faster and non-destructive technique has been devised for analysis of personal dosimeters based on Direct Radon and Thoron progeny sensors using Fourier Transform IR spectroscopy. The principle of analysis is to relate transmittance of vibrational bands obtained using FTIR spectroscopy to deposited particle flux and hence to dose. This technique is useful for occupational environment wherein high progeny concentrations are generally encountered.

Environmental Radioactivity Measurement Laboratory participated in the IAEA-RML-2015 PT exercise involving a total of 17 laboratories from 15 countries for quality assurance and quality control of analytical methods. This involved estimation of low level activity of ^{3}H and ^{90}Sr along with Cs isotopes in the seawater samples. Ratio of lab reported values to IAEA target values for PT were in good agreement with all the reported measurements fulfilling the accuracy and precision criteria of acceptability. The participation in inter-comparison exercises has demonstrated competence in radionuclide identification and estimations, validated adopted analytical methods and introduced traceability to measurement at national and international level.

Calibration of radiation dosimeters used in external beam therapy and brachytherapy was provided to more than 400 radiotherapy centres to ensure

HDR ^{192}Ir calibration system

accurate dose delivery to the patients. Automation of the High Dose Rate (HDR) ^{192}Ir calibration system was carried out at BARC. The unit consists of a calibration bench along with source movement and transfer system for the calibration of well type chambers used in brachytherapy. The unit is designed to standardize the source strength in terms of reference air kerma rate. The unit also has a facility of safe loading and unloading of ^{192}Ir source from the source container.

A two member team from BARC participated in the 35th Indian Scientific Expedition to Antarctica and carried out radiation measurements around 'Bharati' station. For recording γ dose rates (terrestrial and cosmic), two IERMON) systems were installed, inside and outside the station and auto transfer of data to BARC via NCAOR server was established.

IERMON System installed inside and outside Bharati Station (Antarctica)

Handheld γ Spectrometer (H2S2), Compact Arial Radiation Monitor (CARMS), RadEye G meter, γ register, γ tracer and neutron REM counter, Tissue

Radiation survey over the sea ice of McLeod Island with system mounted on a movable platform

High radiation level (755 µR /hr on a rock in Betts Island

Equivalent Proportional Counter (TEPC) were used for extensive terrestrial radiation survey around 'Bharati' station. Lake water and snow was collected for ^{3}H analysis. In Betts Island, a rock exceeding an exposure rate of 600 µR/h was found as compared to the surrounding rocks with 30 µR/h due to high ^{232}Th content. High background areas in Antarctica such as Progress Granite in the Larsemann Hills were identified.

Environmental samples are collected from various matrices such as air, water, soil and biota and radioactivity levels are measured using highly sensitive instruments. Samples are collected from the power plant environment up to a distance of 30 km radial distance. Environmental surveillance programme carried out during the past, around nuclear facilities, clearly indicated that the dose to the member of public at fence post is only a small fraction of regulatory limit of

1000 µSv/y and negligible compared to the dose received by the public from natural sources (2400 µSv/y). At larger distances from the plant, the doses are much lower than 30 µSv/y.

An analytical method based on fluorometry was developed for the determination of ultra-trace amount of U in aqueous samples using quantum dot (QD) nanosensor.

NPCIL has recorded about 451 reactor years of safe operation of reactors by the end of December 2016. Review of safety of operating stations was carried out on a regular basis. All safety significant proposals and documents were reviewed by a multidisciplinary Safety Review Committee (SRC) to meet the regulatory compliance. The individual and collective doses of radiation workers at various NPPs were maintained within the budget approved by AERB by following the principles of As Low as Reasonably Achievable (ALARA) and maintaining the highest standards of safety within the Nuclear Power Plants (NPPs). The radioactive effluents discharged from NPPs to the environment were maintained well below the authorized limits specified by AERB. NPCIL continued to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At all operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001: 2004 and Occupational Health and Safety Management System (OHSMS) as per IS-18001: 2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

For Chutka, Environmental Impact Assessment (EIA) study is completed and proposal for MoEF clearance is submitted. EIA study is completed and is under review by MoEFCC for Mith Virdi. In respect of Mahi Banswara, draft EIA report is under review before submission to MoEF for clearance. Application for Public Hearing is planned to be submitted. MoEFCC has extended the validity of ToR for EIA/ EC for the project. Terms of Reference (TOR) was approved by MoEFCC in September 2016 for Kaiga-5&6. Environmental monitoring for EIA study is in progress. First season monitoring works are completed and second season monitoring works has been initiated. At Kovvada, seasonal data monitoring has commenced with eight stations located in different areas. MoEFCC granted revalidation of Environmental Clearance (EC) for JNPP and RAPP 7&8 based on NPCIL application along with the Form-1 and status of the project. Environmental & CRZ clearances from MoEFCC for Away From Reactor (AFR) facility is in progress at KNPP.

The Environment Stewardship Programme (ESP) is a voluntary activity of NPCIL, with the aim of protecting environment in and around nuclear power plants. A variety of nature programmes focusing on scientific studies of the bio-diversity in and around all nuclear power plants are done through ESP. Through ESP, training of local volunteers, surveys, organizing public awareness campaigns on environment, informing local public on various environment related issues, publishing articles on ESP etc. are also carried out.

The Butterfly Gardens are established at Kakrapar, Tarapur, Kaiga through ESP. Similar gardens are planned and under progress at Narora and Kudankulam. The Project Turtle at Narora is taken up under ESP to protect the endangered species of turtles in river Ganga. The nest of two species of turtle viz. Batagurdhongoka and Chitraindica, are explored and the eggs are collected and incubated in our turtle facility developed in NAPS Township in association with Turtle Surveillance Agency - an expert conservation agency. The hatched neonates are kept in the hatchery with proper nutrition and care. After attaining desired growth, the turtles are released in river Ganga.

NPCIL organized Bird marathons at Narora and Kaiga in the process of ESP. An Avian Survey of various bird species and numbers are done at KAPS – Gujarat. A MoU is signed with the Wildlife Institute of India (WII) – an autonomous body under the Ministry of

Environment and Forestry, Government of India for various conservation activities. NPCIL in partnership with WII is associated with Namami Ganga Project – a project for protecting river Ganga by Govt. of India. Similarly, a pair of mudflats was established at KKNPP Township in association with BNHS to provide a safe foraging habitat for water birds and migratory birds. A Botanical Garden is under development at KAPS under ESP.

A Coffee Table book "Fliers of our Courtyards", on the birds in and around our nuclear power plants is under final printing. Films on the surrounding environment of nuclear power are made for climate change summit. A special feature "From the lands of the lamas - One of the world's highest-flying avian wintering in the backyards of three Indian nuclear power plant sites" has been published in "Wild Bytes - Online". An article - "Fall of the Vultures" around our RR site has also been published in "Science Reporter".

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

On Safety part, the Manuguru plant completed 3 million man hours of continuous working without RDI on 18.06.2016. The Hazira Plant has completed 2962 nos. of accident free period as on 31.12.2016. The Thal Plant completed 2591 nos. of accident free days as on 31.12.2016 since last reportable injury on 07/12/2009. At Thal, all the 110 Nos of canned motor pump's electrical feeders in MCC for exchange tower 12T1A, 12T2A, 12T1B & 12T2B were provided with CBT (Core Balance current Transformers) and ELCBs (Earth Leakage Circuit Breakers) to ensure equipment and personnel safety. 11KV & 3.3 KV feeders were provided with remote operation panel to ensure safety of Electrical O&M personnel in case of occurrence of flashover.

In the field of environment management, the Manuguru plant is implementing the road map for fly ash management during next five years for complete disposal of dry fly ash. This include supply of fly ash to cement industries, ash bricks making, land filling and other uses. Agreement is being worked out with an industry for setting up a ash brick unit at plant site. Stowing of bottom ash in underground mines to M/s Sigareni Collories at Rudrampur near Kothagudem, is continuing. Against the work order for 6,000 MT of fly ash disposal, entire quantity has been lifted by the party. Tendering action is on hand for further fly ash disposal of 1,15,200 MT. Extension of H_2S Monitoring has been taken up at HWP (M) by installing 45 nos. of sensors along the periphery of the plant. Environment Survey Facility has been set up by commissioning PM2.5 and PM10 monitors for ambient air quality monitoring.

RESEARCH & DEVELOPMENT

NPCIL's Directorate of Technology Development consists of four verticals of R&D Facilities, Remote Tooling, Indigenization and Construction Time Minimization. Corporate R&D Centre, Tarapur carries out execution related to experimental set ups and mock-ups for qualification and validation of design. These activities are aimed at achieving continual enhancement of nuclear & radiation safety, reliable operation and reduction in costs of Nuclear Power Plants (NPPs).

R&D Facilities

Post Fukushima Safety Enhancement measures

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

Hydrogen Recombiner Test Facility (HRTF)

This facility has a 60 m^3 vessel with other equipment and control room provision to inject high

concentration of Hydrogen, steam & air etc. with accurate online measurement and extensive safety measures. Based on extensive performance tests on several different design of Passive catalytic Recombiner Devices (PCRDs) of BARC, optimal design shortlisted and bulk procurement initiated through technology transfer. New Corderite based design is being readied for testing.

Containment Filtered Venting System (CFVS)

Significant post – Fukushima safety enhancement measure for beyond design basis accident scenario. All planned tests (Stage I & II) including characterization on a scaled down test set up were completed and results were reviewed by Regulatory body. Full scale vessel assembled with all internals and erected at TAPS -3. Tendering activities are in process for 220MWe PHWRs.

Iodine Scrubbing thru Containment Spray System

Full scale mock-up tests were conducted to quantify the coverage, mass flux distribution, demonstration/study the mixing phenomena in containment. Review has done by Regulatory body and further experiments are planned.

Integrated Thermal Hydraulic Test Facility (ITFT)

This facility comprising of NPCIL Thermal Hydraulic Test Facility (NTTF), BARC's AHWR Thermal Hydraulic Test Facility (ATTF) and AHWR Fuelling machine Test Facility (AHWR FMTF) has been progressing well on all fronts in spite of several challenges. Copper Bus Duct (60 T Copper) for all Five Full Power Rectifiers has progressed near to completion.

NPCIL Thermal-hydraulic Test Facility (NTTF)

The PDHRS simulation test in NTTF was taken up and attained close to full temperature and pressure conditions on both Primary side and secondary side. This preliminary nature has established that the thermo-siphon or natural circulation takes place in the primary circuit and the heat is transferred to the Passive Decay Heat Removal System through Steam Generators in an effective manner.

AHWR Thermal hydraulic Test Facility (ATTF) & AHWR Fueling Machine Test Facility (AFMTF)

Significant progress and readiness for re-commissioning at much higher power level in early 2017 after commissioning of Full Power Rectifiers achieved. Test Channel has been installed in FMTF facility.

Fueling Machine Test Facility (FMTF) for 700 MW PHWR

Milestone of Phase-1 Qualification Testing of two Fuelling Machine (FM) heads of 700 MWe (KAPP-3&4) achieved. Phase-2 qualification testing with hot water with hot interconnect from NTTF is under execution.

Environmental Qualification (EQ) Activities

Severe accident condition profiling was done on standard 100 terminal JB & transmitters at LOCA chamber. LOCA qualification of MAPS scale down 30HP moderator pump motor completed. Main Steam Line Break (MSLB) qualification tests carried out on TAPS 3&4 & KGS 1&2 instruments.

Primary Coolant Pump Test Facility (PCPTF)

For indigenous development and manufacturing of PCPs, pump Characteristics and Endurance Testing under full temperature and pressure conditions are required. In this regard, design note and Detailed Project Report (DPR) are issued and design finalization of equipment/Technical Specifications and tendering preparations are in process.

Remote Tooling

Reactor Fuel Channel inspection Campaigns

These campaigns are related to ensuring integrity of Pressure Tubes and encompass a range of activities related to inspection, repair and removal of PTs or surrounding components. These are carried out by utilization of expertise of BARC, RRCAT and NPCIL. Following activities have taken place:

Pressure Tube (PT) In-Service Inspection (ISI) campaigns using BARCIS for 220/540 MW PHWRs (RAPS-3, KGS-1, NAPS-1&2 & MAPS-1, TAPS-3) was successfully carried out. Out of the above units TAPS-3, NAPS-2, MAPS-1, RAPS-2&3, KGS-1has also underwent nodular corrosion assessment of PTs by using BARCIS. End Fitting & Pressure Tube Laser cutting of one channel was done successfully along with RRCAT, in KAPS-1. Refurbishment of 220MWe BARCIS control system for several units has been completed. BARCIS Inspection Heads upgraded by DRHR, BARC were delivered and utilized. MoU finalized for signing with BARC for 700MWe BARCIS system development, manufacturing & supply. New concept Tool for sag measurement of Coolant Channel (CC) jointly developed with BARC and successfully deployed at RAPS-3. Further modified sag tool is planned to be deployed during BSD at other units. Coolant Channel shock absorber nut/ triangular block cutting by Laser cutting carried out during RAPS-3 BSD.

Carrier Tube Assembly (CTA) Removal

Full scale mock-up and cutting trials of CTA removal tool was demonstrated at R&D-Center Tarapur. Shielding flask manufacturing is under progress.

Development of automatic Inspection system for D_2O Heat Exchangers

Order has been placed for modified pusher puller development for HX tube inspection. Specification and drawings have been completed for various types of manipulators. In-house Software programming of SCARA based inspection arm has been taken up.

Indigenization initiatives

Indigenous development of hitherto imported items of critical nature has been further advanced for various components and equipment. Salient progress are as follows:

Steam Generator tube sheet forging for 700MWe PHWRs

Alloy Steel 20 MnMoNi55 of size 2.3 m dia &700mm thickness has been successfully developed and delivered for the first time in the country. Qualification have included extensive set of tests for Chemical composition, micrographic examination, mechanical yield, strength tests plus hardness & impact testing plus full volumetric and surface non-destructive examinations by LP & UT tests. This development called for extensive trials and utilization of feedback of earlier developed ingot casting, forging and heat treatment experiences.

Indigenous 700 MWe SG Tube Sheet Under Machining

Pre-formed Large Dia. Pipe Bends

Indigenous development of full scale hot induction bent preformed spools for large diameter & high thickness (600mmNB & 50mm Thick) Primary system piping of impact tested Carbon Steel (ASME SA333 Gr 6) has been successfully completed meeting detailed qualification requirements including mechanical & metallurgical evaluation.

Pre-formed bend manufacturing

Stainless Steel End Shield Tube Sheet Plates

Indigenous vendor development has been initiated and is under retendering.

Shutdown Cooling Pump (SDCP)

To ensure availability of indigenous supply chain, this alternate vendor development order placed earlier has progressed significantly. Pump manufacture test facility erected. Helium leak tests for pump assembly is over. Full performance testing is expected to be completed by early 2017.

Indigenous 700MWe S/D Cooling Pump in Test Rig

Primary Coolant Pump motor of 6.0 MW capacity

Based on completion of Mechanical design, Seismic analysis, certain radiation & thermal aging of components sub orders are under follow up.

High Pressure, High Temperature Compression fittings

Development, Qualification and supply indigenous vendor has been completed successfully. Qualification of other indigenous vendors in the advanced stage.

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

Indigenous development of PCPs & BFPs is in process.

Ball-way bearing for Z-Motion of Fuelling Machine

Re-circulating Ball Type Ball-way Bearing Assembly is a heavy duty anti-friction bearing for which Development Order is under execution. Test Set-up details finalized and material qualification is under progress.

Cobalt Adjustor Rods (CoARs) & Tools

Based on full scale trials with tools and coolant

CAROT Control Panel

CAROT Tool under Performance Testing

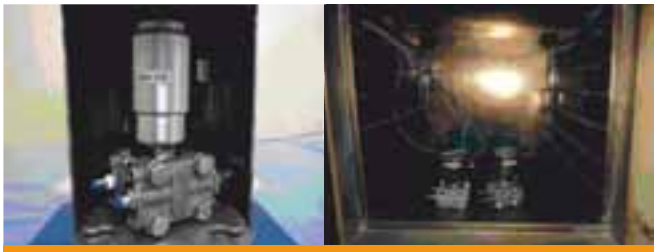
flow studies, modifications incorporated in 700MWe Cobalt Adjuster Rod design and full scale assemblies received from NFC. Dummy Shielding Flask with integrated tool for handling of CoARs received at R&D Centre and full scale operation trials carried out. Design and development of Cobalt AR Remote Operating Tool (CAROT) for SFSB under water operation completed.

Self Powered Neutron Detectors in-Core Qualification

Platinum clad SPNDs are developed and in-core evaluation has shown them to be 45-50% more sensitive in comparison to Inconel SPNDs in line with expectation. Development of Vanadium SPND is in process by two vendors and mainly for its first time use to measure Bulk N Power using 18 Pitch long step less 2mm OD SPNDs.

Electronics based Radiation Resistant PT/DPTs

Electronic Pressure/Differential Pressure Transmitter (PT/DPT) as developed and earlier qualified for DBA (Design Basis Accident) - LOCA was further upgraded for qualification against requirement of severe accident Beyond Design Basis Accident (BDBA), which has been completed and further improvement is identified.

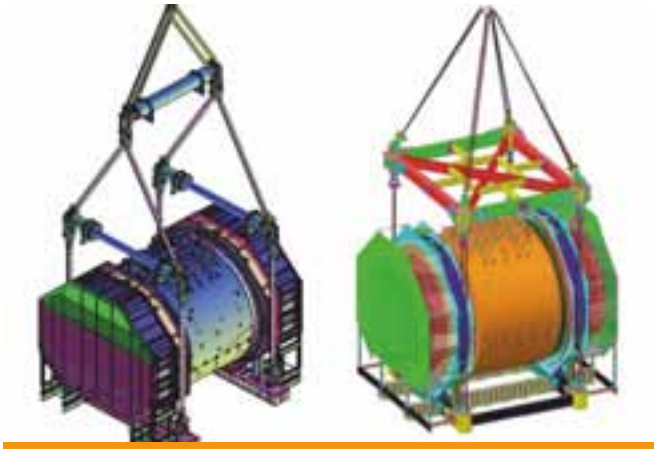


Radiation Test on Transmitter and Accelerated Thermal Ageing on Transmitter in progress

Construction Time Minimization

End Shield Calandria Integral Assembly (ESCIA)

As part of Technology Development evolution for 700 MWe PHWRs Modular Construction this concept is being developed/ detailed to establish feasibility, for reduction in overall construction time.



End Shield Calandria Integral Assembly

Bellow lip welding tool

The development of an Automated Welding Tool (AWT) for remote seal welding of AGMS bellow ring with CS end ring was successfully developed by R&D center. This is an improvement on to existing mechanical welding jig with respect to speed of deployment & positional accuracy.

AGMS bellow lip welding in progress and optimizing the AWT parameters at RAPP-7&8

Engineering and R&D in Electronics

Ongoing 700 MWe Projects

All the engineering drawings for KAPP-3&4 and RAPP-7&8 were completed and frozen. Stress analysis including seismic qualification of all safety related

equipment pertaining to mechanical, electrical, Instrumentation and piping systems was completed. Regulatory review of design of 700 MWe PHWRs at KAPP 3&4 and RAPP 7&8 was completed. Regulatory review of next stage of consenting, i.e. commissioning stage for KAPP 3&4 commenced.

Algorithm for Pre-boiling primary thermal power estimation for 700 MWe PHWR finalized. The capability of accurate power estimation was demonstrated by comprehensive analysis considering random distribution of measurement errors, different combinations of allowed unavailable instrumented channels and different possible reactivity device configurations. Simulation of dynamic experiments to be carried out during Phase B commissioning of 700 MWe PHWR was performed. Transient power and dynamic in-core detector responses (Shut down Systems, Regulating System and Flux Mapping System) were simulated using 3D Kinetics Physics computer code, developed and validated in-house. Developed software for Flux Mapping System (FMS) for 700 MWe PHWR. Reactor Setback logics and their set points have been finalized. Performed validation of Flux Mapping Algorithm (FMA) for 700 MWe.

As a part of the implementation of post-Fukushima safety up-gradation measures, a methodology was developed and a detailed roadmap was prepared for completing the assessment of all operating as well as NPPs under construction for beyond design basis extreme natural events (other than earthquake). Application of this methodology has been demonstrated for safety evaluation of Nuclear Power Plant SSCs against such beyond design basis events through typical studies.

Conceived and completed engineering for water conservation scheme for KAPP-1 to 4, which will result in substantial reduction in operation costs. Completed engineering and analysis of First of a Kind (FOAK) Containment Spray System (CSS) header and access platform assembly for 700 MWe projects. Completed engineering of 5 m diameter Concrete Mortar Lined and Coated (CMLC) piping (FOAK) for Condenser Cooling Water (CCW) system of KAPP-3&4 & RAPP-7&8. Engineering and analysis of Containment Filtered Venting System (CFVS) was completed. Implemented Aerosol based fire protection system for Diesel generator (DG) rooms in place for conventional CO_2 flooding system for fire protection.

Present Reinforced Cement Concrete (RCC) trenches for active waste disposal modules are codal design. New Safe Shutdown Earthquake (SSE) qualified RCC trench with improved features was developed in-house to minimize water ingress, de-watering provision, more disposal volume, improved lifting arrangement etc. Similarly, an improved design of tile hole was developed in-house, with tile hole in vault design, incorporating multi-barrier concept. This design minimizes land usage.

First-of-its-Kind 8 m high, 46 m diameter and 355 MTon Inner Containment dome liner assembly consisting of 53 panels was installed successfully at KAPP-3 on 9th June, 2016.The conceptualization and the entire engineering of the IC dome liner system including installation aspects have been carried out in-

Installation of dome liner assembly

house. Successful installation of this IC dome liner assembly at KAPP-3 marks a major step towards implementation of state-of-the-art modularization technique in Nuclear Power Plant construction.

Experimental studies were carried out on full scale shutdown system sub-assembly of 700 MWe to evaluate the responses under multi support seismic excitation, simulating rock site and alluvium soil condition. Critical parameters viz., added mass coefficient and damping factor of the tube under submerged conditions were evaluated. Further, in order to study the interaction of these tubes with the nearby structure/assemblies under beyond design basis seismic excitation, experimental studies were also carried out to quantify the variation of impact forces with gap sizes, and their influence on the dynamic behaviour of these tubes. Non-linear analytical calculations were carried out simulating the above test conditions.

Functional qualification of Main Steam Isolation valve (MSIVs), viz. flow interruption, end loading & seismic equivalent tests was carried out successfully for KAPP-3&4 and RAPP-7&8. Flow interruption requirement for MSIVs in case of Main Steam Line Break (MSLB) has been envisaged in design for the first time to limit the pressure rise inside containment. Also, functional testing of Pilot Operated Main Steam Safety Valve was successfully completed.

Manufacturing of components, inspection, assembly, shop testing of all 6 (six) Fueling Machine (FM) Heads for KAPP-3&4 project were completed and delivered to Site. Calibration, functional testing & qualification of various sub-assemblies of two FM heads and 10-cycle testing of operation of various actuators, plugs and receiving / loading of four dummy fuel bundles from/to Test Channel were successfully completed at Fueling Machine Test Facility (FMTF) at R&D center, Tarapur. The refueling operation was performed on fully auto mode from Control room.

Qualification of prototype modules and assemblies for Computer Based Systems (CBS) manufactured by the package contractor were completed and bulk production has commenced. Internal validation of software for different types of modules for Computer Based Systems (CBS) is in progress. Verification and Validation of software for cluster IV CBS system is being completed and released for loading at site to facilitate site activities.

Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) 1&2

Layout of safety related main plant buildings viz. Reactor Building, Reactor Auxiliary Building, Control Building, Station Auxiliary Building, Waste Management Building, Pump Houses, Safety Related Electric House for GHAVP 1&2 finalized and drawings issued. Changes on account of increased gap between buildings, increase in the diameter of Inner Containment Wall (ICW) & Outer Containment Wall (OCW), structural changes in various buildings, improvements and construction feedbacks were incorporated while finalizing the building layout drawings.

Pile-raft foundation system is envisaged for safety-related structures founded on alluvial soil deposit at GHAVP site. The development of analysis/design methodology for Pile-raft foundation system simulating structure-soil-pile-raft interaction and its review by external experts were completed. Geo-technical investigations completed and Design Basis Report issued.

Carried out detailed liquefaction analysis of founding medium of various plant structures and finalized the depth up to which the ground is to be improved to prevent liquefaction of soil. Technical specifications were issued and trial mock ups conducted for improvement of founding medium of various plant structures of GHAVP 1&2 site. Based on this, the ground improvement techniques to be adopted for treating the ground in different areas of plant was finalized.

Operating Stations

Developed a computer code to generate input matrix used for flux mapping system for 540 MWe PHWR and implemented at TAPS 3&4. The new tool takes care of change in inserted locations and loss of sensitivity of vanadium Self powered Neutron detector (SPNDs) due to irradiation during reactor operation.

Cobalt absorbers from RAPS-3 and RAPS-5 were replaced and Cobalt-60 isotopes were supplied to BRIT.

Analysis methodology for Seismic Margin Assessment (SMA) of safety related civil structures of NAPS 1&2 was finalized, as a part of post Fukushima activities. The approach is to find out the maximum earthquake resistance capacity of all elements of the structures in terms of Peak Ground Acceleration (PGA).

Root cause analysis, inspection, examination and testing activities are in progress in the context of KAPS-1 Pressure Tube incident.

Upcoming Projects

Application has been submitted to AERB for regulatory consent for siting of NPP at Chutka.

R&D relating to PHWR

An In-Service Inspection (ISI) system 'PRESAM 220' has been developed by BARC for measurement of sag of pressure tube in 220 MWe PHWRs. The system measures local curvatures using radiation-resistant, under-water serviceable Linear Variable Differential Transformer (LVDT) mounted tool head. Tool head is operated remotely and data is acquired to generate the sag profile. 'PRESAM 220' has been successfully deployed in RAPS Unit 3 after 12.9 Full Power Years of

PRESAM 220' tool-head

Split Plug Assembly

Control System for ADM

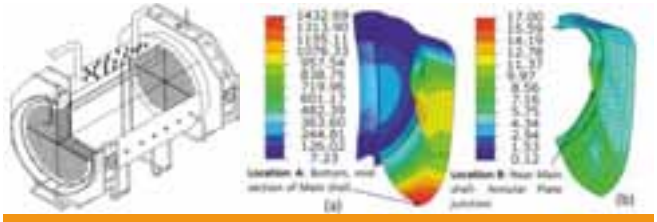
Advanced Drive Machine

plant operation. A Graphical User Interface (GUI) based software was developed to integrate the sag estimated from measured curvatures at different locations.

Remotely operated Advanced Drive Machine is designed, commissioned and demonstrated in simulated reactor conditions for regular inspection of coolant channels of 540 MWe reactor

The code ASTEC (Accident Source Term Evaluation Code) developed jointly by France-Germany for estimating "Source Term" was modified for PHWR specific horizontal reactor core to assess severe accident progression, Source Term estimation and Verification of Severe Accident Management Guidelines (SAMGs) under CESAM (Code for European Severe Accident Management) project and Indo-French bilateral cooperation in Nuclear Safety.

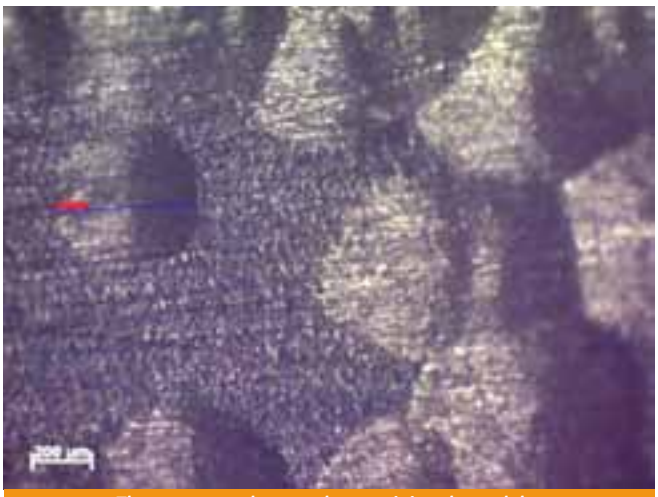
The following figures illustrate Calandria temperature transient with and without Fire Fighting Water (FFW) addition in the reactor vault. Modified ASTEC is also used for determining hydrogen generation for 220 MWe PHWR under severe accident conditions for assessment of Passive Catalytic Recombiner Devices design basis.



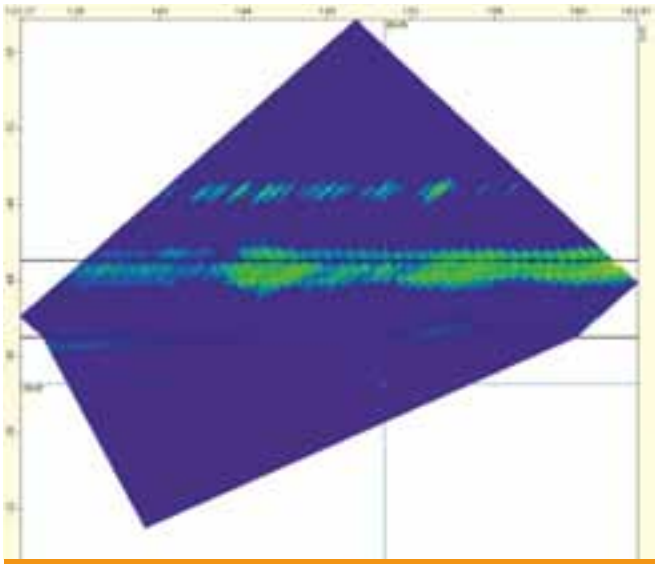
Schematic of calandria & end shield support assembly & structural response of assembly at 90 hrs after core collapse (a) Deformation (mm) (b)Von-Mises stresses(MPa)

Detailed finite element analysis was carried out for accounting realistic elastic-plastic and creep deformation for postulated severe accident scenario of a large loss of coolant accident + loss of emergency core cooling system+ moderator heat sink to ensure in vessel corium retention. The deformation and von-Mises stresses in the assembly at around 90 hrs after core collapse and progression of deformation and creep life fraction of calandria was shown. The studies showed that the calandria vessel is able to withstand against both creep rupture and excessive inelastic deformation failures under the severe accident thermal/structural load for more than 3-days time after the core-collapse.

An ultrasonic technique using an angle beam was developed to detect the presence of zirconium oxide nodules in pressure tubes of PHWR during in-service inspection. Studies were carried out on a pressure tube coupon containing nodules generated in the laboratory by autoclave. Ultrasonic technique is based on the use of a linear array transducer. By using the focal laws, the sound beam emanating from an active aperture is steered to achieve the required angle of refraction in the pressure tube material.



The pressure tube sample containing the nodules generated in the laboratory by autoclave

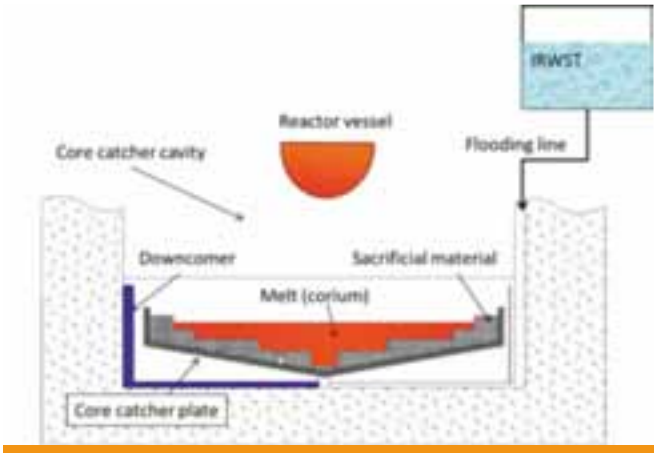


The B-scan image generated by the phased array examination

The sound beam is also focused on the outside surface to ensure a good signal to noise ratio so that nodules of sub-millimetre dimensions could be detected reliably. Since the data is acquired by a linear array, a B-scan image showing the cross-sectional view of the pressure tube is generated. Pressure tube sample containing nodules and the B-scan image generated clearly showed the presence of nodules on the outside surface. This technique was subsequently used in the field using a single crystal conventional ultrasonic transducer for detection of nodules during in-service inspection of PHWR pressure tubes.

R&D relating to LWR

Severe accident management has become an integral part for advanced nuclear reactor designs. To arrest the progression of core melt accident in IPWR (Indian Pressurised Water Reactor), an ex-vessel core catcher has been has been designed to manage 100% core melt.



Scaled core catcher

Cooling history of melt temperatures

A 1:450 volume scaled core catcher facility was setup and experiments were carried out using simulating material at 1200 °C poured inside the vessel under decay heat conditions and the melt was flooded with water in same manner as in actual core catcher. It was observed that within one hour, the entire melt is quenched and the temperatures were reduced to near water saturation temperature, demonstrating the efficacy of the SAMS strategy of IPWR.

The structural integrity assessment of Reactor Pressure Vessel (RPV) in presence of flaws discovered during in-service inspection of welds during the 24th Re-Fuelling Outage was performed. The stress analysis of the RPV under design basis thermal transients was performed using finite element analysis. This work was helpful in granting license to TAPS-2 power plant for further operation.

Direct Contact Condensation (DCC) is almost an inevitable phenomenon during accidental condition for all LWRs. Rapid condensation caused by the direct contact of steam and sub cooled water leads to Condensation Induced Water Hammer (CIWH). The study of the underlying physics of CIWH phenomenon in a horizontal pipe under different inlet conditions such as inlet water temperature, pressure difference between steam and water section, steam superheating, steam quality and duration of valve opening using RELAP5/Mod 3.4 reveals that the presence of superheated or wet steam could possibly avoid the occurrence of CIWH.

SA302B (nickel modified) steel, cladded with stainless steel is used as the Reactor Pressure Vessel (RPV) material for the Tarapur Atomic Power Station (TAPS) boiling water reactors (BWR). RPV surveillance specimens of the pressure vessel base, weld and heat affected zones irradiated at the wall locations for 25.5 Effective Full Power Years (EFPY) were removed and

Surveillance basket received for testing from wall location of TAPS BWR (Unit 1) after 25.5 EFPY

characterized. Picture of specimen basket and impact test results for base metal for different EFPY irradiation levels are shown in figure.

Calculated RPV embrittlement parameters w found to be well within the specified screening criteria and in agreement with earlier surveillance test results. RPV material was found to be fit for further operation with adequate safety margin.

In-service inspection of the weld joints in the upper shell and the core belt region of Reactor Pressure Vessel (RPV) of boiling water reactor at TAPS-2 was carried out. The examination involved ultrasonic testing using multiple transducers and eddy current testing using a surface probe coil. Field data was recorded and analysed to detect flaws in the weld joints, heat affected zones and the parent metal and their characterization in terms of location, size and nature.

A methodology was evolved for assessment of uncertainty in the sizing of flaws and their location with respect to the weld-centre line and the scanning surface. This assessment was useful for the proximity analysis of two nearby flaw indications.

A series of experiments were carried out to assess core cool ability as part of Severe Accident Management Guidelines (SAMG) validation program under Indo-French collaboration on Nuclear Safety. A scaled down 1.5 m long indirectly heated fuel assembly simulator was fabricated. The simulator is consisting of 59 pins with a 45% of flow area blockage by ballooned pins.

Bundle simulator & Test Section

Experiments were conducted at 0.5% and 1% decay power levels with different initial peak clad temperatures ranging from 350-650°C with variation of flow rates from 10-40 gm/s. It is observed that below 25 gm/s coolant injection, rewetting of highly ballooned region is not successful. The flow rate is equivalent to 1 gm/s per degraded (ballooned) pin. This flow rate is lower than the SAMG designed flow rate of 1.6 gm/s per pin of PWRs.

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

A high temperature Pyrohydrolysis (PH) system (operating temperature up to 1500°C) for extracting halides and boron from several refractive and other materials, which cannot be Pyrohydrolysed with the normal PH apparatus operating at about 1000°C, has been indigenously designed and developed. It is for the first time a high temperature system was developed with alumina reaction tube instead of high cost Pt or Ni tubes. Developed apparatus is being used for analysis of halides in matrices, such as, SiC, TRISO fuel and Zr-Nb alloy.

The design, development, production, qualification and delivery of a plant wide networked Radiation and Gas Monitoring System (RGMS) for Compact Light Water Reactor Project has been completed. The system consists of total 293 nos. of various units comprising 35 types of deliverable sensors for providing plant and personnel radiation safety by automatic and remote online monitoring of processes and environment. The radiation and gas monitors are networked to a centralized operator console for reliable and real time data and alarm display.

High Temperature Pyrohydrolysis System

RGMS Units connected at Integrated Test Facility

CHAPTER 2

View of Nuclear Island

NUCLEAR POWER PROGRAMME STAGE-II

1.5 m3/h Annular Linear Induction Pump during testing

CHAPTER 2

FAST REACTORS

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

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

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

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

Prototype Fast Breeder Reactor

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

The major jobs that have been completed during the period are as follows:

A committee consisting of experts from IGCAR & NPCIL reviewed the actions taken for Integral Leak Rate Test of Reactor Containment Building and the feasibility to adopt suitable measures for further improvement of leak-tightness. After completion of micro-pressure grouting at observed leak paths, the ILRT of RCB was repeated and reduction in leak rate was achieved.

Vacuum cleaning of Main Vessel Cold Pool Zone

The cold pool area of the reactor assembly was inspected and the sufaces were cleaned. Visual examination was carried out remotely in the annular interspace between main vessel & safety vessel and the space was cleaned using a specially devised vacuum method.

Pressure hold test for reactor asembly was carried out, leak paths were identified, and corrective actions were taken. Pressure run down test for inflatable seals in Large and Small rotatable plugs was completed to check their leak-tightness. Two numbers of Extended Electrode Leak Detector (EELD) in Safety Vessel- Main Vessel interspace were mounted in position. Insertability of Startup Neutron Detector Handling Mechanism (SNDHM) in Central canal plug was ensured by physical insertion of SNDHM.

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

- About 5820 nos. of Fuel clad tubes (crimped with middle plug) were dispatched to AFFF, BARC, Tarapur for MOX fuel pins fabrication.
- 29 nos. of Fuel Sub-Assemblies (SA)

(Cumulative-184 nos.).

- 8 nos. Diluent SAs have been manufactured for the first time
- 800 nos. of Antimony oxide (Sb_2O_3) capsules and 183 nos. of Source pins required for Source SA fabrication were manufactured.

In fuel handling system, three uninterrupted cycles of operations of handling the sub-assemblies from In-vessel Transfer Port (IVTP) to Ex-vessel Transfer Port (EVTP) and vice versa were done from Handling Control Room (HCR). Two cycles of bowed sub-assembly handling movement, viz. one from IVTP to an empty position in inner core and another from IVTP to an empty position in outer core and vice versa were completed. Subsequently, two cycles of normal sub-assembly handling from IVTP to EVTP and vice versa using Inclined Fuel Transfer Machine was completed.

Towards commissioning the shutdown system, all three Diverse Safety Rod Drive Mechanisms (DSRDM) were operated and frictional force was measured. DSRDM commissioning in air at room temperature was completed. Response time of electromagnet and drop time for all nine Control Safety Rod Drive Mechanisms (CSRDM) along with control rods were measured. Further, frictional force and motor characteristics data were generated for all nine CSRDMs.

Performance and pressure hold tests of Primary Sodium Pump – Intermediate heat exchanger (PI) flask (35 m tall & 140 t weight) was completed. Handling of PI flask using RCB crane from storage location to pump location and lifting of one Primary Sodium Pump (PSP) from its position with the PI flask were demonstrated.

Manufacturing and inspection of multipurpose flask for handling In-Vessel Transfer Port plug, Observation port plug and Under Sodium Ultra Sonic Scanner was completed. As part of Multi-purpose flask commissioning, load testing of connecting pieces of

Pump inside flask

PI flask over Reactor top

Under Sodium Ultra Sonic Scanner, In-Vessel Transfer Port shield plug and Observation Port plugs were completed.

Towards commencement of integrated pre-heating, segmental trial pre-heating of all secondary system sodium pipes were completed. Further, augmentation of heaters in the secondary pipe-segments for ensuring adequacy of heating based on observations of steady state temperatures attained in different pipe segments are in progress.

With respect to steam water system, pressure hold test (tube side) of all the 4 Steam generators in SGB–2 was completed. In-Service Inspection vehicle of Steam Generators was qualified in the full scale mock-up facility and the vehicle was deployed in the Steam Generators. Pre-service Inspection (PSI) data of 10 % of tubes in seven steam generators and 100 % of 547 tubes in eighth steam generator were collected.

CHAPTER 2

PFBR SG Inspection System

In-service inspection vehicle (DISHA) for inspection of dissimilar weld of roof slab was developed for visual & ultrasonic examinations. The mock up facility for qualification of DISHA vehicle at room temperature and operating temperature is being established.

Emergency Mode Transfer (EMTR-1 and EMTR-2) panel was connected with various field equipments like 6.6 kV, Motor Control Centre, Power Control Centre, Heater Control Centre, Diesel Generator, Main Control Room panels and is ready for commissioning. Digital Distributed Control System (DDCS) network-2 commissioning was completed in Control Building, Steam Generator Building-2, Rad Waste Building, Reactor Containment Building and Fuel Building.

The pre commissioning works of sea water system have been completed. Condensate cooling water pump-1 of 49,000 cubic metre / hour capacity was operated through condenser by charging the tunnel and fore-bay.

All the commissioning activities are in progress and commissioning of all primary and secondary systems for integrated preheating are in advanced stage. Primary and secondary heat transport systems will be preheated after ensuring inertness of the systems with nitrogen. After filling sodium and completing the Initial Test Programme, fuel loading will commence towards approaching first criticality.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

Fast Breeder Test Reactor (FBTR)

During 2016-17, Fast Breeder Test Reactor (FBTR) continued to play an important role in testing the fuel, structural materials and special neutron detectors for FBR programmes.

Twenty fourth Irradiation campaign was completed with one Mark-I fuel subassembly and two Mark-II fuel subassemblies reaching their burn up limits. The reactor core was configured to twenty fifth irradiation campaign. One Mark-I and two Mark-II fuel subassemblies, which have attained their peak burn up limit of 155GWd/t and 100GWd/t respectively, were replaced with fresh Mark-I fuel subassemblies. One more Mark-I fuel subassembly was added to take care of the reactivity loss due to burnt subassemblies. The present core consists of 52 fuel subassemblies (39 MK I,5 MKII,8 MOX) and one special subassembly at centre for irradiating Yttria.72 thoria subassemblies were loaded in twelfth ring of the reactor core towards production of Uranium-233 after discharging steel subassemblies. In this campaign, irradiation of Yttria, natural U-Zr sodium bonded metal fuel pins, Uranium (14.3% enriched) metal pins, ternary fuel pin U-Pu-Zr and impact specimens of 304LN & 316LN for low dose irradiation is being carried out.

Fast Breeder Test Reactor (FBTR) sub-assemblies related activities undertaken at NFC included fabrication of 6 nos. of MK-I Fuel subassembly and fabrication of 4 nos. of carrier subassemblies required for irradiation experiments.

An experiment for measuring the replacement reactivity worth of fresh Mark-I fuel subassembly, replacing a burnt Mark-II fuel subassembly with a burn up of 100GWd/t in the fourth ring was carried out at IGCAR. The change in reactivity worth was found to be +269 pcm. Two more experiments to measure change in

worth with fresh Mark-I subassembly replacing nickel subassembly and MOX subassembly replacing nickel subassembly in the fifth ring were also carried out. After measurements, Mark-I subassembly was discharged and MOX fuel subassembly was loaded in its place. The change in worth was found to be + 393 and +348pcm respectively. These experiments will help in predicting the critical height after core configuration changes more accurately in future. To carry out these experiments, the reactor was made critical three times.

Twenty-fifth irradiation campaign was started on 30thJune and the reactor power was raised to 27.3MWt on 18th July for the first time and turbo generator was synchronized to grid generating a power of 5.8 MWe.

During the period, major surveillance tests such as calibration of the high range gamma monitor, measurement of sodium flow through the sub-assemblies, grid plate level measurement, containment integrity test, inspection of reactor vessel internals and viewing of sodium flow through siphon break pipe & emergency injection pipe and ultrasonic examination of severely stressed joints in one of the secondary sodium loops were carried out. Replacement of exhaust filters of reactor containment building and checking of the efficiency of iodine and particulate filters were also carried out.

As a part of post Fukushima retrofits, life extension and ageing management, construction of new flood safe building for emergency diesels, and installation and commissioning of two mobile diesel generator sets were completed. As a part of life extension of FBTR, commissioning of a new 1 MVA transformer along with associated switch gear for augmenting existing power supply was completed. As a part of ageing management, a new demineralized water plant was installed.

During the period, the total operating time of reactor and the turbo generator was each 1531hours. The total thermal and electrical energy generated was 117816MWh and 6.5 million units respectively.

R&D relating to PFBR

Necessary design expertise and technical support towards commissioning and obtaining regulatory clearance was continued for the PFBR systems. BHAVINI-IGCAR Task forces were constituted for various reactor systems. Measures are being taken to resolve the technical issues towards smooth deployment and functioning.

Estimation of neutron source strength of the external neutron source subassembly and validation

Antimony-beryllium is being used as an external neutron source in PFBR. Source subassembly is located in the core-blanket interface. Sufficient neutron source strength ensures a reliable indication of neutron level on the most sensitive monitoring instruments (detectors). The estimation of detector count rate was updated with new cross section libraries. The requirement of source subassemblies could be reduced to one from three in normal operating conditions with the estimated counts.

Estimation of site boundary dose for various reactor containment building leak rates

Reactor containment building contains the possible radioactivity release during a core disruptive accident. Release of the radiologically important isotopes was re-estimated. The source term in reactor containment building was estimated based on published experimental information. The source term in the environment was estimated. It is observed that the maximum contribution to source term comes from the fission gases followed by Iodine and other radionuclides.

External flood preliminary safety analysis

The Fukushima accident highlighted the significance of external events like seismic, flood events etc. in the safety of nuclear power plants. Redundancy of safety systems is one of the various principles adopted to achieve high level of functional reliability. External events pose a definitive challenge to redundancy, due to its ability to induce common cause failures. The external flood preliminary safety analysis was carried out with reactor core as the source of radioactivity. Three phenomena namely, i) Tsunami ii) storm surge and iii) rainfall are considered in this analysis. Detailed hazard analysis was carried out for these three phenomena. The step fragility function is used to model fragility.

Shield estimations for PFBR components and other radioactive facilities

A combination of carbon steel plates and heavy density concrete in the roof slab is a shield for neutron as well gamma radiations in PFBR. Many air ducts are provided for cooling the concrete in the roof slab. These air ducts allow streaming of radiations from the sodium pool gammas. Based on the regulatory observation, more detailed calculations were done for arriving at the complementary shields. Shield calculations were also done for the intermediate heat exchanger complementary shields with the actual site conditions by taking care of the gaps between intermediate heat exchanger and the shields.

Further, shield design calculations for hot cells in the post irradiation examination facility for spent fuel of FBTR were carried out. FBTR Mark-I fuel with burn-up 165GWD/t after one year cooling has an activity of approximately 1 Ci/cc is the source. Also shield design calculations were carried out for special nuclear material storage room of demonstration facility for metal fuel fabrication plant.

Seismic qualification of important reactor components

Shake table experiments on air heat exchanger tubes

Seismic qualification experiments for long extended stem valves

Seismic qualification of sodium to air heat exchangers of decay heat removal system and long extended stem valves used in primary sodium purification piping system was carried out in the 100 ton multi axial shake table. Studies on air heat exchangers were carried out for operating base earthquake, safe shutdown earthquake and beyond design basis earthquake conditions. Structural integrity of tube the bundle was demonstrated by repeating the experiments for safe shutdown earthquake and beyond conditions. Tests were performed on the valves along with the long stem of around 12 metre length and

manual/electric actuator and the performance was ensured

Design of tool for in-situ calibration of diverse safety rod drive mechanism load measurement system

Diverse Safety Rod Drive Mechanism (DSRDM) is one of the two independent, fast acting and diverse shutdown systems in PFBR. The load measurement system of DSRDM requires calibration in periodic intervals, mainly to monitor the frictional force. Time for carrying out these operations will affect the availability of the plant. In view of this, a method and tool is developed for the in-situ calibration of DSRDM load measurement system without dismantling of the DSRDM from pile, which is partially wetted by sodium.

Determination of acceptable crack size in core support structure support shell

The growth behaviour of a 6 mm deep postulated crack incore support structure and its support shell weld, under seismic events and thermal transient was studied. It is observed that there is insignificant increase in the depth of the crack and the final crack length is within the critical crack length. The study will also aid in determining the time and required frequency of inspection.

Qualification of trailing cable system

Profile for trailing cables under different plug

As part of qualification of trailing cable system of PFBR, which is designed to carry cables to rotatable plugs during their rotation, testing of the system for 2,000 cycles was completed. Neither any physical damage to mechanical system nor any deterioration in the cables performance was noticed.

Sodium piping as-built analysis

As-built analysis was carried out for the sodium piping in steam generator buildings. The changes required in the piping to meet the design criteria were communicated to BHAVINI and the same were implemented at site. The list of pipe supports required to be changed to suit the as-built piping analysis is also furnished to site for installation.

Heaters on sodium piping/components

In light of the as-built heater layouts, review of sodium piping heaters was carried out. Modifications to heaters of various piping systems were reviewed and consolidated changes are being carried out at site to meet the design intent. The heater capacity of the pre heating system of the air heat exchanger was reviewed for natural circulation and revised to meet the design conditions.

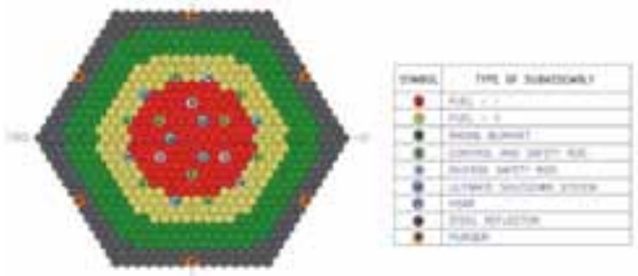
FBR-1&2: Conceptual Design Features of 600 MWe FBR

IGCAR is designing the advanced MOX fuelled FBR, incorporating many safety features, in line with the international approach. Towards this, an improved and state-of- art design safety criteria for MOX fuelled future FBRs is being finalized in collaboration with AERB, by incorporating the experience learnt from Fukushima incidence and the evolving Gen-IV safety standards. Conceptual design of the major systems for the twin unit FBR 1&2 was worked out, incorporating the latest standards and design approaches. The conceptual design was reviewed in detail and design report was finalized. A BHAVINI-IGCAR joint task force was

constituted for arriving at the plant layout.

Conceptual design of 600 MWe oxide fuelled core

Towards practically eliminating severe accident scenarios, the design of oxide SFR core (FBR-600) is carried out with the main objectives of sodium void



Core layout of CBR-600 MWe

coefficient less than 1 $ and breeding ratio higher or equal to that of PFBR. Homogeneous, axial & radial heterogeneous core configurations were evolved to meet the primary design targets. Based on the assessment of their merits and demerits, a homogenous core design using 6.6 mm diameter fuel pins, having 1000 mm active length, is chosen as the reference core. The core has two enrichment zones of mixed oxide (PuO_2-UO_2) fuel. The sodium void coefficient achieved for this core is 0.9 $. It has a breeding ratio of 1.1 with reactor doubling time of 24 years. Detailed core design is being carried out.

Coupled thermal hydraulics analysis of Intermediate Heat Exchanger

Intermediate heat exchanger of Fast Breeder Reactor forms an intermediate boundary between the radioactive primary sodium and the non-radioactive secondary sodium. During cross flow of primary sodium in the shell side over tube bundle from the periphery towards the inner regions, sodium loses significant amount of heat. As a result, the inner rows of the tubes experience relatively cold primary sodium compared to the outer rows leading to large scale temperature non-uniformity at the secondary sodium outlet. In order to establish the temperature non-uniformity in large diameter and short height sodium to sodium heat exchanger, a network based 1D model was developed and validated against 2D porous body based CFD model. Using the model, temperature field in the intermediate heat exchanger was predicted. Through a detailed parametric study, the secondary side flow zoning option that gives minimum temperature difference among the tubes, which is an important parameter leading to thermal load in intermediate heat exchanger was identified.

Thermo-mechanical analysis of thick plate rotatable plugs

Coupled thermo-mechanical analysis of thick plate concept for rotatable plugs was carried out towards finalising the thicknesses required. The allowable slopes at the support locations of control plug and fuel handling machine are taken as design criteria during the analysis.

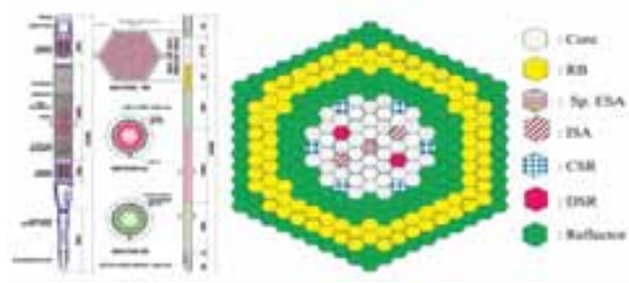
Process design of steam generator

Process design calculations were carried out for the steam generator of 600 MWe FBR for enhanced life of 60 years.

Metal Fuelled Test Reactor

A new test reactor facility using metal fuel is planned for continuing the irradiation program towards FBR technology development. It has the design objective of full-scale testing of fuel pin and assembly of metal fuelled commercial FBRs and demonstration of their safe operation with closed fuel cycle mode.

Core Design of 100 MWt test reactor



Core layout of FBTR-2

A conceptual design of a loop type 100 MWt metal core and associated systems was completed. The core is optimised using homogeneous core concept and single enrichment zone. The selection of pin diameter is made after studying the core performance, inventory requirement, dimension close to that of a typical power reactor pin and also by considering the established technology of fuel manufacturing. In-Vessel shield design calculations were worked out based on the dpa limits for the structural materials.

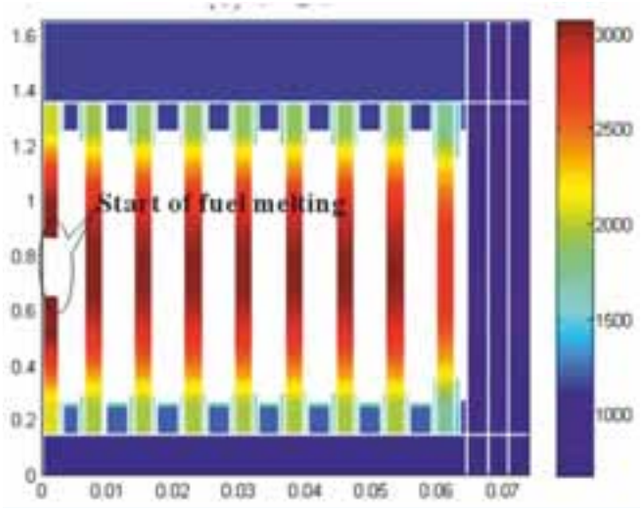
Site Selection

Site selection for the proposed 100 MWt Metal Fuel Test Reactor was carried out and preliminary layout for the plant was prepared. Various sites considered were studied suitable site was proposed and salient features of the selected site for construction were brought out. Feedback from PFBR was extensively used for evolving the preliminary plant layout. Conceptual design for the major systems for the reactor was carried out in line with the latest safety standards and practices.

R&D on FBRs

Numerical analysis of total instantaneous blockage single fuel subassembly

Total instantaneous blockage at the inlet of a fuel subassembly is considered as a beyond design basis event in sodium cooled fast reactors. It is the bounding case of various types of local blockages and to cater for this event, a core catcher is provided at the bottom of the core. The extent of core damage propagation, before reactor trips, forms an important input for thermal design of the core catcher. Reactor trip by core temperature monitoring system of the neighbouring subassembly is affected by heat transfer between the molten fuel pool and the neighbouring subassembly, number of fuel pins in the subassembly, rate of melting of the hexcan and thermocouple time constant. Towards understanding the thermal hydraulics of the damage propagation involving complex phenomena such as sodium boiling and clad/fuel melting, a coupled 2-dimensional transient thermal hydraulic model was developed. By detailed parametric studies, it is established that the damage is restricted to seven subassemblies.



Predicted temperature distribution

Investigation of sodium fire and hydrogen production following a core disruptive accident

During core disruptive accident in pool type sodium cooled fast reactor, primary sodium from hot pool is expelled into the top enclosure, which is vented to reactor containment building. Sodium coming in contact with oxygen and moisture undergoes combustion and forms sodium oxide / sodium peroxide and hydrogen releasing large amount of heat. The phenomenon of sodium combustion in the form of pool fire and reaction of sodium with moisture present in the air producing hydrogen was modelled and various parameters were estimated.

Simulation of rapid voiding scenario under severe accident conditions in FBR

During severe accident conditions, boiling of coolant would happen in the reactor core and associated reactivity transients is a major concern due to the positive void coefficient of reactor core. Boiling also causes changes in the core coolant flow rate due to changes in pressure drop of flow channels resulting in

reduction in flow through the channel and rapid voiding of core. In order to simulate this phenomenon, liquid sodium boiling model was developed based on enthalpy formulation and incorporated into the one dimensional plant dynamics code. The applicability of the code was demonstrated by simulating the event of station black out together with failure of all shut down systems. The core would be developed further by incorporating material dis-integration models.

Design and development of Electromagnetic Pumps

1.5 m^3/h Annular Linear Induction Pump during testing

A rugged and maintenance free annular linear Induction type electromagnetic pump with a flow capacity 1.5 m^3/h was designed, indigenously manufactured and tested in a sodium facility.

In house developed electromagnetic flow meter

Design and Development of Electromagnetic flow meters

Indigenously manufactured permanent magnet flow meter

A compact, in-house manufactured electromagnetic flow meter, used to measure the flow of liquid sodium, which can work up to 550 °C was tested in a sodium facility. Samarium cobalt based permanent magnet flow meter having lower weight and smaller size was also developed for measuring sodium flow in stainless steel pipes above 200 NB.

Performance test of Diffusion Bonded Ultrasonic Transducer in Silicon oil

Liquid Sodium is opaque to light and hence viewing objects immersed in liquid sodium is made possible by means of ultrasound. An Under Sodium

Diaphragm and PZT crystal

Bonded Crystal

Ultrasonic Scanner (USUSS) was developed to detect protrusion, growth and bowing of the fuel-subassemblies before every fuel handling operation. The sodium-compatible ultrasonic transducers can work only up to 1800^{0}C. In order to develop high temperature ultrasonic transducer, a 1MHz PZT crystal bonded with Nickel washer by diffusion bonding technique, was immersed in silicon oil and tested in a stainless steel vessel provided with heater and temperature control. The testing was carried out at 2500^{0}C for more than 100 hours continuously and the performance of the bonded crystal was found to be satisfactory.

Qualification of mutual inductance type level probe using indigenously manufactured mineral insulated cables

Mutual inductance type level probe

Mutual inductance type level probes are used for measuring sodium level in FBRs. 1000hours of endurance testing of a mutual inductance type continuous level probe with indigenously developed mineral insulated cable was successfully completed at sodium temperature of 550°C.

Testing of gate valve shield plug

Gate Valve and Shield plug on transfer vessel

Gate valve and shield plug of Inclined Fuel Transfer Machine (IFTM) will be in sodium aerosol environment during reactor operating condition. The effect of the sodium aerosols on the performance of these components during subsequent fuel handling operation is ascertained by testing under simulated condition. Repeated performance testing of gate valve and shield plug was conducted for more than 100hours in sodium at 500^{0}C. Gate valve seat leak test was carried out after every 50 cycles of gate valve operation and no drop in pressure was noticed. No seat leak is observed even after 600 cycles of operation. The torque values of both gate valve and shield plug were measured and visual examination at the bottom of the shield plug during removal of shield plug from test vessel did not reveal any sodium.

Indigenous development of 450NB sodium frozen seal butterfly valve

Butterfly type sodium service valves with frozen seal and back up gland packing are used in the secondary sodium system of Indian FBRs at the upstream and downstream of steam generators. Based

Three dimensional schematic of valve

on the design basis operating conditions and design requirements, one 450NB sodium frozen seal butterfly valve with SS316L material is being fabricated by industry. Numerical studies were conducted to evaluate the heat transfer under external environmental conditions at the vicinity of the valve and for the design optimization of the fins and the bonnet geometry as part of the development of the valve. The valve bonnet geometry with 17 fins configuration with 25mm fin spacing was finalized for fabrication. Valve is at the final stage of fabrication and after the fabrication of the valve, it will be tested in the sodium facility to confirm the frozen seal at various operating temperatures.

Numerical study on impurity precipitation in cold trap and its validation by experiment using surrogate solution

In sodium cooled fast reactors, cold traps are used for online purification of sodium oxide and sodium hydride impurities present in sodium, which will be precipitated inside the cold trap. A numerical model is developed to study the precipitation phenomena and predict the precipitation pattern over the wire mesh of a cold trap. Experiments were conducted to validate the numerical model for impurity precipitation pattern in wire mesh packed cold trap. The experiments were conducted with surrogate fluid in wire mesh packed unidirectional flow system instead of liquid sodium. The precipitation pattern obtained from experiment was compared with the results obtained from code. The experimental results of precipitation pattern and amount of potassium chlorate deposited over the wire mesh of the cold trap are fairly in good agreement with the numerically predicted results of precipitation pattern over the wire mesh. The design and operating procedures of existing cold trap can be studied by using the developed code to optimize the maximum cold-trap loading.

Sodium cooled pool hydraulic studies using large scale water model

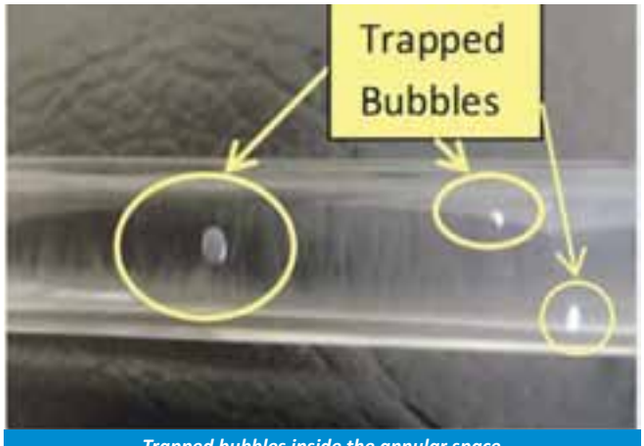
Experimental set up

Sodium cooled fast reactor related pool hydraulic studies were being investigated using a 5/8th scale 90° sector model test facility. The studies carried out to measure velocity distribution around intermediate heat exchanger inlet window revealed that the flow distribution is highly non uniform around the intermediate heat exchanger. The non-uniformity in flow distribution is around 142%. All the experimental data are important input for hydraulic design validation

of future reactor primary pool.

Experimental investigation of PFBR source pin wettability using water as test medium

Source sub assembly, comprising 61 pins of Antimony oxide, acts as neutron source for PFBR. Heat generated inside the source pin is removed by sodium present in the small annular space provided between pellet and the clad. However, entrapped gas bubbles in annular space may reduce the heat transfer. Hence experimental investigation of the flow pattern and wetting behaviour in the annular space was conducted using water as flowing medium. Visual inspection and characterization of locked gas bubbles at different experimental condition were carried out. Further the entrapped bubbles were measured using optical



Trapped bubbles inside the annular space

instrument. It is found that on an average 40 numbers of bubbles per dipping experiment were trapped out of which majority of the bubbles were found to be very small (0.1 to 0.5 mm). The statistical distribution for bubble size trapped in annular space is plotted. Experiments were also carried out with fluid flow inside the annular space. No visible air bubbles were found in the annular space during flow condition. It is concluded from the experiment that this small amount of entrapped bubbles are not a major concern for the safety of the system.

Control systems & sensors

VME64X bus based 32-Channel Digital Input Card,

Design and Development of VME 64 bus based input card, used in Real Time Computer based safety critical, safety related and non-safety related I&C systems of Fast Breeder Reactor, was completed.

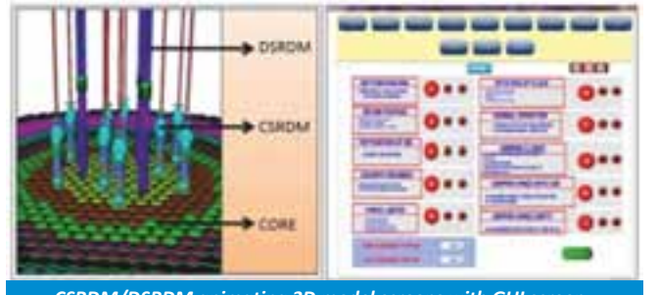
Testing of digital input card

A test application was developed to check the functionality of the card. The digital input card was tested successfully in VME64X platform by running the test application in the CPU card. Safe to insert/remove the card from the live system is observed on the fascia panel LED. The card was detected and configured successfully. DI Card removal from the live system was also detected successfully by CPU and resources were de-allocated.

3D Modelling and Animation of Plutonium Processing Section of Fuel Reprocessing Plant of FRFCF

The Fuel Reprocessing plant of Fast Reactor Fuel Cycle Facility houses the Plutonium Processing Section that consists of eight concrete shielded process cells. Each of these cells houses stainless steel tanks for storing process solution and high dense piping. It also houses exhaust fan rooms, service areas, transmitter gallery etc. Civil structure, process equipment and process piping of the fuel; reprocessing plant was modelled and process-workflow was animated.

3D Modelling and Simulation of CSRDM / DSRDM



CSRDM/DSRDM animating 3D model screens with GUI screen

for Operator Training

3D models of control & safety rod and diversified safety rod drive mechanisms were developed, integrated with process and logic models of simulator, tested and verified for functionality. Animated 3D models will aid the operator in better understanding of the operation of control & safety rod and diversified safety rod drive mechanisms that need to be carried out in nuclear plant

Development and deployment of Knowledge Management Portals for Fast Breeder Reactors

IT-enabled nuclear knowledge management system is designed as a generic, customizable framework and developed in-house. Knowledge management portals with advanced content management and search features were developed and deployed for acquisition, preservation and utilization of records of Prototype Fast Breeder Reactor and Fast Breeder Test Reactor. The knowledge repository was created with the explicit knowledge available in the form of drawings, various notes and procedures, manuals, reports and flow sheets etc The PFBR knowledge management portal has around 5200 design reports and 20000 drawings, while the FBTR Portal has around 2000 reports and 4800 drawings.

STUDIES ON MATERIALS FOR FBRs

Development of Ceramic Coatings for Sacrificial Core Catcher Application

250 micron thick yttria top coat with NiCrAlY bond coat (50–80 micron) was deposited by atmospheric plasma spray process over type 316LN stainless steel coupons for sacrificial core catcher application in FBRs. The coated samples exposed to static molten sodium at 400°C for 500 hours revealed that yttria coating was stable with no interaction with molten sodium.

Development of Yttria coating on high density graphite crucibles for Uranium Melting

Yttria (250-300 µm) was coated on high-density graphite crucibles, without interlayer by atmospheric plasma spraying for uranium melting by induction heating at the demonstration facility for metallic fuel fabrication. The yttria-coated high-density graphite crucibles exhibited excellent adhesion and easy release of the uranium metal ingot during uranium melting runs.

Development of nanophase modified fly ash concrete for seawater applications

Detailed investigation was carried out on the long term corrosion behaviour, durability and antimicrobial evaluation of nanophase modified fly ash concrete by long term exposures in seawater. After one year long exposure studies, it was found to have optimum concrete properties, durability, degradation and bio fouling resistance and it emerged to be a potential candidate for seawater applications.

Advanced molecular biology analysis of metal - microbe synergy in the corrosion of stainless steels

Using advanced molecular biology techniques, dominant families of manganese oxidizing bacteria and their higher diversity were identified in the biofilms on stainless steels exposed to Kalpakkam coastal waters. A metal-microbe synergy in the pitting corrosion was also established.

Investigations on caustic cracking of modified 9Cr-1Mo steel in concentrated sodium hydroxide solutions

Modified 9Cr-1Mo steel is used as a structural material for steam generator in PFBR. In the event of an accidental leak in the steam generator tubes, high temperature water would get mixed up with liquid

sodium leading to a violent chemical reaction generating concentrated sodium hydroxide (caustic) solutions. The mixture of chemicals can cause caustic stress corrosion cracking of modified 9Cr-1Mo steel. Hence, caustic cracking studies were carried out on modified 9Cr-1Mo steel specimens using slow strain rate testing technique. It is found that with increase in the concentration of the caustic solution, the time to failure decreased and linear crack growth rate increased.

Technology development for welded rotors for Advanced Ultra-Supercritical Power Plant (AUSCPP)

Large dimension cylindrical forgings of Nickel based super alloy 617M were successfully manufactured for the first time in the country in collaboration with Indian Industry. 16 numbers of forgings of 200, 400 and 800 mm diameter were produced. These forgings are used for developing procedures for dissimilar metal joining of Alloy 617M rotors with 10Cr Steel rotors using Narrow Gap–Tungsten Inert Gas (NG-TIG) welding process with the objective of technology development for welded rotors for the steam turbines of advance ultra-supercritical thermal power plant. Dissimilar welding of 200 mm Alloy 617 and 10Cr steels rotors using NG-TIG process was already demonstrated.

3D- electron backscatter diffraction characterization of deformed and recrystallized mod. 9Cr-1Mo steel

Three dimensional orientation mapping of grains in modified 9Cr-1Mo steel subjected to heavy deformation and also after subsequent recrystallization was studied by electron backscatter diffraction technique. The 3D texture map generated, contains volumetric microstructural and micro textural information. Analysis of the fiber texture components in rolled specimen across the sections showed no significant preference for any particular fiber texture component, though mild enhancement of the α-fiber texture was observed. However, upon recrystallization treatment at 750°C for an hour, elongated grains along rolling direction were observed, together with some smaller polygonal grains.

Deducing the orientation relationship of martensitic transformation in ferritic steels

Martensitic phase transformation is an important strengthening mechanism in steels, and a novel concept of 'Orientational Equidistance' was formulated for deducing the Orientational Relationship (OR) between parent austenite (γ) and product martensite/ferrite (γ) crystals. The room temperature electron backscatter diffraction scan data of α -ferrite crystallites was analysed to identify the 'misorientation angle-rotation axis' relations between α variants, and represent them as concurrent points in Rodrigues-Frank parametric space. The 'Orientational Equidistance' point of γ from product α variants was then geometrically solved as the common intersection point of equidistant planes passing between pairs of α points. The representative OR estimated in 9Cr-1Mo-0.1C steel was useful in prediction of high temperature γ grain orientations and for categorization of martensite boundaries.

Characterization and performance of magnesium oxide coated 316 SS

Magnesium oxide having high refractoriness, good corrosion resistance along with the thermal expansion coefficient that matches well with stainless steel, makes it a possible coating for structural materials employed in sodium incineration applications. Magnesium oxide coatings on SS316L, using Pulsed Laser Deposition (PLD) technique was developed. In order to tailor the microstructure and ensure the uniformity of these coatings to achieve desired properties, the process parameters were varied to get uniform coatings. XRD was carried out to check for the phase purity and the strain associated with the coating.

SEM studies reveal the microstructural integrity and morphology of the coatings in addition to establishing the chemistry of coatings. It was found that the coating deposited on stainless steel exhibited uniform microstructure. In order to check the compatibility of the coatings with liquid sodium, coupons of magnesium oxide coated SS316L were exposed in the incineration tank where the temperature of the liquid sodium was found to be 700°C. XRD pattern and SEM micrographs of the samples before and after exposure indicates that there is no phase other than MgO found on the substrate.

FBR - FRONT END FUEL CYCLE

Glove box train facility for plutonium based fuel fabrication

U-Pu mixed carbide fuel pins for Fast Breeder Test Reactor (FBTR) were fabricated and supplied by BARC as per the requirement. The glove box facility for fuel fabrication is shown in the photograph.

Studies related to the development of (U-PuO_2), (U-PuC) and (U-PuN) based Cermet fuel have been taken up. Pellets have been fabricated on laboratory scale and characterization studies were carried out.

As an extension of already existing Neutron Well Coincidence Counter (NWCC), a Neutron Multiplicity Counter (NMC) has been developed for the estimation of Pu from as low as 30 mg up to kg level in sealed containments and finished products of various configurations. Range of applicability has been tested by counting several standard sets of PuO_2 samples. Monte Carlo simulation has been used to optimize the design parameters. The simulated efficiency at the centre of the counter is 34%, which is in very good agreement with the corresponding experimental efficiency.

Top and side view of the Neutron Multiplicity Counter

As a part of Chemical Quality Control (CQC) of FBTR fuel, a total of about 130 samples involving (U-Pu)O_2,(U-Pu) C, (Pu-Ga) alloy , BeO samples were analyzed for 22 trace metallic impurities using d.c.arc – Atomic Emission Spectroscopy (AES) and Intrinsically Coupled Atomic Emission Spectroscopy (ICP-AES) methods. As a part of quality assurance of FBTR fuel, 45 (U,Pu)C samples were analysed for Pu, U contents and isotopic compositions of Pu and Am by using bi amperometry, thermal ionisation mass spectrometry and α spectrometry.

The U based alloys containing Zr and Nb were synthesized by arc melting technique and their phase transition temperatures and specific heats were determined using a high temperature calorimeter. It was observed that addition of either Nb or Zr to U increased its specific heat; the increase was lower in case of Nb than that of Zr and the phase transformation temperature of the U rich U-Zr-Nb alloy was much lower than that of U-Zr binary alloy. Thus, U rich U-Zr-Nb alloy may be projected as a good alternative fuel for fast reactor. A simple chelation chromatography separation method for separating Zr in presence of large concentration of U has been developed with a view to determine Zr in U-Zr alloys. Separation was carried out under high acidic condition on a polymeric reversed phase column using 2,6-Pyridine Dicarboxylic Acid (PDCA) as the chelating agent. It is for the first time the simultaneous separation of Zr and U is reported.

Metallic fuel will power the future fast reactors

due to its various advantages and U-Pu-Zr alloy is considered as the driver fuel, is produced by vacuum induction melting technique at IGCAR. The injection casting process is proven to be a good choice for metallic fuel slug fabrication. As a prelude, casting of U-Zr alloy slugs was carried out at Demonstration Facility for Metallic Fuel Fabrication. Yttrium oxide is chosen as the ceramic coating pigment as it satisfies the requirement. The procedure for standardizing yttrium oxide coating on the inner surface of the quartz mould was also developed. Yttrium oxide is used as coating pigment and sodium carboxymethyl cellulose as a binder. Experiments were carried out to optimize the particle size of yttrium oxide and amount of carboxy methyl cellulose. Good and uniform adherence of yttrium oxide coating on inner side of quartz tube was demonstrated.

Uranium deposit from electro refining of U-Zr alloy in hot cell

When metal alloy is used as the fuel, pyro chemical electro refining method was proposed for reprocessing of spent fuels. A 10 kg engineering scale facility is being setup for demonstrating two major process steps of the pyro process flow sheet, viz. electro refining and cathode processing. 10 kg of natural U alloy containing Gd (simulating Pu) and non-radioactive isotopes of important fission products will be processed in each batch operation, in the facility.

For the demonstration of pyro chemical reprocessing of U-Zr fuel capsules irradiated in FBTR, a laboratory scale (100 g) hot cell facility is being developed. Electro refining of U-Zr alloy was carried out at 773 K. A hard compact uranium deposit (35 mm dia., 35 mm height) was obtained. Further work is in progress to repeat similar experiments with irradiated U-Zr samples.

In pyro processing, the salt waste generated can be immobilized using chloroapatite matrix. In order to see the efficacy of various other glass compositions, studies were carried out on various glasses. Studies on synthesis, characterization and thermo physical properties of these glass-ceramics were done. Alumino borosilicate glass shows better thermal properties for use as glass bonding for chloroapatite waste form.

The development of flow sheet for pyro chemical reprocessing of spent metallic fuels using molten salt electro refining in LiCl-KCl eutectic (at 773 K), requires thermodynamic and electrochemical data of actinides and fission products in such eutectic. Towards this, development of exchange current density database for actinides and fission products in LiCl-KCl eutectic were carried out and a Tafel plot obtained for various systems.

Thorium based metallic alloys are being considered as fuel/blanket in future metal fuelled fast reactors. Conventionally, thorium metal is produced by calciothermic reduction of ThO_2, and by chemical reduction of thorium halides by sodium, magnesium or calcium. Feasibility of reduction of ThO_2 to metal using a new Direct Electrochemical Reduction route for the first time was studied and the results are encouraging.

Towards the sol-gel related activity, a plutonium solution handling glove box was commissioned and gelation studies on $(U_{0.79}Pu_{0.21})O_2$ by viscometry was carried out. The gelation temperature which is indicated by abrupt large change in the viscosity was observed at 313 K after 2 hours in the isothermal method and at 348 K in the dynamic mode.

Wetting behaviour of sodium at low temperature is of considerable significance in the context of under sodium viewing with Under Sodium Ultrasonic Scanner (USUSS). As this experimental data is

Experimental facility for contact angle measurement

not available in the literature, a contact angle measurement system for liquid metals was commissioned and contact angle of sodium on SS316LN was measured for the first time.

Liquid lithium (Li-6) is being considered for use in the third stage shut down system of commercial fast breeder reactors as a liquid poison. Towards this, identification of a suitable container material compatible with liquid lithium at reactor operation temperature (823 K) is important. In order to identify a compatible steel, chemical compatibility study of steel samples along with pure iron were carried out in liquid lithium at 823 K for various time durations, It was observed that the austenite to ferrite transformation occurs at the surface of the steel sample and selective removal of material from the surface over a depth of 25 to 50 µm was noticed. No such microstructural changes were observed on the surface of pure Fe, indicating Fe is more compatible to Li, compared to steels.

A compact tin oxide sensor was developed to monitor trace levels of hydrogen in argon cover gas over sodium systems. This sensor was integrated at the downstream of the TCD based sensor system in FBTR. The mean background hydrogen concentration in the argon cover gas was monitored and it was to found to be less than 1 ppm. Performance of the sensor system in secondary sodium circuit of FBTR towards hydrogen injections in the argon cover gas over sodium during shutdown condition of the reactor (sodium temperature, 453 K) was also evaluated. Calibration experiments were conducted by admitting hydrogen in the argon cover gas of FBTR.

FBR- BACK END FUEL CYCLE

Reprocessing of mixed carbide spent fuel of FBTR

CORAL (Compact Reprocessing of Advanced fuels in Lead Cell) facility was set up for reprocessing of spent fuel discharged from FBTR. This facility will be completing successful reprocessing of 14 spent fuel sub-assemblies as licensed by the regulators. As a part of extending the use of facility, a proposal is being prepared for putting up to regulators for licensing to reprocess 15 more sub-assemblies of spent fuel from FBTR.

In-situ replacement of degraded radiation shielding window was successfully carried out, after getting clearance from AERB, with very low dose exposure, which is the first exercise of its kind in DAE. The replacement of radiation shielding window has restored the visibility and paved way for successful maintenance and rectification of feed clarification centrifuge which has resolved many problems in operation.

Third phase formation during solvent extraction with high plutonium bearing solution has safety implications and hence a methodology of

detection of third phase in solvent system by using electrical conductivity method is successfully demonstrated for the first time in solvent extraction equipment.

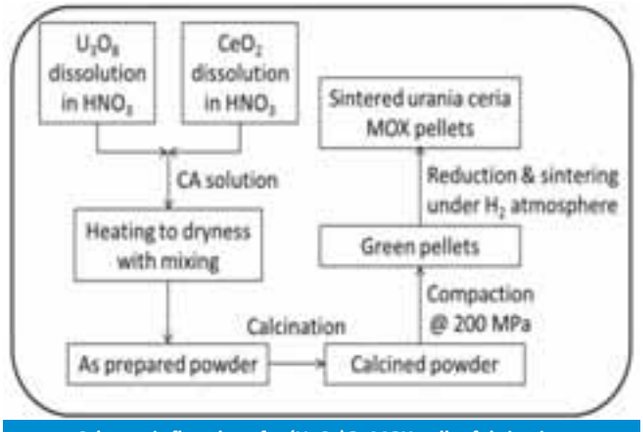
R&D on Fast Reactor Fuel Reprocessing

Installation and commissioning of a compact short path distillation unit for solvent recovery

Solvent purification system

A lab scale solvent purification system based on short path distillation was installed and commissioned. Trail runs are being carried out with simulated degraded solvent to assess the purification capacity and solvent recovery of the compact short path distillation unit.

Process steps involved in the fabrication of (U, Ce)O_2 MOX pellet



Schematic flowchart for (U, Ce)O_2 MOX pellet fabrication

Fabrication and dissolution of simulated Uranium, Cesium mixed Oxides fuel in nitric acid

Simulated U, Ce MOX fuel pellets, with Ce as a non-radioactive surrogate of Pu, was fabricated by combustion synthesis route using citric acid as the combustion fuel. The green pellets obtained were subjected to two-step sintering at 800 and 16000C under reducing atmosphere to get the final sintered pellets.

Four different compositions of MOX pellets, prepared with Ce, were subjected to dissolution in nitric acid medium at 80^{0}C under different mixing conditions to evaluate its dissolution kinetics. It was found that the ratio of [U]/[Ce] remained the same all through the dissolution process irrespective of the conditions. This indicates the complete formation of solid solution in the sintered pellet. It was also found as the Ce concentration increases in the pellet, the dissolution rate decreased. Also similar to UO_2 pellets, the simulated MOX pellets also showed a decrease in its dissolution rate as the mixing intensity is increased. This can be explained in terms of autocatalytic effect of nitrous acid.

Development of Ferris-wheel type dissolver

A prototype of Ferris-wheel type rotary continuous dissolver prototype was designed for lab-scale studies, fabricated and Commissioned. Dry run was conducted for concept validation.

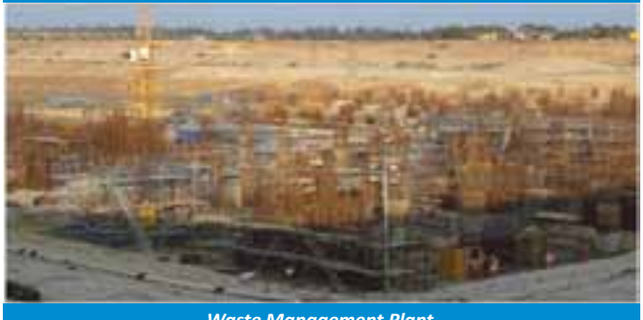
Open View of Ferris Wheel Dissolver

Fast Reactor Fuel Cycle Facility

The Fast Reactor Fuel Cycle Facility (FRFCF) is being built with the objective of closing the fuel cycle for the 500 MWe Prototype Fast Breeder Reactor (PFBR) and facilitate its sustained operation. The facility consists of various radiochemical process plants for Reprocessing, fuel fabrication and waste management. In addition to these, it also houses various services and infrastructure facilities.

In the nuclear island, where the plant buildings are founded on hard rock due to seismic qualification

View of Nuclear Island



Waste Management Plant

Administrative Building

Multi pin chopper

Inter cell sub assembly transfer machine

Attritors for fuel fabrication

requirements, deep excavation works including controlled blasting, geotechnical investigation, geo mapping and grouting works were completed. The civil construction works are in progress for the major process plants. The construction of infrastructure and service facilities such as the administrative building, training centre, central control room etc., are in advanced stage of completion. On the housing front, work order was released for the construction of 600 units and the work commenced.

Procurement action was initiated for raw materials and major long delivery items. 3000 tons of stainless steel plates, 4250 tons of lead ingots and, long delivery items and fuel fabrication process equipment received. Orders were placed for the procurement of other long delivery items such as different versions of Master Slave Manipulators, glass slabs for radiation shielding windows and lead bricks.

The design of process equipment, process vessels, material handling equipment, hot cell and remote handling equipment, piping and equipment layouts and its associated services was completed. Design validation and mock up testing for equipment like fuel pin chopper and inter cell transfer system were completed

Extension of regulatory consent for construction of FRFCF was successfully obtained from AERB, after meeting all the regulatory requirements. Construction works are being carried out with a good safety record and about 8.7 million man hour of work was achieved, so far without any incident

Under the project "Fast Reactor Fuel Cycle Facility" (FRFCF) at Kalpakkam, NFC is setting up two plants i.e., Reprocessed Uranium Oxide Plant (RUP) & Core Sub assembly Plant (CSP). The activities that were carried out included the development of various process equipment for the first time and Co-ordination activities with various Task forces at NFC for process equipment & Task forces at IGCAR for Plant design and clearance issues for both the plants which are under construction by contractor M/s Tata Projects Ltd.

In the Developmental works in Fast Reactor Facility, successful commissioning of Robotic PFBR Fuel Pins & Components Assembling & Welding System was done. The system is successfully commissioned at IFSB, FBTR Complex, IGCAR and all the performance trials carried out with dummy fuel pins gave satisfactory results. A proposal is put up to Safety Committee (SORC-FBTR) for approval for fabrication of fuel and diluent subassembly fabrication with the help of the system.

Robotic PFBR MOX Fuel Pins Assembly Equipment

REPAIR & INSPECTION TECHNOLOGIES

Steam generator Tube inspection of PFBR at BHAVINI with indigenously developed PFBR steam generator inspection system

PSGIS device installed on the steam generator

The PFBR-steam generator inspection system was designed and developed for inspection of steam generator tubes using remote field eddy current testing probe for the full length of the tube. The device is designed in a modular fashion for easy assembly and dismantling. The inspection of more than 500 tubes in all the eight SGs has been successfully completed so far.

Development of Ultrasonic Glancing Angle Imaging Methodology for Mapping of Fuel Subassembly Heads

An ultrasonic glancing angle imaging methodology was developed for mapping of fuel subassembly heads of PFBR. This demonstrates the capability of ultrasonic glancing angle imaging methodology to map subassembly heads and to detect their protrusion if any without the need of placing an ultrasonic transducer just above the targeted subassembly.

Baseline data generation for PFBR steam generator tubes by remote field eddy current technique

RFEC instrument and probe developed for baseline data generation of SG tubes

The field-worthy remote field eddy current instrument and probes developed for pre-service and in-service inspection of PFBR steam generator tubes were used to obtain baseline data of eight steam generators of PFBR. A specially designed robotic system was used for tube indexing and for insertion as well as retrieval of the probe. Suitable software was developed for controlling the device and for off-line analysis of the baseline data.

Real-time X-ray radiographic analysis on nickel dispersed sodium nano-fluid suspensions

Nickel nano particles (20 nm size, 3.5 wt.% dispersed in liquid sodium) are being explored to reduce the reaction kinetics of liquid sodium. Studies were conducted to assess the dispersion of nickel nanoparticles in sodium using real-time X-ray radiography technique. Studies reveal that 3.5 wt% of nickel loaded sodium suspension is stable at 400°C and the dispersion of nickel particles is uniform.

HEALTH, SAFETY & ENVIRONMENT

Radiological Safety

Effective radiological surveillance and health physics services were provided for the radioactive facilities. TLD personnel monitoring services, covering about 3000 occupational workers of IGCAR and BARC facilities, whole body counting, routine and special monitoring procedures for about 750 occupational workers of various active labs of IGCAR, contract workers engaged by active facilities and bioassay services for about 140 occupational workers were also carried out.

In-situ/in-house testing of more than 110 HEPA filters was completed. Dose data and personnel data along with the finger print and photograph of the radiation workers were periodically updated. Various samples around active facilities and other samples for low level counting and determination of the radioactivity from different institutions and industries were also catered to.

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

Nuclear counting and calibration facilities were extended to various institutions involved in BRNS

projects, researchers and industries in southern region.

Radiation awareness training programmes were conducted for the benefit of staff, general public and students in and around Kalpakkam. Indigenously developed Online Nuclear Emergency Response Decision Support system was demonstrated during offsite radiation emergency exercises. Environment, industrial, fire and occupation health awareness programmes were also conducted successfully for employees.

CHAPTER 3

2x25 cell modules at Electrolyser plant

NUCLEAR POWER PROGRAMME STAGE-III

PAWAN Experimental Facility at BARC

THORIUM BASED REACTORS

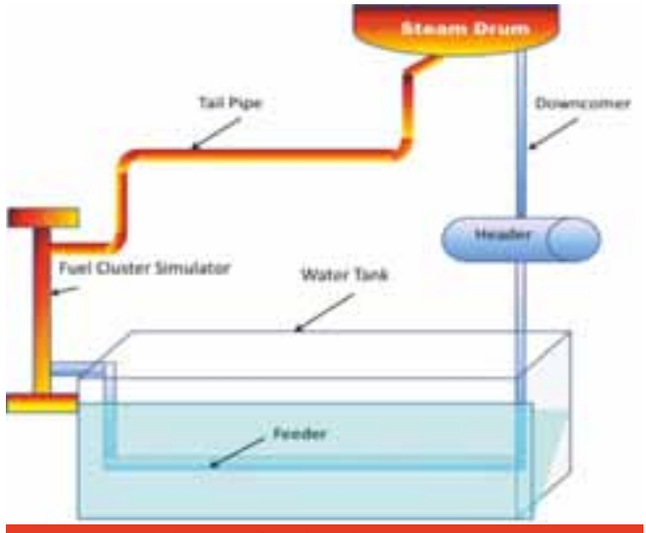
Nuclear power employing closed fuel cycle is the only sustainable option for meeting a major part of the world energy demand. World resources of thorium are larger than those of uranium. Thorium, therefore is, widely viewed as the 'fuel of the future'. The Indian Nuclear Power Programme Stage-3 aims 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

In the Advanced Heavy Water Reactor (AHWR), the simulation studies have shown that due to certain size break in feeders, flow in the channel can stagnate, leading to high rise in the clad temperature. Experiments carried out to detect break of feeder by acoustic signal emanating from the leakage steam proved the possibility of flow stagnation and flow reversals in a cyclic manner to cool the channel. The break in the feeder was detected by acoustic sensors to instantaneously trip the power supply to the channel. These experiments have met the major regulatory requirement of need to trip the reactor in case of feeder break in the vault.

Setup for Stagnation Channel break detection

In case of Beyond Design Basis Accident (BDBA) like earthquake, water from Gravity Driven Water Pool (GDWP) gets relocated in the feeder vault. The experiments proved that the submerged feeder pipes remove decay heat generated in the core and reduce the pressure from 70 bar to less than 10 bar in 18 hrs.



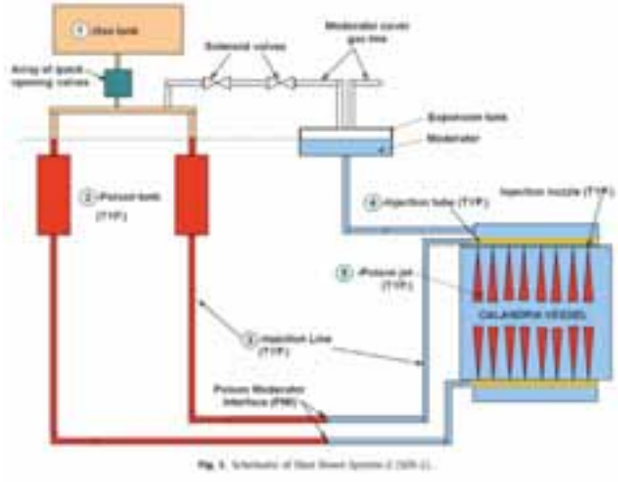
Schematic of Feeder submergence setup

The Advanced Heavy Water Reactor (AHWR) features external core catcher for containing and cooling of core melt in case of remote possibility of severe accident. The core catcher is a concrete structure at the bottom of the core. A scaled concrete model was fabricated with embedded sensors to demonstrate

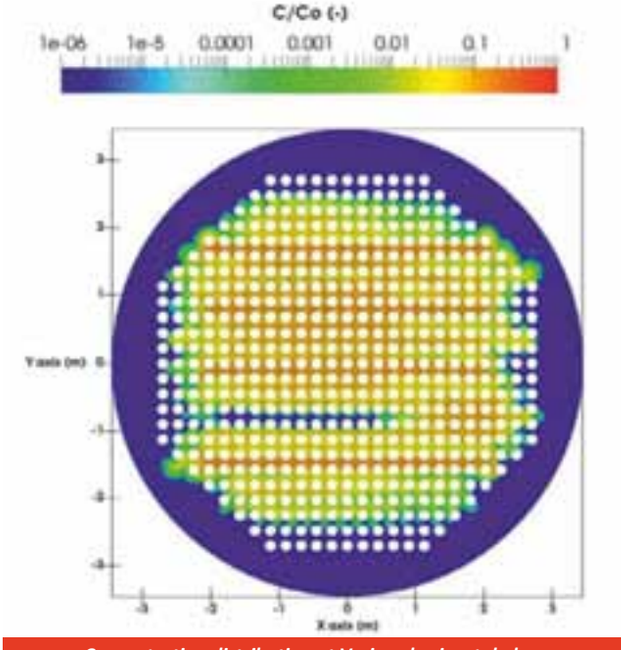
PAWAN Experimental Facility at BARC

cooling of the concrete by passive means. The test was completed at 1000C. using Passive Thermal Sensors (PTS) embedded in sacrificial concrete block. The pressure rise in PTS gets transmitted passively and open passive valves to initiate cooling. The thermal gradient in the concrete and pressure rise in the sensor network was modelled in Computational Fluid Dynamic (CFD) Analysis.

In AHWR, two active, independent, functionally diverse, fast acting shut down systems, namely, Shut Down System-1 (SDS-1) consisting of mechanical shut off rods and Shut Down System-2(SDS-2) based on liquid poison injection into the moderator, are provided. Each shut down system is fully capable of independently shutting down the reactor and keeping it under safe shut down condition for a prolonged period. Shut Down System 2 (SDS-2) operates on the principle of direct injection of poison (gadolinium nitrate solution in heavy water) into bulk moderator in a very short time by means of high pressure helium. High neutron absorption cross section of gadolinium solution makes the reactor subcritical resulting in shut down of the reactor. A schematic of SDS-2 is shown in the figure. Poison concentration distribution in the calandria has been obtained with time by accounting heat generation in the moderator. Results obtained are useful in analyzing the performance of SDS-2. The poison concentration distribution is depicted in figures in various planes of calandria



Schematic of Shut Down System-2



Concentration distribution at Various horizontal planes

In Probabilistic Safety Analysis (PSA), Large Early Release Frequency (LERF) of the Nuclear Plant is one of the important inputs for offsite emergency planning. Only core damage accidents that can lead to large, unmitigated releases from containment before effective evacuation of the nearby population have the potential to cause prompt fatalities. Such accidents generally include un-scrubbed releases associated with early containment failure. The frequency of all accidents of this type is called LERF. Deterministic analysis focuses on the analysis of the physical processes of an accident (timing and magnitude of radioactive release) and the response of the containment.

Containment pressure and temperature transients study showed that LERF of AHWR is 1x10-13/year, which is several orders less than the permissible limit of 10-6/year further confirming the very high reliability of the safety/mitigating systems.

Passive Containment Isolation System (PCIS) of proposed AHWR has been designed for preventing the release of radioactivity to environment in the event of accident. PCIS consists of a PCIS tank and tube. In the event of Loss of Coolant Accident (LOCA), steam is

released into V1-volume and pushes the stored water from PCIS tank to U-tube shaped ventilation duct till the differential pressure is available. In this way, water collected in the ventilation duct seals the containment and isolates it from the environment passively. To evaluate the performance of PCIS under accidental scenario, a 3D transient analysis has been carried out by using commercial software CFD-ACE+ through Volume of Fluid (VOF) approach. It is observed from the CFD analysis that the PCIS will perform its intended function by 21 seconds.

KAlpakkam MINI (KAMINI) Reactor

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

OTHER THORIUM REACTOR SYSTEMS

Special tools and fixtures were developed for machining of fuel tube, moderator blocks and reflector blocks and the procedure for machining from High density isotropic graphite was qualified. Machining of the components is in progress.

Preliminary Safety Analysis report for Molten Salt Breeder Reactor Developmental Facility (MSBRDF), Vizag was completed. Estimation of quantum and nature of waste generation was carried out. Scheme for production of hafnium free anhydrous zirconium fluoride starting from anhydrous zirconium chloride was worked out. Procurement of zirconium fluoride for initial studies and X-ray Diffraction (XRD) examination of the salt was completed. Fabrication of oscillating cup viscometer, for determination of molten fluoride salt viscosity without exposing the molten salt to any kind of contaminating atmosphere was completed.

Machining of hexagonal simulated BeO moderator and reflector blocks and cutting fixture

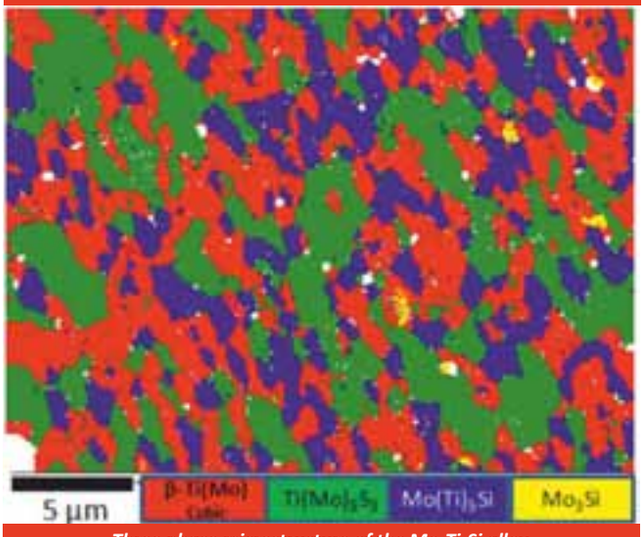
Machining of hexagonal graphite fuel tube and downcomer tubes

Machining of convex and concave profiles of graphite reflector blocks and their cutting tools

MATERIALS

150 nuclear fuel samples were analysed for isotopic composition by thermal ionization mass

60 mm diameter and 5 mm thick Mo-Ti-Si alloy plates produced by vacuum hot pressing



Three phase microstructure of the Mo-Ti-Si alloy consisting of β-Ti–Ti_5Si_3–Mo_3Si_3

spectrometry (TIMS), α spectrometry, γ spectrometry and thermogravimetry to support various DAE programs.

Self-passivating Mo and W based alloys are designed, developed and tested as the alternate materials, suitable for high-temperature applications beyond the capability limit of conventional superalloys. These materials are potential structural materials for high-temperature nuclear fission reactors and first wall of fusion reactors. The addition of the alloying elements such as titanium, silicon, boron, and chromium is studied to produce an alloy having superior oxidation resistance and mechanical properties at high-temperatures.

The selected few alloys being prepared and tested at high-temperatures are composed of Mo-Ti-Si, Mo-Si-B, Mo-Cr-Si, and W-Cr-Si.

The equipments have been designed and fabricated in-house for carrying out hydrogen reduction of WO_3 to produce high purity tungsten (W) metal powder in kilogram quantity batches. The process has been successfully demonstrated in 1 kg batches of WO_3 under the flow of hydrogen gas and 100% conversion efficiency has been achieved.

W metal powder produced by hydrogen reduction

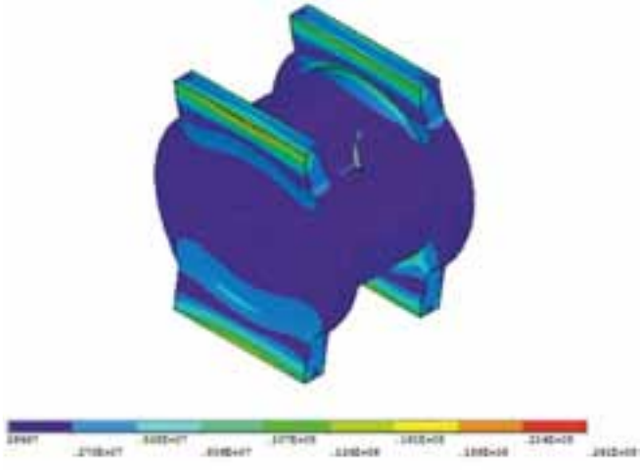
HYDROGEN ENERGY

Pd based metallic membrane of composition $Pd_{0.77}Ag_{0.10}Cu_{0.13}$ and thickness 100 µm was developed for separation of He from ^3H. A membrane module was fabricated using vacuum brazing technique. The membrane was found to have infinite selectivity towards hydrogen isotopes and can be a potential membrane material for efficient purification and recovery of hydrogen isotopes in the fuel cleanup system and blanket tritium recovery system of fusion fuel cycle. Experiments with synthetic mixture of hydrogen (1%) and helium were carried out which confirmed that due to infinite hydrogen selectivity and higher flux, $Pd_{0.77}Ag_{0.10}Cu_{0.13}$ alloy foil membrane is a suitable material for separation of decay product ^3He from ^3H.

Membrane module

Very compact electrolyser systems consisting of cell module, gas purification systems with minimum moving parts were developed and demonstrated at small and medium scale of production capacity. These electrolysers operate at very high current density and water is the only raw material used. Stress analysis of the compact electrolyser plant was performed using FEM code to check the system integrity under external shock. Performance evaluation of solar PV assisted system has shown potential for use in household purpose. Improvements in cell and process components are also accomplished for improved safety and product quality.

2x25 cell modules at Electrolyser plant



Stress concentration profile of Cell Module under external shock dia

MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

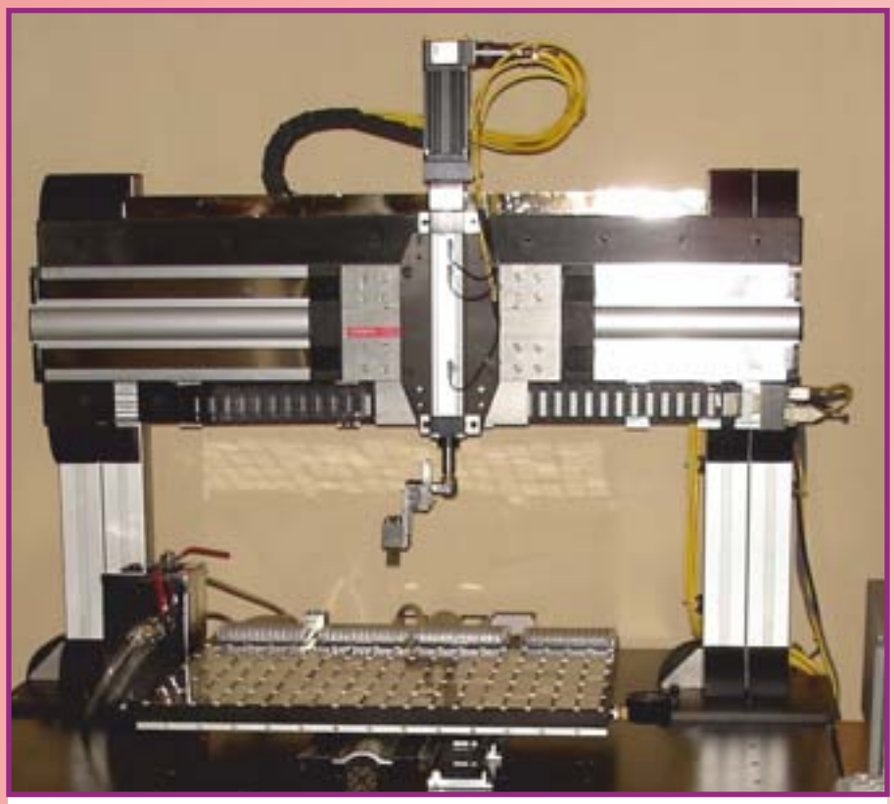
Chemical characterization of lithium titanate and lithium aluminate, (proposed tritium breeding blanket materials in D-T based fusion reactor) was carried out by Particle Induced Gamma-ray Emission (PIGE) using 4 MeV proton beam from FOTIA, BARC and trace elemental impurities belonging to long lived nuclides were determined by Instrumental Neutron Activation Analysis (INAA). The concentrations of Li, Ti, and Al were determined by PIGE.

INAA using high neutron flux from Dhruva reactor was utilized for determination of concentrations for 12 trace elements namely Sc, Cr, Fe, Co, Zn, Zr, Sb, Cs, Ce, Eu, Tb and Yb in lithium titanate and Sc, Cr, Fe, Co, Zn, Zr, Sb, Ce, Eu, Tb, Hf and Ta in lithium aluminate. Determination of elements belonging to long lived activation products (a few days to years) will be helpful to calculate the dose from lithium based samples, which are useful for providing effective cooling period and shielding after irradiation for tritium release studies.

CHAPTER 4

Neutron imaging beamline

ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES AND THEIR APPLICATIONS



An indigenously developed DNA Microarrayer

CHAPTER 4

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.

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

DAE has been working in close cooperation with other organizations of the Government of India to widen the reach of the technologies for the benefit of common man. The major activities and achievements of DAE organizations during the report period were as follows.

RESEARCH REACTORS

APSARA

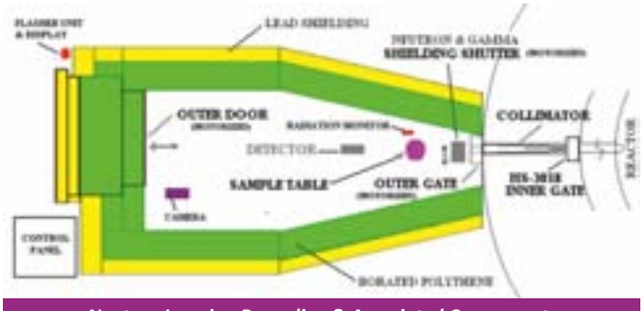
Civil construction of reactor pool, annex building, pump house and dump tank were completed and construction of reactor hall & electrical substation are nearing completion. Process equipment erection and piping work are in progress. Load testing of Electric Overhead Travelling (EOT) crane has been completed. Fabrication of reactor core component is nearing completion. Computer based system racks have been delivered at site. Ion chambers are delivered and are being tested.

DHRUVA

Research reactor Dhruva continued to operate with a high level of safety and with an availability factor of around 72% and capacity factor of around 61%. The reactor was operated up to the rated power of 100 MW (th) as per the researchers requirements. More than 700 samples were irradiated for radioisotope production. A number of research scholars from various academic institutions in the country utilized the reactor under the aegis of the UGC-DAE Consortium for Scientific Research.

A twisted pin geometry cluster, consisting of dispersion type fuel was successfully irradiated up to its target burn-up to study aspects related to fuel performance such as reaction between dispersant and diluents, swelling characteristics, clad deformation behaviour, etc.

Neutron Radiography and Tomography Facility has been commissioned at Dhruva Reactor to enhance reactor utilization. A dedicated neutron imaging beam line has been set up at Dhruva Beam-hole HS-3018 for real time neutron imaging and neutron tomography.



Neutron Imaging Beam line & Associated Components

Neutron Tomography Set-up

The facility consists of a dual purpose collimator for both neutron tomography and phase imaging experiments requiring high spatial coherence. With high neutron flux at Dhruva, it is expected that excellent quality of imaging data could be achieved in terms of signal-to-noise ratio, less data acquisition time and better resolution.

The facility is available for various tomography studies e.g. Hydrogen ingress in zircaloy, examination of PHWR fuel pins, cracks in failed turbine blades, real time investigation of lead melting, etc. This facility will meet neutron imaging demand of various user groups from BARC and other organizations such as ISRO. The tomography set-up will be extended to include new imaging techniques such as magnetic phase contrast imaging using polarized neutron.

The required no. of fuel clusters & other components for 'Dhruva' were fabricated & delivered

Assembly hall for the 'Dhruva' fuel clustures

Product collection area of D_2O Upgarding Plant

ensuring uninterrupted operation of the Reactor. The figures show the assembly hall for the fuel clustures. Operation of Heavy Water Upgrading Plant at BARC was continued for improvement of Isotopic Purity (IP) of the downgraded heavy water of Research Reactors.

Major revamping & modifications of utilities and equipments were carried out to achieve desired heavy water product quality and improved capacity as per the requirements. Modifications of process components are done to handle wider range of feed composition, better yield & utilization factor.

A state-of-the art Prognostic and Health Management (PHM) Laboratory for the life and reliability assessment of electronic components is being set up at Cirus. Equipments like Photon Emission Microscope, Thermal Shock Chamber, etc., are procured and commissioned.

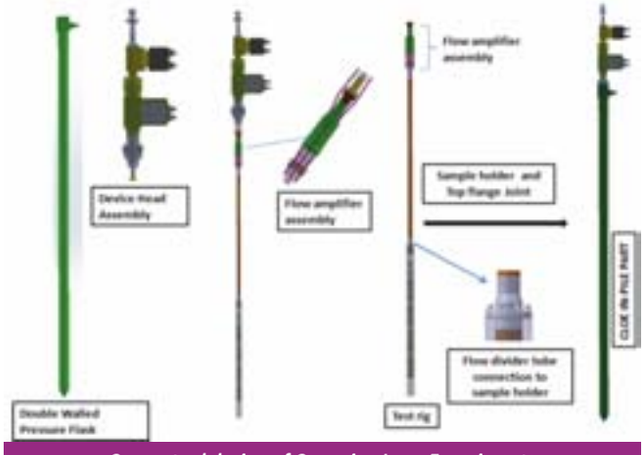
High Flux Research Reactor

Preparation and review of preliminary safety analysis report, part-A and preliminary architectural

drawings of all civil structures for the upcoming high flux research reactor has been completed.

Studies in Research Reactors

Corrosion Loop Experiments (CLOE) for Jules Horowitz Reactor (JHR), CEA, Cadarache, France is in progress. Conceptual design was carried out for placement of Flow amplifier in the Test device considering thermal hydraulics and mechanical design aspects. Preliminary design of different components of Test device was carried out using French code RCC-MRx. The concept has been reviewed by CEA. Preliminary thermal hydraulics analyses of the process loop were carried out using thermal hydraulic computer code CATHARE. To optimize and validate the performance of flow amplifier an experimental set up was fabricated for carrying out the parametric study with different flow amplifiers.



Conceptual design of Corrosion Loop Experiments (CLOE) with Flow Amplifier

Experimental set up for parametric study of amplifiers

Prototype sample holder for the for Corrosion Loop Experiments flow (CLOE) for Jules Horowitz Reactor (JHR)

A prototype sample holder was fabricated for qualification of Loading device and feasibility of routing mineral insulated cables for four nos. of test specimen.

In open pool type nuclear research reactor, a hot water layer at the pool top is maintained to reduce the radioactive particles like Na^{24} and Ar^{41} to reach at the pool top through convection. Studies on the behaviour of thermal stratification were carried out for different

Thermal image of hot water layer

geometrical and process parameters in the test facility. Experiments were carried out to observe the phenomenon of transport of radioactive tracer (^{99m}Tc) from cold water zone into the Hot water layer.

ACCELERATORS

At BARC, the Pelletron-Linac facility has achieved 80% uptime by November, 2016 delivering various ion beams through Pelletron and Linac booster as per the user requirements. The facility has been re-authorized for five years after complying with all the major safety recommendations. ISRO (Indian Space Research Organization) groups utilized the low flux Proton irradiation set up to perform radiation damage studies for testing the space bound electronic devices. 6 Meter level irradiation set up was utilized to estimate wear rate in stainless steels samples using thin layer activation technique through ^{56}Fe(p,n)^{56}Co reaction.

At RRCAT, facilities for fabrication, processing, and low temperature RF testing of Superconducting Radio Frequency (SCRF) cavities have been set up which includes a large size centrifugal barrel polishing machine. A single-cell 650 MHz (Beta=0.92) superconducting cavity, TB9-RRCAT-304, was fabricated using the in-house electron beam welding facility. It was leak tested and barrel polished. Around 200 micron material was removed from the equator using ceramic, plastic and colloidal silica solution to remove surface defects and polish the internal surface of the cavity. The barrel polished cavity was thermally processed at 600^{0}C for 10 hours in high vacuum using high temperature annealing furnace facility, specifically setup for niobium material. The last step of polishing was light electro-polishing to remove 20 micron material using electro-polishing facility. After electro-polishing the cavity was ultrasonically cleaned. The cavity was rinsed with ultra-pure water at 100 bar pressure and dried and prepared for 2 K testing in a class 100 clean room. Finally, the cavity was at 120^{0}C in oven in high vacuum. The cavity was tested using in the VTS facility at RRCAT. An excellent quality factor of $3x10^{10}$ was achieved with an accelerating gradient of Eacc 12.8 MV/m.

Electro-polishing of single-cell 650 MHz SCRF cavity

RRCAT has initiated fabrication of HB 650 MHz (β=0.92) five-cell bare cavity. Design and fabrication of various cavity fabrication tooling and fixture like forming tooling, welding and machining fixtures have been completed. Component fabrication for first prototype five- cell SCRF cavity including half cells, beam tubes, flanges etc. have been completed. The first prototype HB 650 MHz five-cell cavity fabrication is expected to be completed by March 2017. It will be subsequently taken up for its further processing and testing at 2 K for qualification. Such elliptical 650 MHz cavity with two different beta (β=0.61 and β=0.92) would be required for the superconducting proton linac for the DAE's two future major accelerator projects namely, ISNS and ADS.

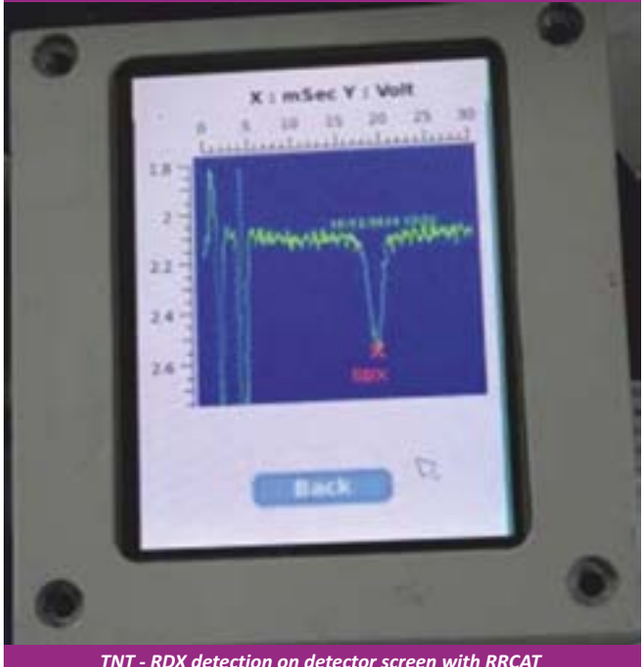
SCRF cavities are highly expensive but essential components of high intensity particle accelerators. At RRCAT a 5-cell laser welded Superconducting Radio Frequency (SCRF) cavity has been fabricated. This technology for fabrication of SCRF cavities, with laser welding technique, has been developed for the first time in world. This replaces expensive electron beam welding technology, being currently used internationally for this application. This technology is a breakthrough in the fabrication technology of SCRF cavities as it will bring down the cost of fabrication of SCRF cavities very significantly. The feasibility of this technology was proved when the first single cell cavity

5-cell laser welded superconducting radio frequency cavity

fabricated by this technique at RRCAT was tested at Fermi lab and it gave a gradient of 31.6 MV/m at quality factor Q0 of 1 x 10^{10} at 2 K. This is similar to the performance of a conventionally fabricated SCRF cavity. The technology has been granted patent in USA (US 9352416 B2) and Japan (Patent No. Jp5632924).

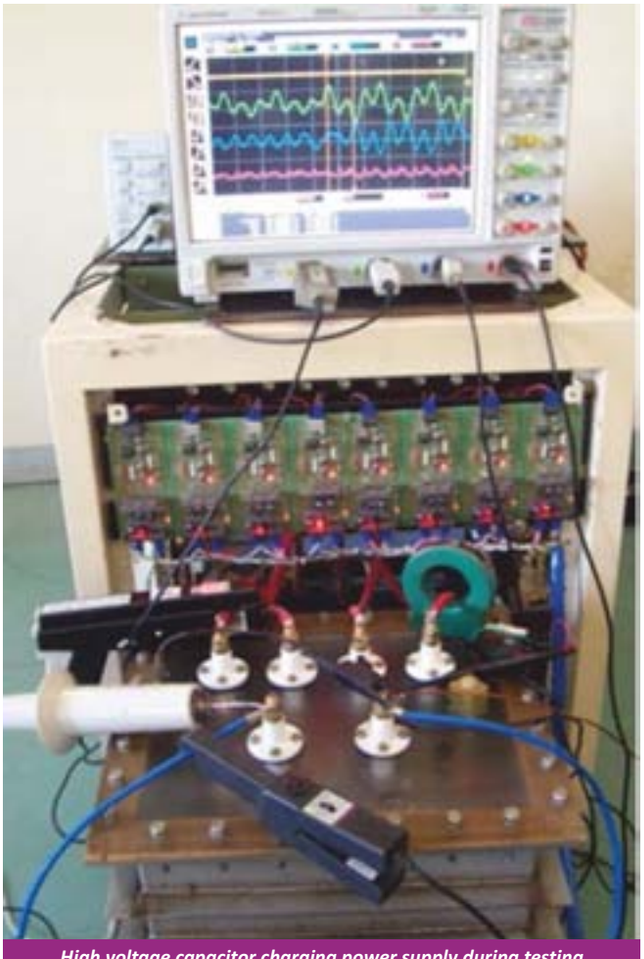
Explosive detection facility is an important requirement for the security of our nation. Presently India does not have any indigenously developed explosive detection system. ECIL Hyderabad and IGCAR, Kalpakkam took up the development of an Ion Mobility Spectrometry (IMS) based indigenous explosive detection system in the year 2012 under Technology Development for India for detection of explosives like TNT, RDX, PETN etc. High voltage pulsed and DC supplies required for the drift tube of the IMS detector were developed at RRCAT, Indore.

Oxygen detection on detector's screen with RRCAT HV pulse and HV DC supplies



TNT - RDX detection on detector screen with RRCAT HV pulse and HV DC supplies

High stability, high power capacitor charging power supply for future projects has been developed at RRCAT. This power supply will be used to charge pulse power circuit capacitors of septum / kicker pulsers at a repetition rate of 25 Hz. The capacitor charging power supply was designed and developed to charge 50 µF energy storage capacitor from 0 V to 2 kV within 35 ms, exhibiting a charging power of 2.8 kJ/s. The measured output voltage stability at 25 Hz was ± 0.01%.



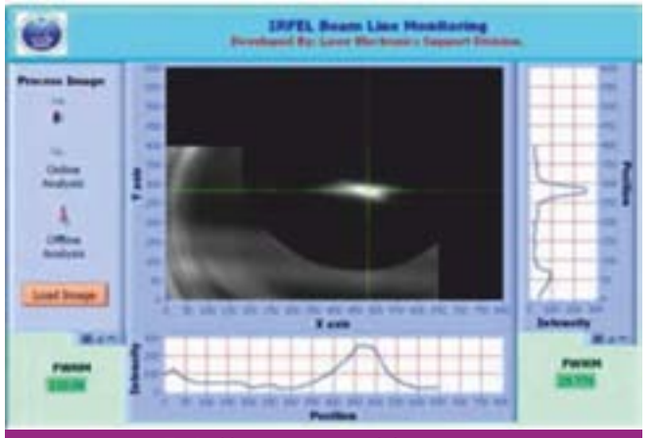
High voltage capacitor charging power supply during testing

First linac tested at beam power of 5 kW

Second linac tested at beam power of 1 kW

RRCAT, Indore has indigenously developed a 10 MeV, 5 kW electron linear accelerators (linac) for agricultural, medical, and industrial applications. The accelerating structure is traveling wave type and operates in S-band (2856 MHz). The first linac has reached a power level of 5 kW in long duration operations. This linac is under beam characterization to be deployed at Agricultural Radiation Processing Facility being set-up at Indore. The second linac of the series, with several refinements in engineering design, has been tested at a beam power of 1 kW following the stipulations of Atomic Energy Regulatory Board. It is now ready for long term endurance testing at a beam power of 5 kW.

An indigenously developed Infra-Red Free Electron Laser (IR-FEL) is being commissioned at RRCAT. It has a 2.5 m long pure permanent magnet undulator with 50 mm period, and an injector linac system capable of delivering a 15 MeV to 25 MeV



Typical beam spot at undulator entry

electron beam. The accelerated electron beam from the injector system is transported to the undulator by an electron beam transport line that manipulates the round beam at linac exit to a flat beam with desired properties at the undulator entry. Electron beam diagnostics in the form of integrating current transformers (ICTs) and beam profile monitors (BPMs) are employed to monitor the electron beam properties at different locations of the IR-FEL setup. The high stability (±100 / ±400 ppm) 13 A /15 V power supplies required for the various magnets were designed at RRCAT. The production and testing was carried out by ECIL, Hyderabad. Installation, cabling and testing of 45 power supplies in local made was completed last year. This year the power supplies were interfaced with the central control room for remote operation. They have been in regular use for the past one year. The IR radiation generated in the IR-FEL setup is out-coupled through a 2.5 mm hole in the downstream mirror, and the out-coupled IR power is measured using a liquid helium cooled bolometer. The first signature of lasing at 34 μm wavelength has been successfully observed with an estimated gain of 10^4 over enhanced spontaneous emission during experiments with an 18.3 MeV electron beam with approximately 26 A peak micro-pulse current over a 5 μs electron beam macro-pulse. Further experiments are presently underway to achieve saturation of the FEL gain.

An optimum lattice for the 1 GeV H- injector linac for Indian Spallation Neutron Source (ISNS) has

been designed for the expected beam parameters at the exit of the ion source. The current design includes a 1.9 m long Low Energy Beam Transport (LEBT) section, 3.49 m long Radio Frequency Quadrupole (RFQ) section, 3.68 m long Mid Energy Beam Transport (MEBT) section and 252 m long linac section comprising 20 nos. of Single Spoke Resonator (SSR0) cavities, 28 nos. of SSR1 cavities, 48 nos. of SSR2 cavities, 54 nos. of mid beta cavities and 48 nos. of high beta cavities, along with solenoids and quadrupole doublets. Beam dynamics simulations have been done with this configuration and it has been checked that all the stringent beam dynamics criteria are met.

A parallel pumping test bench has been developed to measure the non-linearity in microwave ferrite and garnets. 1 mm to 2 mm diameter spheres of yttrium garnets and I-CVG have been fabricated and tested in this system. No non linearity is observed in ferrite and garnets up to 100 kW in below resonance operation. Based on above results, a ferrite disk resonator of 207 mm diameter and thickness of 5 mm at 505.8 MHz has been made using plural (triangle) ferrite pieces. Tests of circulator performance at high power has been carried out by passing hot water surrounding disk resonator with stripline which resembles temperature rise of 800C on the ferrite surface. This is equivalent to 100 kW CW power operation. The

I-CVG disk using plural pieces

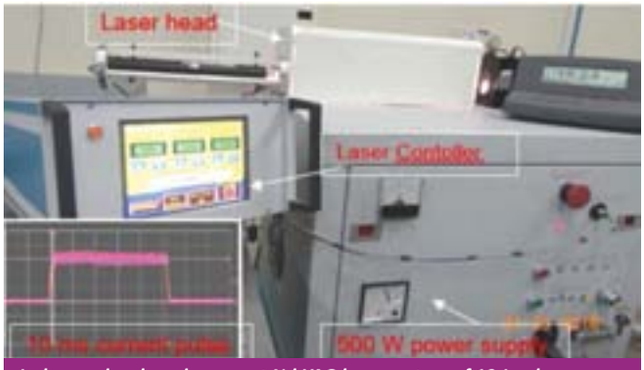
Single-cell Lb650 niobium cavity

performance of the circulator is measured for three types of distribution of the applied field by varying the shape, size of the pole piece of an electromagnet. These studies have been very useful for tailoring the correct molecular engineering compositional design of microwave ferrite and garnets for indigenous development of high power CW ferrite circulator (> 100 kW) for RF systems of Indus-2 ring and 650 MHz ferrite circulator for proton linac.

The Variable Energy Cyclotron Centre (VECC) has been involved in the design, analysis and development of 650 MHz, β=0.61, elliptical Superconducting RF (SRF) cavity for high intensity proton linear accelerator. This is a part of research and development activities on SRF cavities and associated technologies under Indian Institutions Fermilab Collaboration (IIFC). A single-cell niobium cavity has been designed and developed in-house, with the help of Electron Beam Welding (EBW) facility at IUAC, New Delhi. The cavity has been fabricated with 4 mm thick ultrapure niobium (RRR >300) sheet. After fabrication, various measurement or tests have been carried out at VECC and then the cavity was sent to Fermilab, USA, for processing and testing at 2K temperature in Vertical Test Stand (VTS). The test result shows a remarkable achievement with a maximum accelerating gradient attained 34.5 MV/m, which the highest value achieved so far in the world, in case of LB650 cavity.

LASER TECHNOLOGY

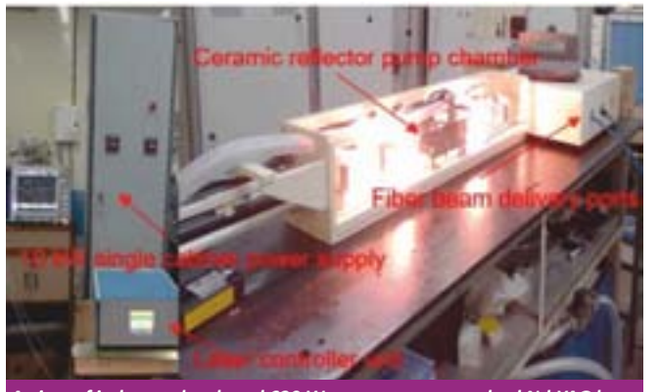
An Nd:YAG laser system based on compact



In-house developed compact Nd:YAG laser system of 12 J pulse energy

ceramic reflector and single flash lamp pump chamber has been developed. The laser provides maximum pulse energy of 12 J in 10 ms pulse duration having laser beam diameter of 4 mm. Output pulse energy can be varied from 0.5 J to 12 J by variation in flash lamp current. Its pulse duration and repetition rate can be varied in the range of 2 ms to 10 ms and 1 Hz to 4 Hz, respectively. For this system, a compact 500 W average power pulsed power supply with controllers is developed. An electrical to laser conversion efficiency of 2.5% has been achieved with a pulse-to-pulse stability of better than 5%. The laser system is equipped with dual port fiber optic beam delivery through 200 µm core diameter optical fibers on time sharing basis. This laser system will be used for leak tight welding of high dose rate brachytherapy assemblies of miniature size (80 µm wall thickness, 1 mm diameter) at BRIT, Mumbai. One of the fiber ports will be used for welding in hot cell and second port for welding outside hot cell using a real time CCD camera based viewing system.

A double-lamp ceramic reflector based pump chamber and Nd:YAG laser system providing a maximum average output power of 630 W and 13 kW peak power in ms time duration has been developed for laser cutting of irradiated FBTR components in hot cell at IGCAR. Laser pulse duration can be varied in the range of 2 ms to 40 ms and pulse repetition rate from 1 Hz to 100 Hz. An electrical to laser conversion efficiency of 6.3% has been achieved, which is the highest reported worldwide for similar laser systems. Yellow glazed ceramic reflector based pump chamber is expected to enhance life of pump chamber to 5 years as compared



A view of in-house developed 630 W average power pulsed Nd:YAG laser

to 1 year for earlier used gold coated elliptical reflector based pump chambers. Resonator length is also reduced to 0.71 m as compared to earlier resonator length of 1.4 m for similar output power. Due to smaller resonator length, mechanical stability has been improved, which resulted in pulse-to-pulse stability of ±3% as compared to earlier value of ±5%. Beam quality factor M2 also improved to a value of 83 as compared to earlier value of 120. A single unit power supply of 10 kW average power and a laser controller to drive two lamps synchronously with maximum 5 kW electrical input to each lamp has been developed. Laser output has been delivered through an optical fiber of 600 µm core diameter with 90% transmission efficiency. This high power laser has also been equipped with three energy/time shared ports for providing simultaneous three linear cuts to fuel tubes for dismantling of fuel assemblies.

As a part of the indigenization effort to replace the imported technology, RRCAT has designed and developed a prototype laser radiator unit for defense applications, for laser guiding of a missile fired from a tank. The laser consists of an arc-lamp pumped Continuous Wave (CW) Nd:YAG laser emitting in the near infrared region of wavelength 1064 nm. The electrical and mechanical parameters of laser are matched to the imported laser. The required output power of laser is 13 W with pulse duration of up to 20 sec. The highly efficient prototype laser radiator unit developed at RRCAT delivered an output power of 25 W with water as coolant and 15.5 W with special coolant

The photograph of the laser radiator unit

having low freezing point, for the same pulse duration which is more than 20% of the requirement.

An all-fiber Thulium Doped CW Fiber Laser (TDFL) has been developed with stable CW output power of 18 W using in-line fiber Bragg grating mirrors with a slope efficiency of 45% and centered at 1940 nm with sub-nanometer line width. These lasers have wide applications in material processing of metals and non-metals, surgery, defense and space applications. Laser output is emitted from 12 μm core diameter of thulium-doped fiber with half angle divergence of 140 mrad.

A mode-locked Ytterbium (Yb) doped fiber laser has been developed under stretched pulse configuration by implementing a grating pair inside the cavity for control of dispersion. The laser produces highly stable train of mode-locked pulses at 45 MHz repetition rate of duration 500 fs which were compressed to less than 50 fs duration with energy of 3 nJ in an external grating compressor. Two in-fiber Polarization Controllers (PC1 and PC2) were placed near Collimators (COL1 and COL2) in combination with the polarization beam splitter. The mode locking in the oscillator is observed by biasing the polarization controllers.

A lab model of frequency doubled narrow-line-width CW Ytterbium Doped Fiber Laser (YDFL) emitting 5 W at 515 nm with narrow line width of 0.07 nm has

Table-top view of green fiber laser

been developed for dye pumping applications. The laser is developed in two stages. The first stage of laser system is YDFL emitting 1030 nm radiation, which is based on all-fiber architecture for alignment free ruggedness. This stage provides linearly polarized CW output power of 20 W in narrow line width of 70 pm, which is within the spectral Full Width at Half Maximum (FWHM) of non-linear crystal for efficient SHG. The slope efficiency in terms of absorbed pump power is more than 70%. About 5.5 W of output power at 515 nm has been generated with SHG conversion efficiency of 25% using this set-up. This laser has a potential to replace Ar-ion lasers operating at this wavelength for pumping of Dye lasers.

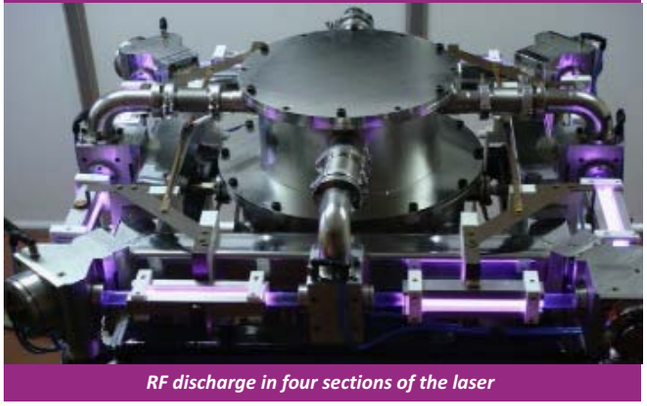
Pulsed blue lasers operating in spectral range of 450 nm to 460nm have their great importance in special applications such as communication between aircraft and submarine and under water communication. A table-top model of high power pulsed blue laser source operating precisely at 456 nm wavelength has been developed. The laser provides average output power of 1.2 W in pulses of duration 400 ns at 20 kHz repetition rate. Pulsed blue laser source precisely at 456 nm finds potential application for deep sea under water communication. Fiber coupled diode laser with 28W of maximum power and central wavelength of 808 nm at 25°C was used as the pump source. The Z-shape laser resonator consists of a-cut Nd:$GdVO_4$ laser crystal along with an acousto-optic Q-switch modulator. For intra-cavity frequency doubling a LBO crystal was used for efficient frequency conversion. The output power was measured using a power meter after appropriate filters to block the residual pump and fundamental IR power.

Blue laser under operation

A 2 kW RF-excited Fast Axial Flow (FAF) CO2 laser has been developed for material processing application. A noteworthy feature of the laser system is its excitation with an all Solid State Modular RF Power (SS-RFPS) Source. Modular RF power supplies can be pulsed from 100 Hz to 30 kHz giving pulse mode laser output at lower frequencies up to 1 kHz and quasi-continuous at higher frequencies of operation. Pulse mode operation provides dynamic power control option which is very important for laser material processing applications.

Last year two numbers of engineered version of Diode Pumped Solid State (DPSS) green laser systems were developed and installed at BARC for pumping of dye laser amplifier chain. The DPSS lasers were successfully used for several long hour campaigns for resonance ionization experiments. This year four more such DPSS green lasers are expected to be delivered. The DPSS green laser system was a specially designed Q-switched intra-cavity frequency doubled Nd:YAG laser to obtain short pulse duration under high repetition rate. At a pump power of 400 W, more than 40 W of average green power was obtained at 6.25 kHz repetition rate corresponding to pump to green conversion efficiency of 10.5%. At the maximum output power the green pulse duration (FWHM) was measured to be 40nsec. Four such engineered models of DPSS green lasers are ready to be delivered at BARC.

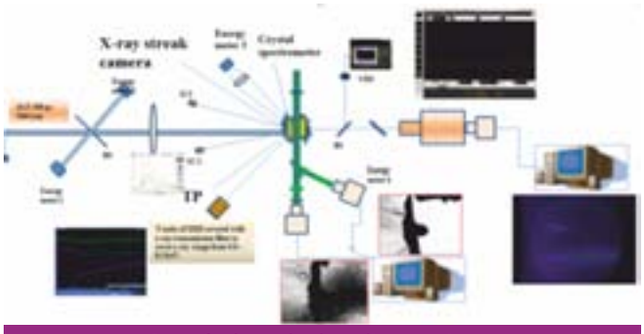
2 kW RF-FAF CO_2 laser



RF discharge in four sections of the laser

Internal layout of DPSS green laser head coupling

DPSS green laser under operation with fiber



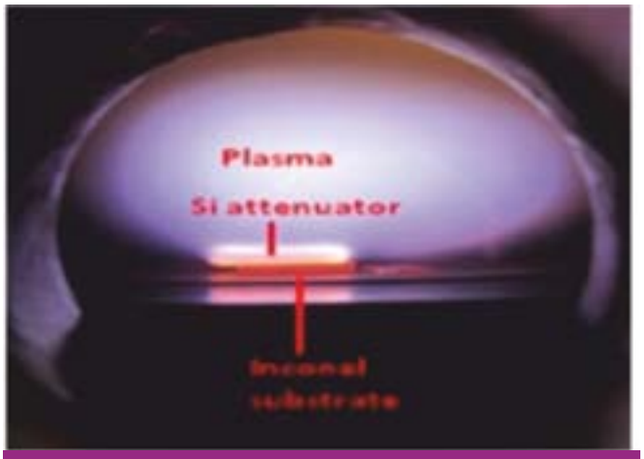
Setup for laser shock studies experiment

Various plasma parameters such as X-rays, ions and Equation-of-State (EOS) data were derived from laser driven shock studies on foam targets. X-ray flux with gold foam targets were optimized for developing short pulse x-ray source for radiography. The experimental set up, radiograph of the S. S. mesh with wire diameter of 100 µm and shock studies experiments carried out on deuterium foam is shown in figures.

Atmospheric Pressure Plasma Jet (APPJ) for Radioactive Decontamination is a portable plasma device which operates at atmospheric pressure. Length of the plasma jet from such a device can range between a few µm to cm. A three-electrode APPJ for better, quicker and effective decontamination was developed. Computer based simulations has been done to find out the optimum dimension and mechanical design of the device. A series of systematic experiments with the device has yielded more than 90% decontamination of radioactivity within 3 minutes of plasma exposure.

(a) Three electrode APPJ device
(b) the device operational with three plasma plumes

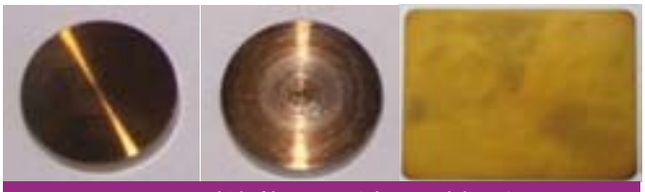
Co-deposition of Carbon Nanotubes (CNTs) along with Nano-Crystalline Diamond (NCD) and Graphene Nanowalls (GNWs) have been made possible by Microwave Plasma Enhanced Chemical Vapour Deposition (MPECVD) for the first time.



MPECVD system

The mechanism involving co-deposition of sp3 and sp2 hybridized nanostructures has been investigated through a series of experiments and windows for co-deposition have been evaluated. CNTs, GNWs have diverse applications e.g. field emitter & cold cathodes, super capacitors, energy storage device etc. NCDs are super hard material, highly inert having good bio-compatibility among other properties.

Boron carbide has emerged as a potential candidate for neutron detection because of the high thermal neutron capture cross-section of ^{10}B isotope besides its excellent stability to withstand radiation damage and non-hazardous nature. Boron carbide films can be implemented as neutron conversion layer in proportional counters.

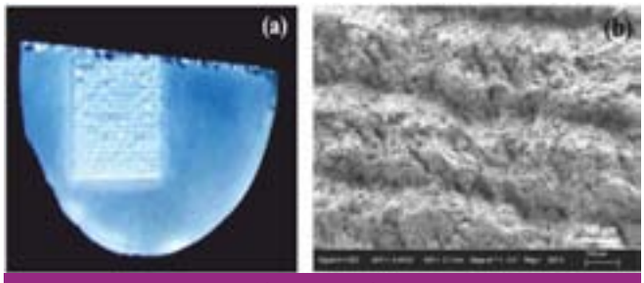


Boron Carbide films on stainless steel discs & Al for neutron detection in DHRUVA

It can be used to fabricate diode detectors as well. A method has been developed for depositing boron carbide films by Radio Frequency Plasma Enhanced Chemical Vapour Deposition (RF-PECVD) technique. Compositional characterization results indicated deposition of boron rich stoichiometric phases at higher self-bias, having desired film thickness and stability. Neutron transmission measurements on

the films were performed at DHRUVA and total macroscopic cross section (Σt) was calculated from the acquired data. These boron carbide films are being investigated for low sensitivity application in neutron detection in DHRUVA. The films exhibited promising results for monitoring neutron beam profile.

Research was focused on techniques which can modify surface properties of implants that encourages growth of Hydroxyl Apatite (HAP) and improve their biocompatibility. Commonly used biomaterials include Bio-Glass (BG), Titanium Vanadium Alloy (Ti6Al4V), Stainless Steel. Laser surface treatment of such bio-materials using either: (i) Nanosec Nd:YAG Laser or (ii) Femtosecond Titanium:Sapphire (Ti:S) Laser were developed. Nanosec laser treated BG samples have shown formation of porous surface microstructures with pore size varying from 50nm to 2micron. In vitro tests of these laser treated samples in Simulated Body Fluid (SBF) revealed significant improvement in formation of bioactive HAP layer in comparison to untreated samples. Femtosecond laser Treated BG samples showed 5 times faster growth of bioactive HAP layer when dipped in SBF, in comparison to untreated BG. Laser treatment enhances surface roughness and hence the effective surface area of the samples. This facilitates rapid interaction of the BG surface with body fluid leading to faster and uniform growth of HAP. Laser surface treatment can thus serve as a potential technique enabling enhanced biocompatibility, fast healing, stronger bonding with host tissues and bones thus reducing risk of rejection of bio-implants.



ns laser treated BG

To prevent formation of biofilm and bacterial infections on implants, several approaches have been undertaken to discourage the initial adhesion of bacterial cells on different implant surfaces. Laser treatment provides an alternative, particularly attractive on account of it being a clean method involving use of no chemicals, allowing treatment focused both, in time and space as well as remote handling. Laser surface treated Bioactive Glass (BG) and bio-alloys with a femtosecond laser has demonstrated antibacterial property. Bacterial rejection and prevention of bacterial adhesion was observed for both gram positive and gram negative bacteria using a novel imprint method that visualizes bacterial growth. While laser surface modification enabled enhanced bacterial rejection, biocompatibility of such treated BG towards growth of human cells remained unaffected. Studies with Staphylococcus aureus (S.Aureus), Pseudomonas Aeruginosa (P.Aeruginosa) & Escherichia Coli (E.Coli) on Femtosecond laser treated bioglass 45S5 revealed enhanced bacterial rejection.

Femtosecond laser treatment of Ti6Al4V alloy resulting in surface micro-structuring enhanced bacterial rejection by surface. Titanium-Aluminium-Vanadium alloy finds wide application as dental and orthopaedic implants as well as implantable electronic devices. Laser surface treatment resulted in formation of self aligned micro-conical surface structures that prevent bacterial adhesion on the surface

Wavelength tunable Lasing action in a 3-dimensional Photonic Crystal (PhC) synthesized using rhodamine-B (Rh-B) dye doped polystyrene colloids was successfully demonstrated. Extended tuning range was achieved using donor-acceptor dyes when both dyes were embedded in PhC. PhC based micro-cavity lasers can serve as tunable radiation source for 'lab-on-a chip' analytical applications.

Dual wavelength Random lasing at 573nm & 664nm was achieved in optimized concentrations of Rh-B and O-170 dyes dissolved in ethanol and dispersed with zinc oxide nanoparticles (50 nm). Both, Photonic Crystal based micro-cavity lasers & Random lasers can

serve as potential miniature radiation sources for 'lab-on-a-chip' kind of analytical applications.

Boosting of process Dye Lasers (DL) power was achieved in the laser facility of RIS project with efficient (89% T) and reliable delivery of recently commissioned Diode Pumped Green Lasers (DPGL) to DL amplifiers using optical fibers (L 23m) of core dia. 600µm and 0.22 NA. Gainfully, the spatial profile of beam transported through the fiber was found to be more uniform compared to DPGL output. Optical imaging of the fiber outputs and re-distribution of CVL-chains power to different DL units is in progress to derive substantially higher power of process dye lasers during forthcoming U-AVLIS campaign.

The high repetition rate (12.5 kHz) laser facility consisting of pump lasers, CVLs (16 nos.) and added DPGLs (2 nos.) and process dye lasers (DL, 10 nos.) with enhanced power were propagated inside the hot prototype plant of the project RIS and operated for round the clock operation for > 100 hrs (cumulative, in 2 batches). A high repetition rate (1-3 kHz) Type-II BBO crystal based solid-state tunable laser, single mode OPO (visible output 490-630 nm, Δν 300MHz) was also achieved for the first time. Characterization with automatic scanning of the single longitudinal mode OPO output at different wavelengths is progressing. Figure depicts setup for transport and characterization of DPGL.

Setup for transport and characterization of DPGL

Laser Applications

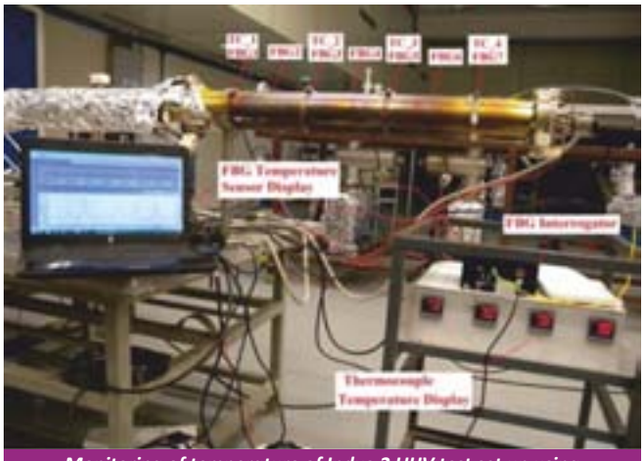
A MoU has been agreed between RRCAT and NPCIL for development and deployment of remotely operable laser systems and advanced laser cutting techniques for refurbishment of nuclear reactors. The MoU includes the development of 250 W Yb-doped CW fiber laser, four number of 5 kW average power Nd:YAG laser power supplies for high average power Nd:YAG laser systems. Different laser cutting tools and fixtures will be developed and deployed for in-situ refurbishing of Indian nuclear power plants in highly radioactive environment. As a part of MoU development of 250 W CW fiber laser are in progress.

Laser cutting of liner tube, end-fitting, bellow lip weld joint and underwater cutting of PT stubs for Q-15 and N-6 coolant channels of KAPS-2 reactor was carried out for confirmation of presence of corrosion and nodules along with its post-irradiation examination data for future operation and en masse coolant channel replacement of KAPS-2 reactor. This cutting procedure was not possible by conventional mechanical methods due to space restrictions.

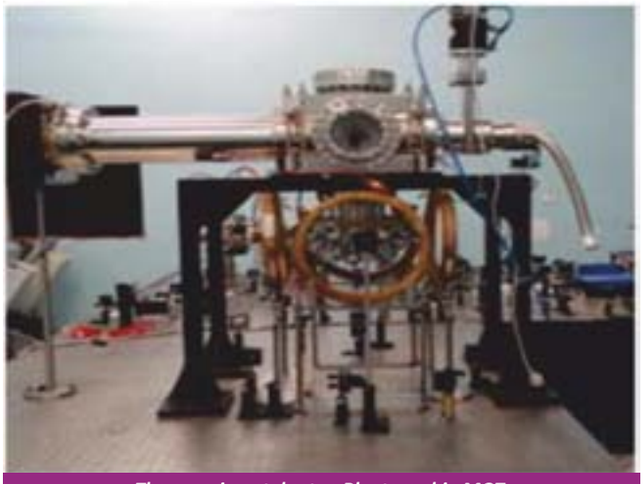
Mock-trial for laser cutting of bellow lip after removal of outboard end-fitting

Laser cutting tool for liner tube and end-fitting

A seven point Fiber Bragg Grating (FBG) based distributed temperature monitoring system is



Monitoring of temperature of Indus-2 UHV test set up using FBG based distributed temperature sensor



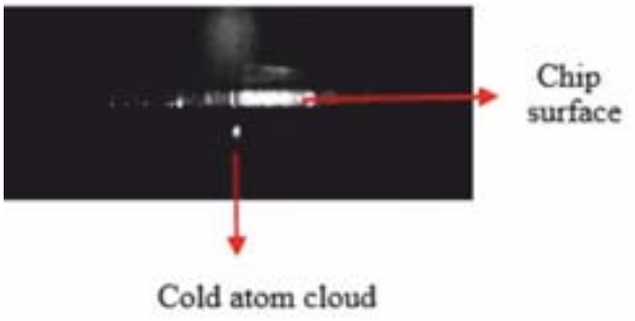
The experimental setup Rb atom-chip MOT

developed using FBG interrogator to measure the temperature with resolution of 1°C. The FBG based temperature monitoring system is advantageous in term of reliable measurement in presence of high Electromagnetic Interference (EMI), more accurate temperature measurement and faster response time as compared to conventional system.

An experiment study on ultrafast shadowgraphy of carbon plasma plume using High Harmonic Generation (HHG)source (sub-fs) for mapping of atomic / ion density has been carried out. The shadowgraphy of fast expanding plumes with ultrashort pulses results in low hydrodynamic blurring and provides sharp shadow grams. A significant intensity variation across spatial profile of the HHG spectra for the different harmonic order was observed.

A Magneto Optical Trap (MOT) on the atom-chip for alkali 85Rb atoms has been developed and made operational. An atom-chip is a plane reflecting surface of gold coated Si-substrate with a thin wire structure en-scripted on it for magnetic trap formation after flowing current through wires. This atom-chip is attached to a chip-mount assembly and placed in an octagonal MOT-chamber at a pressure of 1 x 10-8 torr with Rb-vapor in the background. The chip-mount assembly holds atom-chip and also provides electrical connections to copper strips to generate necessary magnetic field for MOT. Three laser beams in a reflection geometry on the atom-chip surface along

The chip-mount assembly



CCD camera image of the cold atom cloud near the chip surface

with appropriate DC magnetic field make the MOT for cooling and trapping of atoms near the chip surface. In this MOT, cold cloud of 85Rb atoms was observed at a distance of 3 mm vertically below the surface of the atom-chip. The CCD camera image of the cold atom cloud trapped in the atom-chip MOT is shown in the picture. The number of cold atoms in the MOT atom cloud was 2 x 10^5 at an estimated temperature of 350 µK.

A compact laser marker system with high average power of 18 W using diode-end- pumped Nd:YVO4 gain medium has been designed and developed. The complete system was successfully tested for several hours continuously in the ambient temperature between 25^{0}C and 31^{0}C, to ensure the stability of output power. This laser has been installed at Nuclear Fuel Complex, Hyderabad for serial number marking on the end-plates of the fuel bundles. The marking depth of 25 micron in Zircaloy has been achieved conforming to the NPCIL norms.

The laser marker system

SPECIAL MATERIALS

Amidoamine functionalized Multi-Walled Carbon Nanotubes (MWCNT-AA) prepared by surface organic reactions on CNTs have shown higher uptake capacity (101 mg/g at pH 6) for Hg(II) ions compared to conventional sorbents and pristine CNTs. After evaluating the adsorption behavior by batch studies, MWCNT-AA were used in a 5 cm fixed bed column for removal and desorption of Hg(II) ions from aqueous solution. The adsorbent was reused upto six adsorption-desorption cycles without significant loss of uptake.

Sintered lithium titanate Li_2TiO_3 pebbles synthesized by the indigenously developed Solid State Reaction Process (SSRP) were characterized in all respects, viz., single phase formation, density, porosity, surface area, crushing load strength, chemical purity etc.

Sintered Li_2TiO_3

It was found that the sintered Li_2TiO_3 pebbles were meeting all the desired specifications. Irradiation stability of sintered Li_2TiO_3 pebbles were studied at Dhruva reactor for three months at a neutron flux of $0.8x10^{14}$ (n/s.cm^2) whereas the designed maximum neutron flux for D-T fusion reactor is $2.36x10^{14}$ (n/s.cm^2). After irradiation, the SEM analysis did not show any deformation in size, shape and in the microstructure of the pebbles

Rotary reactor for the synthesis of solid breeder material in continuous operation

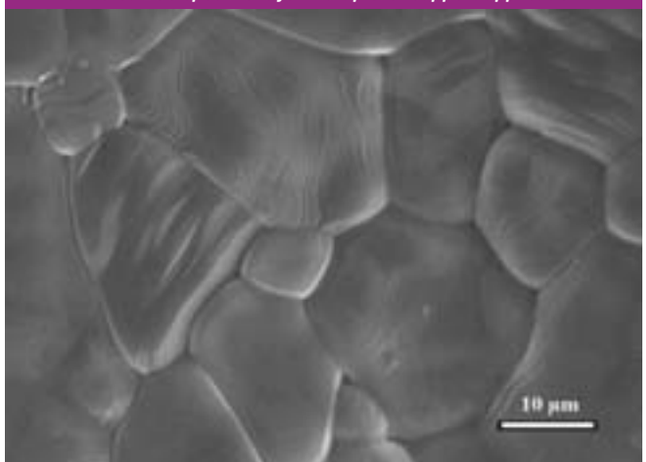
Solid breeder materials viz., lithium titanate or meta-titanate Li_2TiO_3 and lithium orthosilicate Li_4SiO_4 were synthesized and pebbles were fabricated in batch operations. A rotary reactor and an automated granulation system was designed, fabricated, tested and commissioned for the synthesis of Li_2TiO_3 in continuous operation.

Packed pebble bed of ceramic solid breeder materials viz. lithium titanate or meta-titanate Li_2TiO_3 and lithium orthosilicate Li_4SiO_4 are being considered for Test Blanket Modules (TBM) of fusion reactors. Low thermal conductivity of these materials is a key issue in the design of TBM. Experimental determination of thermal conductivity data of the pebble bed under helium is important for the blanket design. Experiments were conducted to determine effective thermal conductivity data of the pebble bed with flow of He. Effect of process parameters such as He flow rate, bed temperature, pebble size etc. on the effective thermal conductivity of the bed were studied. A correlation has been developed from the experimental data to estimate effective thermal conductivity at different particle Reynold's number and bed temperature. It was found that with the use of He, the effective thermal conductivity of bed increases by many folds.

Automated granulation system for the fabrication of pebbles of solid breeder material

High purity (>99.9%) BeO powder has been produced in the Beryllium Facility at BARC. Sintered BeO ceramic pellets of near theoretical density have been fabricated and samples have been evaluated for the functional properties. Specific shapes of high density beryllia (BeO) ceramics are required by VSSC, ISRO for heat sink application in high power output multiplexers for Indian communication satellites.

Sintered BeO specimens for multiplexer-support application

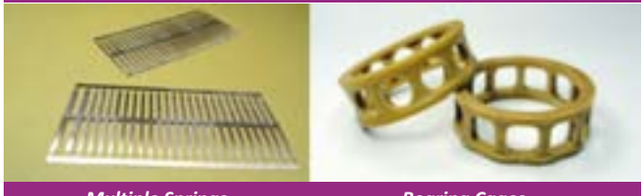


Scanning electron micrograph of sintered BeO Specimen

Multiplexer Module in Indian Communication Satellite

Beryllium Facility at Vashi has machined critical components for Indian Satellite Programme. Gimbal bar for scan assembly of Very High Resolution Radiometer (VHRR) has been made out of Aluminium–Beryllium composite material having high strength, low weight and high dimensional stability. Copper-Beryllium alloy has been precision machined to make multiple springs for use in Solar Array Drive Motors. Further, hybrid and super-precision bearings have been fabricated by precision machining of Glass fibre reinforced polymers, ISOLA, for use in Momentum Wheel Assembly.

Gimbal bar for FAST scan assembly for VHRR



Multiple Springs *Bearing Cages*

ADVANCED TECHNOLOGIES

Linear Transformer Driver (LTD) topology was adopted for the development of a compact Flash x-ray source. A modular cavity, staging 100 kV, 10 kA, 60 ns pulse has been fabricated at BARC-Visakhapatnam and undergoing final design tests. A dual polarity spark gap based LTD cavity (LTD-1) is developed with ten 'bricks'. Each brick in a cavity consists of two energy storage capacitors charged to equal and opposite voltage, a pressurized gas electrically triggered spark gap switch in a circuit enclosing magnetic cores that are common to all bricks in the cavity.

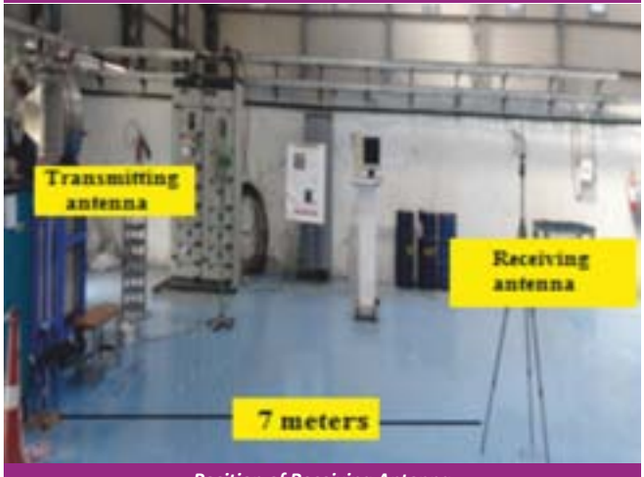
View of Spark gap switch (top electrode removed)

Side view of single LTD brick

Layout of LTD cavity with ten bricks (top plate and load removed)

All the bricks in a single cavity were synchronously fired within a jitter time of 10 ns achieving 20 kV and 26 kA output voltage and current pulses respectively having 120 ns pulse width (FWHM) across matched resistive load.

LIA-400 System



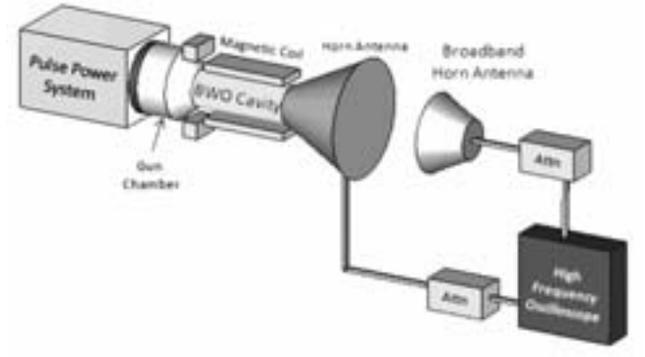
Position of Receiving Antenna

Linear Induction Accelerator (LIA) with relativistic magnetron as load is used for generation of High Power Microwave (HPM) for electromagnetic interference / susceptibility testing. The system is operated in single pulse as well as at lower frequency (8 Hz) and the center frequency of emitted radiation is 3 GHz. Measured electric field and microwave power at 7 m are 36.5 kV/cm and 55 MW respectively operating at 760 V input voltages. A PC could be permanently damaged at a distance of 10 m by the generated microwave

A high voltage Capacitor Charging Power Supply (CCPS) as per following schematic and specifications has been designed and the technology has been transferred to ECIL. It has been implemented with fast protection for dynamic load conditions and is an import substitute.

A dual power supply has been designed and developed for Backward Wave Oscillator (BWO) system. In this system The two capacitor charging power supply - one for Marx generator (50kV,20mA) and other for 25kJ capacitor bank of solenoid magnet coil system (10kV,140mA) in the system is met with single power supply. This dual output power supply has been integrated with the newly developed BWO setup with gas filled 600kV Marx generator.

Experimental Setup with magnetic field coil



Schematic of RBWO power generation Experiment

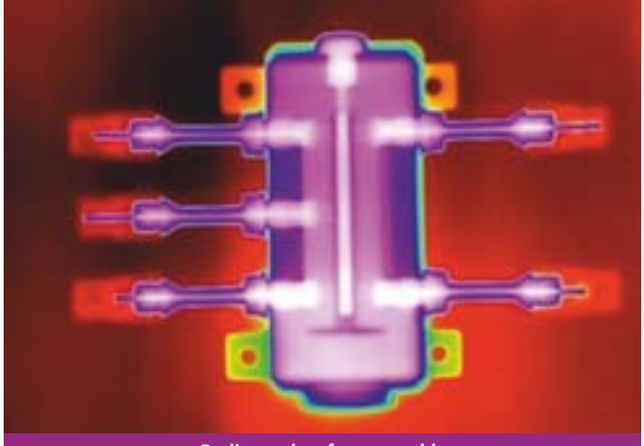
Radiated field from RBWO antenna

A high power microwave source producing pulsed 1 GW peak power in S band is designed, developed and demonstrated for 650 MW microwave power with KALI-30GW system. This system is required by Institute of Plasma Research, Gandhinagar to study microwave-plasma interaction. The system consists of HV pulsed power source; REB diode; Magnetic Field System; Resonant Reflector; CCPS and synchronizing circuit and B-Dot Loop for Microwave Measurement. A relativistic backward wave oscillator has been designed in S-band. It has been operated using KALI 30 GW pulsed power system at 600 keV beam voltage and 6.5 kA beam current to produce 1 GW peak microwave power at 3.28 GHz at a guiding magnetic field of 0.6 T. Also, TM01-mode detection has been done employing neon bulbs array in the far field region, as captured in (c) above.

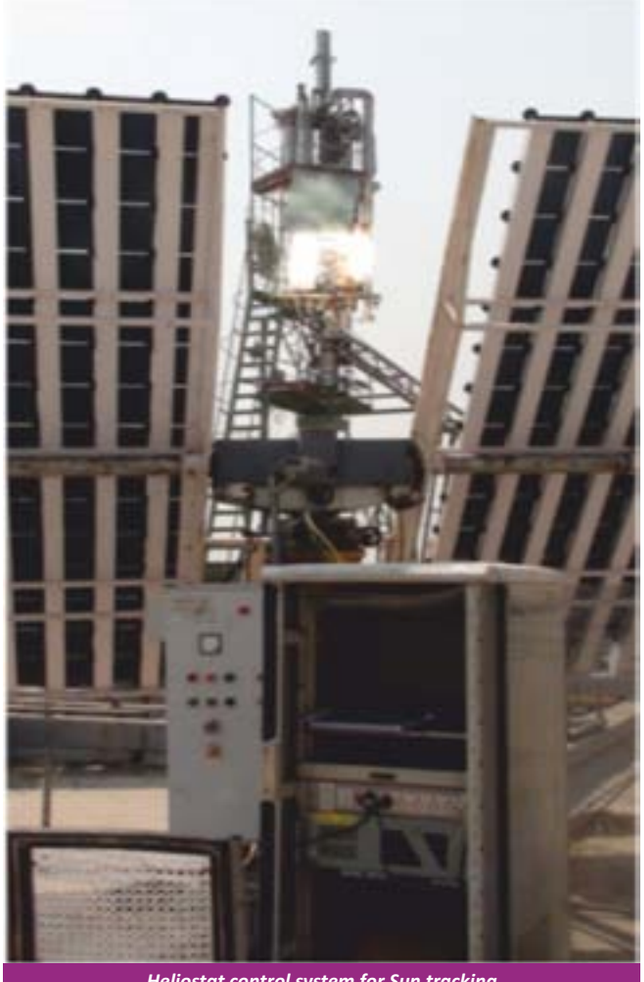
A flash X-rays system rated for 500kV, 10kA, 100ns with cable fed source is designed and developed as an import substitute for ISRO and installed in incubation centre, BARC. This system is useful for dynamic radiography of moving and deforming objects.

This sophisticated technique has many advantages such as capability to radiograph masked objects, undeterred performance in presence of plasma source near zone of interest etc. The major subsystems are Marx Generator, Trigger generator and Control console, HV power supply, HV cable, Turbo Molecular Pump, Ion pump with accessories, Computed radiography system with image processing accessories and FXR tube. This system along with computed radiography and accessories has been developed through ECIL. The system has been operated up to 350 kV with FXR load and a maximum dose of 10 mR was recorded at 1m distance.

FXR System photograph

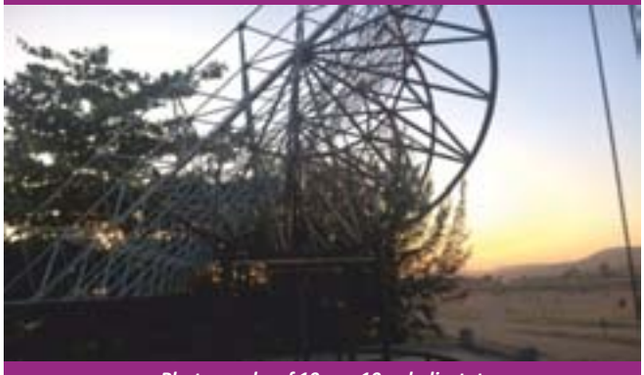


Radiography of an assembly



Heliostat control system for Sun tracking

Photograph SOlar Power TEst Facility while heliostats are focusing on receiver (SOPTEF)



Photogrpahs of 10 m x 10 m heliostat

Photogrpahs of Damaged Rotating Blades

Solar Thermal Technology based on beam up concept with various systems of 20 kW solar thermal test facility like heliostats with two axis tracking, receiver system based on coupled natural circulation (with primary molten salt and secondary steam/water) and air cooled condenser were was demonstrated in BARC. Superheated steam at 52 bar and 310^{0}C was produced in the set up. Control system for auto tracking Sunrise to Sunset was implemented to get the superheated steam. To meet the requirement of 50 kWe and 2 MWe Solar power plant, 10 m x 10 m heliostat was fabricated to demonstrate focus of mirrors, tracking, stability and strength against high wind load.

Seismic switches

6 DOF 500Kg servo hydraulic shake table

BARC has transferred the knowhow to BHEL & NTPC for detecting operating health of turbine blades in thermal power plants. The advanced system can be implemented on turbine of any type of power plants. The system successfully detects early symptoms of defective blades. Two different designs of Seismic Switches for Nuclear reactors have been developed and the technologies have been transferred to ECIL after carrying out various qualification tests.

A state of art six degrees of freedom (6 DOF) 500Kg servo hydraulic shake table meeting IEEE 344 STD has been indigenously developed and commissioned at BARC. An advance control algorithm has been deployed for faithfully tracking the desired acceleration to match the test spectra with required spectra. Various units of DAE are using this indigenous facility for seismic qualification.

Development of three mass spectrometers and their deployment at user sites were completed. Development of a new Water-Hydrogen equilibrium system for D/H isotope analysis of water samples is in

Thermal Ionisation MS for TRP

Ion Mobility Spectrometer

He MS-LD

Star cell Sputter Ion Pump

the final stage. The technology of He MS Leak Detector was successfully demonstrated and is ready for transfer to industry. Incubation MoU for the development of Residual Gas Analyser was signed with L&T. The other mass spectroscopy facilities viz., TOF-SIMS and ESI-TOFMS have been upgraded for regular sample analysis. Ion Mobility Spectrometer for toxic chemical detection is in the final stages of development. Several vacuum generation and measuring equipments have been developed.

Neutron supermirrors are an important class of advanced neutron devices that are used to transport neutron beams over long distances.

The device is based on highly uniform thin film multilayer structures of several layers (500 layers) coated over a substrate with sub nanometer accuracy. A facility for the design and fabrication of neutron super mirrors has been developed indigenously. The facility is a 9 meter long DC/RF indigenously developed magnetron sputtering system which can deposit thin films of three different materials over 1500 mm long substrates.

Using this system, several neutron supermirror polarizers consisting of more than five hundred forty alternate graded thick layers (per side) of Co and Ti layers have been deposited on both sides of 200 µm thick glass substrates. Neutron Reflectivity plot of one such neutron supermirror measured at the polarized neutron reflectivity beamline at Dhruva reactor is shown in the photograph.

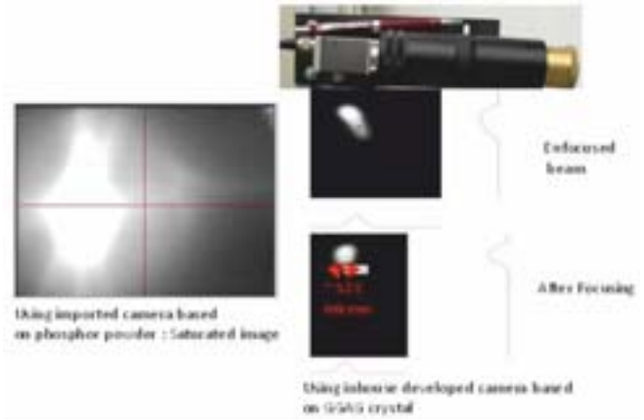
Photograph of neutron supermirror development facility Inset: Ti Plasma glow)

A neutron imaging beamline has been installed and commissioned at HS3018 port, Dhruva, for material science studies. This beamline consists of an advanced collimator (put inside the reactor beam port), shielded experimental hutch with a motorized shielded door made of borated polythene and lead blocks, imaging detector. This beamline has been designed in such a way that neutron radiography, tomography, phase contrast imaging studies can be performed.

Neutron imaging beamline

Thermoelectric figure-of-merit (ZT) of 1.81 (at 1100K) in p-type SiGe alloys was achieved by incorporating metallic yttrium silicide (YSi2) nano-inclusions within SiGe matrix(34% higher as compared to earlier best reported ZT value) (Fig. 17). This facilitates reduction in the grain size, and causes a strong suppression of thermal conductivity without affecting power factor, resulting in a dramatic enhancement of ZT. Additionally, SiGe-YSi2 nano-composites lead to enhancement in mechanical hardness as well as compatibility factor which are useful characteristics for practical applications.

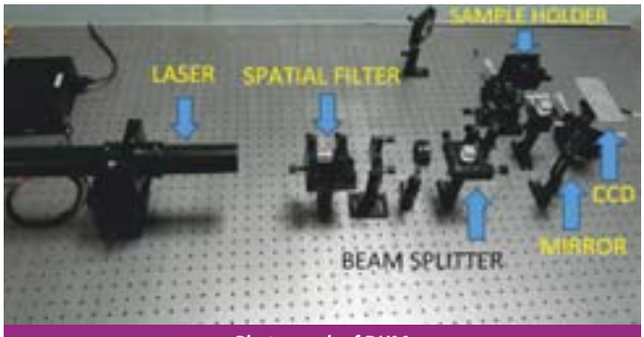
Different types of devices based on scintillator crystals have been developed such as GGAG:Ge crystal based monitor for spatial profiles of x-ray beams (500 µm diameter) at INDUS II; Hand-held, portable γ-spectrometer for environmental monitoring and for recording X-ray micro-radiographs of small specimen and for recording the temporal profiles (down to 20ns) of flash x-ray sources.



X-ray beam profiling at Synchrotron

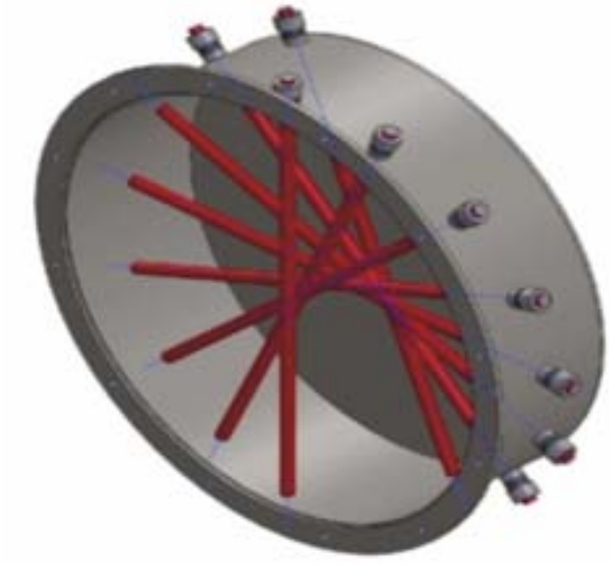
Scintillator crystal based device

A Digital Holographic Microscope (DHM) system has been developed for imaging of phase objects such as living cells which generally have only refractive index contrasts amongst their structures. The system offers quantitative phase information unlike phase contrast microscopes which give only qualitative information and can also be used in 3-D profiling of cells. The DHM system has been assembled using Mach-Zehnder interferometric configuration and Michelson Configuration with spatially filtered He-Ne Laser beam for transmission and reflection modes.



Photograph of DHM

Interferogram of the sample is recorded on a Charge Coupled Device (CCD) optical detector and is processed by Fourier transforming to get the spatial phase contrast image. Fourier transform software for the processing including aberration correction has been developed indigenously using Matlab. The system is calibrated using Height Calibration Standard HS-500MG (used in Atomic Force Microscopes).



3D model of multidimensional detector

A notable improvement in the Photon-to-current Conversion Efficiency (PCE) (5.2%) is obtained for Dye Sensitized Solar Cells (DSSCs) prepared by controlling the quality of TiO_2 layer, which also is attributed to the facile transport as well as proper position of Fermi level without compromising optical and morphological properties.

Mechanical design & Fabrication activities were carried out for various on-going projects like drift tube (DTL) in LINAC, Small Angle Neutron Scattering (SANS),

4-π Gamma Clover Detector Array

Solid target assembly

RF Loads and wave guides for Klystron, 4-π Gamma Clover Detector Array for Dhruva beamline and solid target assembly for RMC etc .

A multiple-reflection white type gas absorption cell (physical length 1.5m) having 60 meter optical path length was indigenously designed, fabricated and installed for infrared spectroscopic detection of gases at trace level using Fourier Transform Infrared Spectrometer (FTIR). The spectra of weakly absorbing molecular hot band of an environmentally important Freon CH_2F_2 gas recorded using the setup is shown in the figure.

Multiple reflection gas absorption cell with FTIR setup

High resolution seismic data recorder has been developed which can be interfaced with broadband seismometer and can record large dynamic range seismic signals with high accuracy of 1 msec. The data acquisition is synchronised with GPS giving benefit of data stamping to a global time standard. This

High Resolution Seismic Data Recorder

PIG with speed control mechanism

development will provide as import substitute. BARC has developed various sizes of Instrumented Pipeline Inspection Gauges (PIG) for buried oil pipelines for Indian Oil Corporation Limited. A 24" Instrumented PIG with speed control mechanism was designed fabricated and integrated for an effective and efficient inspection. The functionality of the mechanism has been validated through extensive test trials in wet test loop.

To ensure cyber security of Instrumentation and Control systems of Nuclear Power Plants, BARC has developed an indigenous device called “ANU NISHTA”

ANU NISHTA Hardware Reference Monitor Board

SBT on Ship Motion Simulator

having the capability to secure the operating system and all application software installed in computer servers of I&C networks. BARC and ECIL have developed an indigenous Ship Borne antenna Terminal (SBT) to support ISRO missions for tracking of re-entry modules and launch vehicles of ISRO's future manned space missions. SBT is a multirole three axis Tracking Telemetry and Tele-Command (TTC) terminal which is ship worthy and can be deployed on a ship deck.

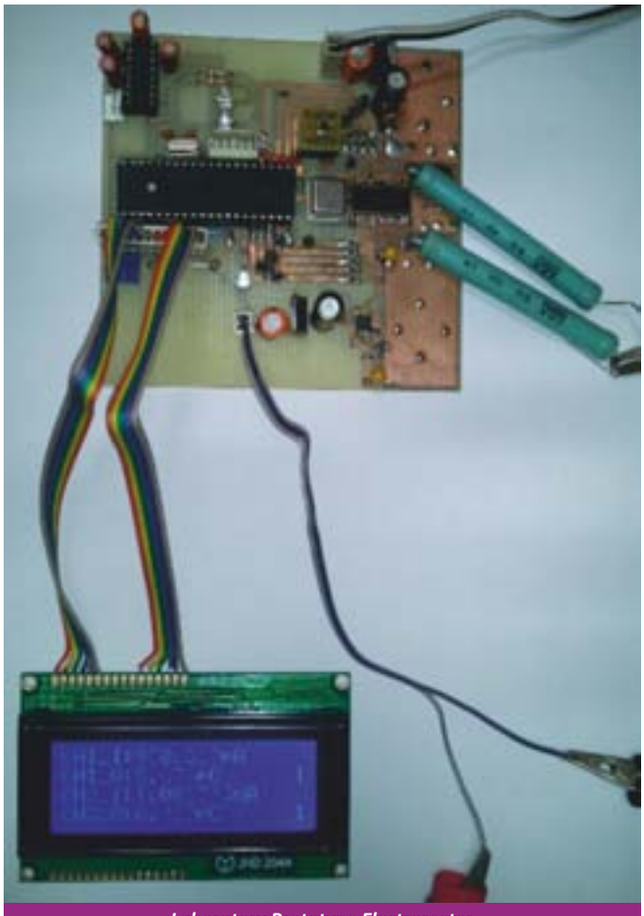
Induction Heating Inverter

An indigenously developed DNA Microarrayer

Induction heating inverters required for five-zone induction furnace for nuclear waste immobilization through vitrification process has been developed. Electrical power to each zone is supplied by individual 50kW, 2-3 kHz Induction Heating Inverter. Ten units have been delivered for deployment.

A Low-cost DNA microarrayer, based on precision robotic axis was developed and used for printing microarrays that contained oligonucleotide probes for detecting mutations responsible for Wilson's Disease (WD). The status of 62 mutations could be evaluated by a single array. Development of microarrays for detecting mutations associated with lung-cancer are in progress.

A dual channel Electrometer based on DDC112 has been developed and tested in the laboratory at VECC. It is capable of measuring current from 1pA to 460nAwith 1% FSR accuracy using the internal capacitor of DDC112. The system is capable of measuring 1pA to 1.7µA (approx.) current in continuous mode with the use of external capacitor option available in the DDC112. The system displays the measured current on a 20x4 LCD along with the average charge flow rate of both the channels. The system is auto calibrated using internal charge injection mechanism of DDC112 which injects and measures a fixed amount of charge 13pC. Auto ranging facility has also been implemented in the system. A GUI has been developed using visual basic 6.0



Laboratory Prototype Electrometer

to provide remote user interface with the system. The user can send commands to the system through RS232 interface and receive the data from the system through the GUI. Continuous measurement and data logging is possible maximum 1.8K sample per second. Data transfer rate to through RS232 is however 11.520Kbps.

Special Programmes

For high purity silicon technology development, a lab scale Chemical Vapour Deposition (CVD) reactor has been installed, commissioned & tested to establish the technology and operating parameters for bulk production of high purity silicon from TCS & H_2 as feed materials. The reactor is being used to study varies kinetics of the polysilicon deposition on Si slim rods.

Alumina base column materials coated with Iron and Chromium has been developed and compared with the existing commercial Alumina column for the

CVD Reactor at BARC

As-grown polysilicon ingot

gas chromatography. Experiments are carried out at cryogenic condition to compare the resolution, efficiency and retention time. Column materials were characterized by using XRD, SEM and BET techniques. The Hydrogen adsorption and desorption isotherm of the column materials have also been determined. It has shown very good performance and potential for long term application in GC.

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, 169 batches of radiochemical of activity 2940 Ci (109 TBq) consisting of radioisotopes ^{99}Mo, ^{131}I , ^{177}Lu , ^{153}Sm, ^{32}P, ^{125}I and ^{51}Cr were processed and supplied to BRIT for the formulation of radiopharmaceuticals for supply to users. 676 numbers of laboratory reference sources and 178 numbers of custom-made special sources were fabricated and supplied to various users through BRIT on commercial basis. 104 numbers of ^{125}I-brachytherapy sources were prepared and supplied to Sankara Nethralaya, Chennai and Sriramakrishna Hospital, Coimbatore through BRIT for ocular brachytherapy applications. 145 numbers of ^{125}I-brachytherapy sources were fabricated and supplied to P.D. Hinduja Hospital, Mumbai through BRIT for prostate brachytherapy applications.

At RAPPKOFF, Kota, total activity of Co-60 which was processed during the year was about 63.52PBq (1717 KCi). Safe handling, transportation of adjuster rods from various reactors were transported to RAPPKOFF, Kota for processing of Cobalt-60 and subsequently transported for fabrication of sources at Mumbai and the necessary documentation of the records were performed.

Sealed source fabrication using tig Welding inside hot cell

Cobalt sub-assemblies in storage pool

^{60}Co Teletherapy sources (CTS) are prepared using indigenous pellets recovered after cutting 09 pellet capsules. This is the first time; we have successfully fabricated more than 200 RAM CTS using indigenous ^{60}Co pellets. Machine and procedure for cutting of pellet capsules, recovery of pellets and filling of pellets in inner CTS containers is developed at RAPPCOF, Kota and duly endorsed by various regulatory committees of AERB.

AGRICULTURE

Crop Improvement

Radiation-induced mutation in plant breeding was employed to produce two new mustard seed varieties (TM108-1 and TM2014). Field trials at Jodhpur revealed TM108-1 to have higher (16-22%) average seed yield over the national check varieties (Kranti, Pusa Bold and Shatabdi). It has been pre-released in 2016, and its release proposal is being placed to the Research Review Committee on obtaining some additional field trial data. Average seed yield of TM2014 is 10.4% and 15.7% higher over Kranti and Pusa Bold respectively. Its release proposal will be placed to State Variety Release committee.

Non-lodging of TRR-1

Larger penicle in TRR-1

An advanced variety (TRR-1) of the aromatic rice was developed through γ ray-induced mutation breeding. It possesses a host of better attributes such as higher yield (51 Qtl/ha), larger penicle length (25 cm), early maturity (145 days) compared to the native local variety. Its semi-dwarf nature prevents lodging of the plants and loss of rice and better aroma is likely to popularize amongst people.

FOOD PROCESSING

Ionizing radiation induced mutation breeding is an efficient tool for increasing the genetic variability for obtaining desired traits in crop like disease resistance, standing capacity in unseasonal rains, increase in productivity, drought resistance etc. Electron beam irradiation of rice and wheat seeds was done at RRCAT, using dual scattering system for obtaining the necessary low dose irradiation for BARC, Punjab Agricultural University, Ludhiana and Indira Gandhi Krishi Vishwavidhyalaya, Raipur. Electron beam facility based

Electron beam irradiation of rice and wheat seeds

on 10 MeV linac operating at RRCAT and delivering pulsed beam was used for the irradiation of these seeds.

A processes for increasing shelf-lives and reduce post-harvest losses of processed mango, banana, papaya, pineapple have been developed at BARC, by reducing their water contents using radiation technology. This prevented bacterial growth and spoilage of the products, which could be stored up to 6 months at ambient temperature, whereas the unprocessed freshly cut samples were spoiled within 2 days. The processing did not reduce the nutritionally adequacy and organoleptic acceptability of the fruits, and the product may be promoted for export.

BARC-processed fruits after 60 days of storage at room temperature

An indigenous technology for extending the shelf-life of litchi has been developed using GRAS (Generally Recognized As Safe) chemicals. A litchi

Litchi preserving facility

BARC-processed litchi even after 60 days

processing facility with 1 ton/h capacity is being set-up at the Indian Council of Agriculture Research-National Research Centre on Litchi (ICAR-NRCL), Mushahari, Muzaffarpur, Bihar for the benefit of the litchi producing farmers.

Xanthan gum is extensively used as a thickener, stabilizer, emulsifier and rheology modifier in foods, cosmetics, oils, and pharmaceuticals. A cost-effective process for its production has been developed using a laboratory isolate of Xanthomonas campestris. This is the first Indian technology for a high-quality of xanthan, and should benefit indigenous industries immensely for supplying to the local and international markets.

High-quality xanthan

BARC-processed SBFs after 8 months

Availability of safe, nutritional, tasty and ambient storable meal is essential during natural calamities as well as for personnel engaged in national duties under adverse conditions. To address these issues, a process and recipe for ready-to-eat “Stuffed Backed Food (SBF) has been developed using radiation technology. The SBF with a room temperature shelf-life of up to 8 months is suitable for defense personal, school lunch program, astronauts as well as general consumers.

A bio-degradable oxocatalyzed polyolefin food packaging film was developed in collaboration with

Preparation of food packaging films

Institute of Chemical Technology, Mumbai. On disposal of these films in the open landfills, in presence of humidity and sunlight, the catalyst develops persistent oxidative radicals degrading the polymeric chains and disposing the polymer waste completely within 6-8 months without release of any toxic gases or any residue. The films developed using electron beam/γ irradiation has improved mechanical and barrier properties. It is nontoxic, non-hazardous and safe when in long-term contact with food.

Radiation Procession Services

Radiation Processing Plant (RPP), Vashi

The Radiation Processing Plant, Vashi has provided gamma radiation processing services for Spices, Ayurvedic raw material, healthcare products and pet feed etc. to 277 customers from all over the country. Source strength of the plant was increased up to 700 kCi so as to increase the throughput of the plant. Eightteen new customers for Spice, Ayurvedic raw material and pet feed were registered with the facility during last 12 months.

During the current financial year, uptil December 2016, 3985 MT of spices and other products were processed. During next four months, facility is expected to process approximately 1200 MT of various products.

Survellience audits for ISO-22000:2005 (Food Safety Management Systems) and ISO 9001:2008 were carried out by NABL accreditation of dosimetry laboratory at RPP, Vashi Complex and was found to be in full compliance.

Additional revenue was obtained from GRPS related products and services were towards the supply of 1.7 Lakhs of ceric-cerous dosimeters to various gamma irradiators in the country for absorbed dose measurement.

As a support for R&D activities, the materials/equipments that were irradiated at various doses to study the effect of radiation so as to develop radiation resistant materials included Gamma irradiation of Stator coils from M/s Crompton Greaves Ltd. for 150 kGy to develop radiation resistant stator winding for motors and Gamma irradiation of various sizes of valves and cable samples from various suppliers of NPCIL was carried out for radiation test qualification.

The quality assurance activities at RPP includes the Export of 2500 Nos. of Ceric-Cerous dosimeters to Atomic Energy Regulatory Board, Srilanka. One Lakh Ceric-Cerous dosimeters were supplied to various private irradiators for low, medium and high absorbed dose measurement in radiation processed medical and food products; Radiation Processing Plant recommissioning dosimetry was carried out in seven plants in the country for low, medium and high dose application. Dosimetry for mango irradiation was carried out at M/s Innova Agri Bio Park, Bangalore for approval of the facility by USFDA – APHIS for quarantine purpose and Dose rate certification of eight Blood Irradiators based on Cesium-137 supplied to various cancer hospitals and four gamma chambers supplied to research universities was carried out.

New MoU for Radiation Processing Plants in Private Sector

A MoU was signed with Bhamji Food Irradiators Pvt. Ltd. for a setting up of Gamma Radiation Processing Plant for disinfestations, shelf-life extension of food products and sterilization applications of healthcare products at Kundh, Chikli Taluka, Navsari District, Gujarat. MoU was signed with M/s KGS Agrotech Pvt. Ltd. for a setting up of Radiation Processing Plant for disinfestations of food products and sterilization of healthcare products at Saiwad, Shahpura Tehsil, Jaipur, Rajasthan. MoU was signed with M/s Gaur Chemtech, for a setting up of Radiation Processing Plant at Rohini, Delhi for radiation processing of food and medical products.

Consultancy was obtained for commissioning Radiation Processing Plant for processing food and medical products by M/s Pinnacle Therapeutics Pvt. Ltd. at Vadodra, Gujarat.

HEALTH

Radioisotope based formulations, techniques and equipment are widely used in the diagnosis and treatment of various diseases. BARC, BRIT, RRCAT and VECC are major contributors in this field.

Radioisotopes are produced, processed and technologies are developed at Trombay for varied applications in the medical field. BARC's Radiation Medicine Centre, a premier centre in the field of radio-diagnosis and radiotherapy in Mumbai, is a regional referral centre of the World Health Organization (WHO) for South East Asia.

BRIT produces and supplies radio-pharmaceuticals for diagnosis and treatment of diseases, teletherapy and brachytherapy sources, radioisotope based kits, various instruments, and radio processing services. Jonaki Laboratory at Hyderabad produces and supplies P-32 labelled nucleotides for research in biology, biotechnology and drug discovery. Jonaki also markets S-35 labelled amino acids produced by labelled compounds at Vashi.

Radioisotopes for medical applications are also manufactured at VECC. The Regional Radiation Medicine Centre in Kolkata meets the radio-diagnostic and radiotherapy requirements of the eastern region of the country.

Radiopharmaceuticals

Radiopharmaceuticals are meant for in-vivo use, mainly for diagnostic and therapeutic purposes. Since they are meant for in-vivo use as pharmaceutical grade products, compliance to Good Manufacturing Practices (GMP) is mandatory. In-vitro Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) Kits and C-14 Urea capsules are used mainly for diagnostic use. The Medical Cyclotron Facility (MCF), Parel continued the production and supply of Positron Emission Tomography (PET) radiopharmaceuticals, mainly 18F-FDG and to a lesser extent, 18F-Sodium Fluoride to meet the requirements of several hospitals in Mumbai. 18F-Flurothymidine (FLT), 18F-Fluoromisoisonidazole (FMISO) is also produced, but the requirements for these are limited.

BRIT continued the regular, uninterrupted, production and supplied the radiopharmaceuticals, to all over India. However, due to limited availability of I-131 radioisotope from BARC for prolonged periods during the year 2016, the production and supply of I-131 labelled radiopharmaceuticals were less compared to previous year.

Approximately 700 Ci of Na131I and over 22500 consignments were processed, formulated and supplied to various nuclear medicine hospitals all over India in the form of solution and capsules. These are used for diagnosis and therapy of thyroid disorders and for the treatment of thyroid cancer.

New Ready-to-use radiopharmaceutical product, '177Lu-DOTATATE injection' was developed, successfully tested on patients at RMC, Parel during the reported period. This is now awaiting the approval from Radiopharmaceutical Committee (RPC), DAE.

77Lu-DOTATATE Automated Synthesis module

Internal layout of Lead shielded hot cell for manufacturing Therapeutic doses of 177Lu-DOTA-TATE

Clinical study (18 h Post Therapy scan) with BRIT 177Lu-DOTA-TATE Performed at RMC, BARC

Facility with in-cell gadgets and synthesis module developed, in an existing lead shielded production plant, for regular production of "177-Lu-DOTATATE Injection".

About 3000 consignments containing nearly 50 Ci of ready-to-use radiopharmaceuticals of 131I-mIBG, 32P, 153Sm in the sterile injectable form and 177Lu as radiochemical were supplied to various nuclear medicine hospitals all over India. 131I-mIBG (both, diagnostic and therapeutic) is used for neuroendocrine cancers, while 153Sm-EDTMP and 177Lu-EDTMP Injections are used for bone pain palliation.

New in-cell roof hanging and remote operated, de-capping tool, for radioactive liquid vials was developed and installed in production plants.

Total number of therapeutic treatments based on supplies is estimated to be more than 30000 patients. This includes therapeutic doses of Na131I for the treatment of thyroid cancer and hyperthyroidism.

During the year, more than 80000 cold kits for formulation of 99mTc radiopharmaceuticals (15 Products; BRIT Code-TCK) is processed, lyophilized and supplied to various nuclear medicine hospitals all over India.

New product, '99mTc-cold kit for the preparation of 99mTc-Macro Aggregated Albumin (MAA) injection' was developed by BRIT during the reported period. This will be useful for lung perfusion imaging and has been approved by Radiopharmaceutical Committee (RPC), DAE. Currently, this product is being imported by the hospitals. Further, RPC Committee has approved the extension of shelf-life (expiry date) of TCK cold kit preparation of 99mTc-Sulphur Colloid injection (Code – TCK-5) from existing 100 days to six months and TCK cold kits of 99mTc-DTPA, 99mTc-Phytate & 99mTc-MIBI from existing 6 months to 1 year.

Re-certification and accreditation for cGMP-Good Manufacturing Practices-Pharma Products' (in accordance with WHO requirements) by United Registrar of Systems Certification of Manufacturing Facility for "Kits for the Preparation of Technetium Cold Kits (TCK)" was completed.

Nearly 150 Ci of 99Mo, in form of Sodium Molybdate solution, for solvent extraction generator, has been supplied. Approximately 455 Ci of 99Mo in the form of Sodium Molybdate is processed and supplied in form of 99Mo-99mTc Gel Generators and alumina column generator (COLTECH).

More than 2,30,165 In-vivo diagnostic investigations are estimated to have been carried out this year with varied diagnostic radiopharmaceuticals, the major one being, 99mTc based cold kits and 99Mo-99mTc generator systems.

The Medical Cyclotron Facility (MCF), Parel, located in the basement of Tata Memorial Annexe Building, continued supplying about 475 consignments of PET radiopharmaceuticals such as 18F- FDG, 18F-FLT,

18F-NaF and 18F- FMISO to various hospitals in and around Mumbai accounting for nearly 263 Ci of radioactivity during the year 2016-17 upto December 2016. Approx. 15000 patients benefitted with PET investigations in the reported year.

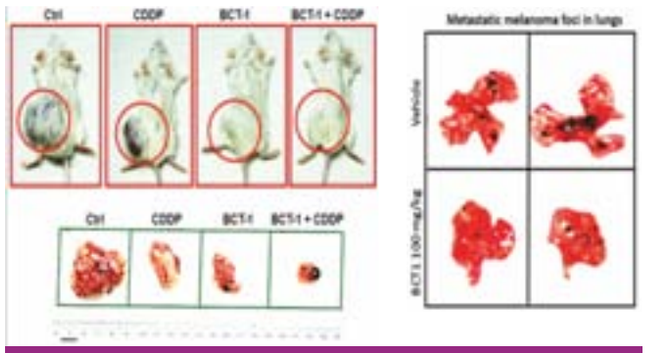
18F-Fluoro ethyl-L- tyrosine (18F-FET) was cleared by Radiopharmaceutical Committee (RPC) for regular supply. 18F-FET PET is superior to 18F-FDG for biopsy guidance and treatment planning of cerebral gliomas. The uptake of 18F-FDG is associated with prognosis, but the predictive value is limited and a histological evaluation of tumor tissue remains necessary. Therefore, amino acids like 18F-FET are the preferred PET tracers for the clinical management of cerebral gliomas.

Indigenously developed 68Ge / 68Ga generator based on nano-sorbent was approved by Radiopharmaceutical Committee (RPC) of DAE for manufacture and supply. DAE-RPC approval obtained for manufacture and supply of indigenously developed 131I-Lipiodol and kit based formulation of 188Re-HEDP injection for radionuclide therapy of hepatocellular carcinoma. Protocols for formulation of clinical doses of four different 68Ga-radiopharmaceuticals without using expensive radiosynthesis module has been developed and clinically demonstrated. Optimized protocol of bulk-scale formulation of ready-to use therapeutic doses of 177Lu-PSMA-617 has been developed and clinically demonstrated. Optimized protocol for formulation of 90Y-DOTA-TATE at hospital radiopharmacy was developed and utilized for the first time in India. Dosimetry studies with 131I-rituximab in patients with Non-Hodgkin's Lymphoma (NHL) were conducted in collaboration with Tata Memorial Centre and Radiation Medicine Centre.

Clinical evaluation studies for Positron Emitting Tomography (PET) imaging of tumors of neuroendocrine origin and prostate origin using 68Ga DOTATOC/NOC and 68Ga DKFZ PSMA11 prepared using in-house developed freeze dried kits.

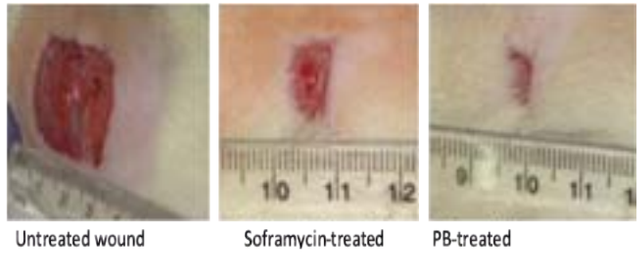
A non-toxic herbal radioprotector (BRP), developed at the centre provided 80-82% survival to mice against whole body γ-irradiation (8.5 Gy). BRP was effective even when administered after 4 hour following radiation exposure and also prevented γ-irradiation (up to 12 Gy) - induced damage to the reproductive system in mice, helping them to produce normal pups. An incubation technology for an oral BRP formulation is being transferred to a private Indian entrepreneur for its clinical trials as a prophylactic as well as a therapeutic radioprotector.

A chemotherapeutic drug (BCT-1) which reduces cisplatin (CDDP) toxicity in normal tissues while enhancing the chemotherapeutic effect of CDDP against melanoma as well as neuroblastoma has been established in preclinical and xenograft mice models respectively. BCT-1 could also inhibit the metastasis and colony formation of melanoma in lung tissues in preclinical mouse model.



BCT-1 as a potential CDDP adjuvant and an antimetastatic agent

A natural wound-healing formulation (PB) has been developed using an Indian herb. Topical application of the formulation provided faster and better healing of external wounds than the commercially available, Soframycin® cream.



Untreated wound | Soframycin-treated | PB-treated

Superior wound healing by PB

A biopesticide based on local isolate of Bacillus sphaericus was developed and its spore-crystal mixture was mass produced. Pilot field efficacy of a spore formulation in preventing Culex mosquito larvae breeding was demonstrated in collaboration with Mumbai and Chennai municipal corporations.

Radiation technology equipment

Anthropomorphic HN Dosimetry Audit Phantom

Volumetric Modulated Arc Therapy (VMAT) is an advanced form of Intensity Modulated Radiation Therapy (IMRT) used for treatment of cancers. Head & Neck (HN) region pose special dosimetry challenges due to its complex anatomic structure. A specialized anthropomorphic HN dosimetry audit phantom was designed and developed at BARC for credentialing of advanced radiotherapy techniques. The phantom body represents average human HN in shape, proportion and composition. This phantom has removable cylindrical inserts containing Planning Target Volume (PTV) and Organs at Risk (OARs) which includes spinal cord, left & right parotid and oral cavity. The PTV and OAR have provisions of holding different types of detectors mainly Thermo-Luminescent (TL) and film detector for dose verification measurement. Pilot studies carried out at radiotherapy centers equipped with VMAT facility have shown that the difference between the TLD measured dose and that obtained using radiotherapy treatment planning system based on the phantom images was within ± 3%.

A specialized anthropomorphic HN dosimetry audit phantom

Blood Irradiator

Two Blood Irradiators-2000 units with Cs-137 source have been supplied to hospitals in India. 69 numbers of sealed sources of Cs-137 with a total activity of 16474 Ci were loaded into 6 units of Blood Irradiator 2000.

Radiography Camera

Production and supply of 100 new indigenous radiography camera model ROLI-2 and servicing and inspection of 658 numbers of BRIT manufactured as well as imported ROLI cameras were the highlights during the reported period.

Gamma Chamber 5000

One unit of GC-5000 was loaded with 14000Ci of 60Co and transported to Crop Research Unit, Research Directorate Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Kolkata, upto December 2016.

Radio Diagnostic & Treatment Services

A total number of about 3800 radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits to serve about 3,87,700 in-vitro investigations were supplied to various hospitals, research centres and immunoassay laboratories throughout India.

The Regional centres at Delhi, Bengaluru, Jonaki, Hyderabad, Dibrugarh & Kolkata, continued the services of ready-to-use-radiopharmaceuticals to surrounding nuclear medicine hospitals, labelled compounds and radioanalytical certifications. Around 3,000 consignments of in-vivo and in-vitro kits were supplied to RCR's for providing extended services to nearby hospitals, research centres, or institutions at these cities.

At the Regional Centres for Radiopharmaceuticals (RCR), Kolkata, 281 Nos. of Technetium cold kits for formulation of 99mTc-radiopharmaceuticals were sold this year (between Jan. 2016 - Dec. 2016) to nuclear medicine centres at Kolkata.

The Regional centre BRIT, Dibrugarh located at Assam Medical College & Hospital is rendering RIA and IRMA diagnostic services for the benefit of patients of the entire North-Eastern region. The Radiopharmaceutical products produced and supplied by BRIT, Vashi complex are extensively used by the RC, Dibrugarh for the diagnosis & investigation of various diseases. More than 7000 patients of the region avail the services from this centre.

The Regional Centre, BRIT, Bengaluru supplied 70 mCi of ready-to-use 99mTc-pertechnatate to nuclear medicine hospitals and 1081 TCK cold kits were sold through retail outlet and door delivery for the preparation of 99mTc-radiopharmaceuticals to nearby nuclear medicine centres. Gamma irradiation services were provided for 1932 blood bags to Kidwai hospital. Also, radioanalytical services for the measurement and certification of residual radioactivity in various commodities such as food items for human & animal consumption, medicine, steel and other miscellaneous items were provided. Radioanalytical Laboratory analyzed and certified 92 samples for the measurement of residual radioactivity in various commodities such as food items for human & animal consumption, medicine etc.

The Regional Centre for Radiopharmaceuticals, Delhi continued to supply clinical grade ready to use 99mTc-radiopharmaceuticals in compliance with GMP and RPC for diagnostic nuclear medicine centres in Delhi and NCR regions.

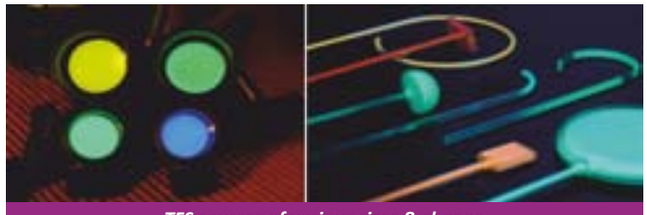
During the period, the Regional Centre of BRIT, Hyderabad (Jonaki) supplied ready-to-use 99mTcO4-(Pertechnatate) and 99mTc-Radiopharmaceuticals through their retail outlet to the nuclear medicine centres of Andhra Pradesh.

Labelled Compounds and Diagnostic Kits

During 2016-17 upto December 2016, Labelled Compounds Programme of BRIT continued the supply of more than 26000 sources of Tritium Filled Self-luminous sources of various sizes and shapes for defence establishments along with the custom synthesis & supply of a variety of 14C, 3H and 35S-labelled products.

Based on the MoU signed between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers.

The Regional Centre of BRIT, Hyderabad (Jonaki) continued to supply 32P labelled nucleotides and a few molecular biology kits and enzymes, for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research of the country. It markets 35S-labelled amino acids products produced at BRIT, Vashi Complex.



TFS sources of various sizes & shapes

Radio Analysis

Radioanalytical Laboratory (RAL) is carrying out the assay of man-made radioactivity in large number of food items, especially those meant for export. Generally, Cs-137 content is measured for certification on man-made radioactivity levels. In addition to the above, Radioanalytical Laboratory carries out the measurement and certification of residual radioactivity content in water samples, uranium content in water samples, Naturally Occurring Radioactive Materials (NORMs) in environmental samples such as coal, fly ash, soil rock phosphate, gypsum etc. and Co-60

contamination in steel. Large number of environmental samples such as soil, coal, flyash etc. were analysed during the year for the presence of 238U, 232Th, 226Ra and 40K content. Another activity taken up by Radioanalytical Laboratory is the survey & certification of surface radiation dose of steel consignments at factory premises and warehouses.

Radioanalytical Laboratory (Vashi Complex) received [IS:17025 (2005)] NABL accreditation in the field of Radiological Testing during September 2016.

During the year 2016-17, upto December 2016, RAL, Vashi alone has carried out more than 3200 tests on export/domestic commodities and 940 tests on water samples (gross alpha, gross beta, 226Ra & 228Ra). Total of three steel surveys were conducted for certification of surface radiation dose. Radioanalytical Laboratory Services both, at Vashi Complex and RCR, Bengaluru, together performed approximately 4734 analyses of food and water samples for the presence of radioactivity,

Radiation Sterilization Plant for Medical Products (ISOMED)

ISOMED facility, engaged in contract gamma radiation processing services for terminal sterilization of the medical products has processed 5385 Cubic mtrs of products.

New Projects

DAE Medical Cyclotron Project: Radiopharmaceutical Facility

Civil construction and related major work for the Medical Cyclotron Facility is in advanced stage of completion. Work on HVAC, electrical work, LCW system etc. are completed.

Indigenous HDR Brachytherapy Equipment (IHDR)

Equipment development and fabrication work is completed and 10 units are ready for supply. Radiation qualification is done by RPAD, BARC and the equipment is found to be satisfactory for all the required conditions. The machine/equipment is currently undergoing IEC qualification test for its compliance. Radioactive Ir-192 source is developed for the equipment. Treatment Planning Software (TRS) is under development.

Setting up of Fission based 99Mo 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 99Mo, utilizing LEU targets. The scope includes commissioning of set of modern hot cells equipped with manipulators, in cell equipments, radiation surveillance instrumentation and data logging system, special AC & ventilation system, waste management equipments, civil construction of building and setting up of world class quality control labs, modern security system, construction of new building at approved site in ISOMED Complex, BRIT near South Gate BARC, etc.

After the site clearance by AERB, the design documents for the building have been 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 is over and installation of new security and surveillance equipment is ongoing. The work on civil construction of laboratory building is nearing completion. The work on installation of facilities for waste management, electrical supply, water supply etc. is progressing.

The procurement of the production plant shall be on turnkey basis. During the year, the procurement vide Purchase order in favour of M/s INVAP, Argentina for design, fabrication, supply, installation and commissioning of facility, was operationalized. Major

Fission Molybdenum Project Site Development

Low level Liquid waste treatment Facility

Under floor embedment installation for Hot Cells and Hot Cell area concrete pouring

work on the construction of Facility and Plant Building is completed. Work on under floor embedment for Hot Cells is also completed. Work on building interior partitions and structures are in progress. M/s INVAP has submitted documents for Critical Design Review (CDR). CDR is being done by a committee, constituted by Director, BARC, consisting of members from both, BRIT and BARC.

Advanced Facilities for Radiopharmaceuticals Production

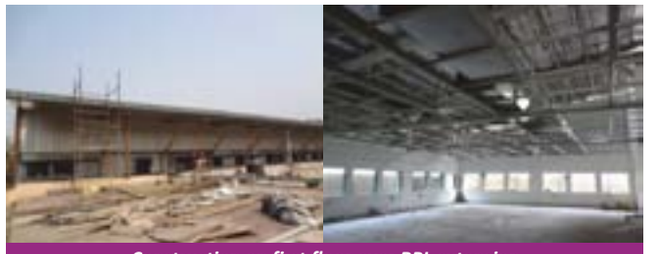
The project scope comprises of building Advanced Radiopharmaceutical Manufacturing and testing facility for new generation Radiopharmaceuticals with radioisotopes using 90Y, 177Lu, 89Sr, 131I, 32P, 153Sm. etc. Also the present production capacity of radiopharmaceuticals and services from RPL, Navi Mumbai and Jonaki Hyderabad would be enhanced under this project.

New Pharmaceuticals Services Facility area is commissioned and is in operation during the reported period. Old facility area is decommissioned. Hot cells in the Main Production Laboratory is refurbished and refitted with the new hot cells for production of new Ready-to-use Radiopharmaceutical product, 177Lu-DOTATATE injection.

Work is in progress for the construction of new sitting place for the staff and the laboratory area above RPL extension building. The work is expected to be completed by April 2017. The project envisages asset built up for overall improvement of technical capabilities of BRIT to meet the advanced needs of Nuclear Medicine. The project scope comprises of building Advanced Radiopharmaceutical Manufacturing and testing facility for new generation Radiopharmaceuticals with radioisotopes using 90Y, 177Lu, 89Sr, 131I, 32P, 153Sm. etc . Also the present production capacity of radiopharmaceuticals and services from RPL, Navi Mumbai and Jonaki Hyderabad will be enhanced under this project.

Highlights of achievement in 2016 are as below

. Construction, Electrical and HVAC work for new laboratory space at first floor over RPL extension building, is in progress (70% completed)



Construction on first floor over RPL extension building (outside view and inside view)

New exhaust system for the fume hoods in synthesis laboratory

· New exhaust system for the fume hoods in synthesis laboratory on the ground floor of RPL extension building completed and commissioned. This has capacity for future extension to laboratory areas on first floor.

Refurbished microbiology lab with interlocking double door system

· Refurbishing and augmentation of microbiology test laboratory for biological testing of radiopharmaceutical products is, commissioned with advanced features and is in regular use.

Pneumatic vial capping and de-capping tools, in 131I capsule plant

· Facility with in cell gadgets and synthesis module developed, in an existing lead shielded production plant, for regular production of “177Lu-DOTATE injection”.

· New in cell roof hanging and remote operated Vial capping and de-capping tools, for radioactive liquid vials, developed and installed in production plants.

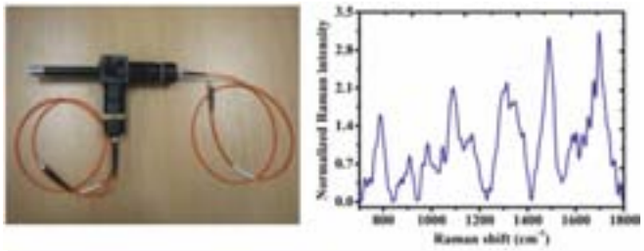
Technology Development for Radiation Technology Equipment

The civil construction for the I-125 seeds plant Facility is in advanced stage of completion at BRIT Vashi Complex. Tender has been floated for the supply of I-125 seeds manufacturing plant which is on 'Turn-key' basis.

Civil construction for the I-125 seeds plant Facility

Biomedical Applications

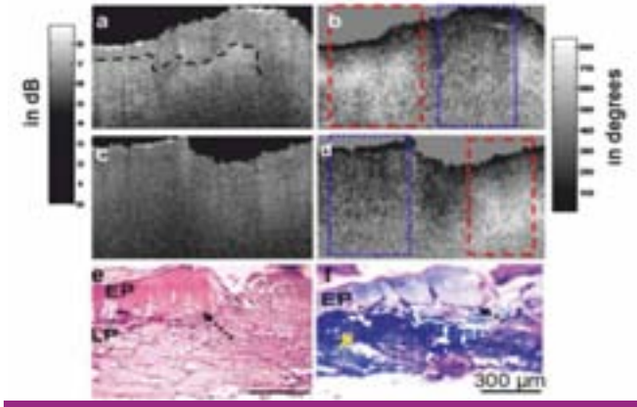
A hand-held Raman probe capable of measuring artifact-free tissue Raman spectra was designed and developed at RRCAT. The design minimizes the fiber and optics generated Raman artifacts, optimizes collection efficiency, and has resulted in highly efficient Raman probe that is capable of collecting high-quality spectral data with a few seconds of acquisition time (Fig. 49). The performance of the probe was found to be better than the two commercially available Raman probes (one of Visionex make and the other of in photonics make) in measuring



The developed hand-held Raman probe and the in-vivo Raman spectrum measured from human palm using the probe

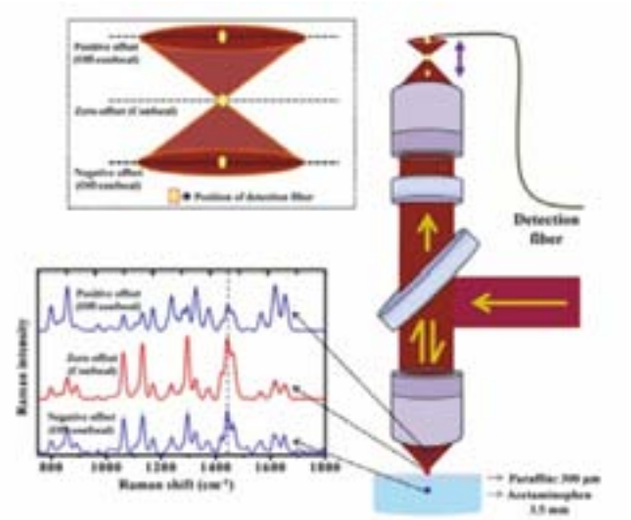
the artifact free Raman signal from biological samples. The capability of the probe for measuring artifact-free Raman spectra is evident from the quality of the measured Raman signal which is comparable to that measured open-air with a bench-top Raman system.

A clinical study was carried out at Tata Memorial Hospital (TMH), Mumbai on healthy volunteers and patients with oral cancer to evaluate the efficacy at Raman spectroscopy in oral cancer diagnosis. It was concluded that for accurate classification of oral lesions the reference normal database should exclude spectral data of tobacco using healthy subjects. An ex vivo imaging study of human oral tissue samples using the spectral domain polarization sensitive optical coherence tomography (PC-OCT) showed that the tissue birefringence derived from the OCT images provided more sensitive monitoring of the neoplastic transformation of oral mucosa.



OCT intensity (a, c) and retardation (b, d) images along the boundary of cancerous lesion. Normal and cancerous regions are marked by red dashed and blue dotted rectangles, respectively, in retardation image

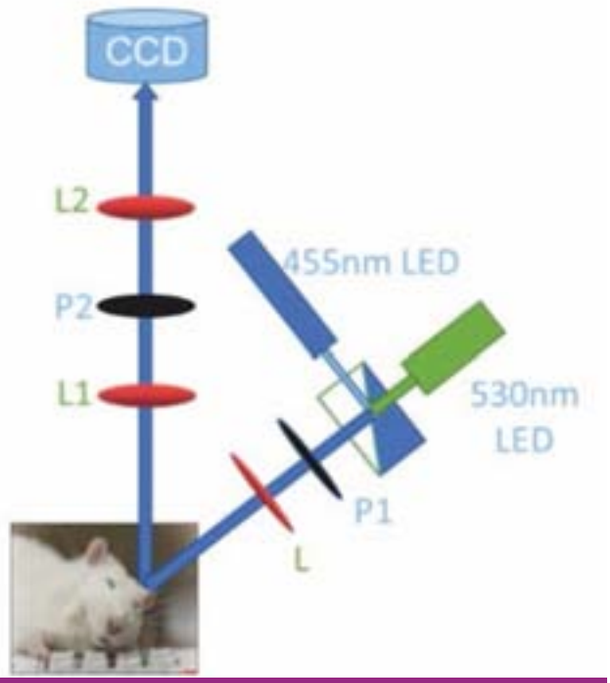
A novel technique of depth-sensitive Raman spectroscopy was developed for non- destructive sub-



Experimental setup for off-confocal Raman spectroscopy. Raman spectra measured from a non-biological phantom at confocal and off-confocal positions

surface interrogation of layered turbid samples using the concept of varying Raman collection zones while keeping the point of illumination fixed on the surface of the target sample. The system adopts the experimental configuration of a confocal Raman, but employs off-confocal Raman detection for probing depths beyond the reach of the conventional confocal Raman. It allows subsurface interrogation by moving the tip of the Raman detection fiber (acting as the pinhole aperture) from the focus of the Raman collection objective either by taking the point of detection away from the objective (positive confocal offset) or bringing it closer to the objective (negative confocal offset). The ability of the system to recover Raman spectra of the subsurface layer was demonstrated using a layered non-biological phantom and a biological tissue sample.

A setup based on orthogonal polarization spectral imaging was developed and its efficacy was demonstrated in measuring high contrast in vivo images of the vasculature network and blood flow through the micro capillaries in animal model. The system comprises a blue (450 nm) and green (530 nm) LED excitation source. The collimated excitation light is polarized horizontally using a linear polarizer before passing through a lens L which focuses it on to the sample. The light passing through the analyzer is than imaged on to a CMOS camera using the combination of lens L1 and L2.



A schematic of the orthogonal polarization spectral imaging setup for in-vivo imaging of micro-vasculature in animal model

The analyzer placed in orthogonal polarization channel helps in eliminating the specular reflection and polarization maintaining components from superficial layers. The validation and optimization of the system on animal models is under progress.

Alternative Applications of Heavy Water

Realizing the potential requirements of Oxygen-18 having application in nuclear medicine and bio-chemical research i.e. in PET scanning and Metabolic studies, HWP, Manuguru has successfully commissioned the first indigenously developed Oxygen-18 water production plant.

H2O18 Production Plant

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 Institute Council of Agricultural Research, Indian Veterinary Research Institute, Institute of Plasma Research, TIFR etc., have shown their interest in this area and HWB has supplied small quantities of heavy water to support their R&D jobs.

As part of developmental activities on non-nuclear uses of Heavy Water, methods for synthesizing deuterated NMR solvents have been developed at HWP, Baroda in laboratory scale. As part of MoU signed between HWB & BRIT, BRIT is marketing these solvents to various reputed research institutes in the country.

Cancer Diagnostics and Treatment Services

The Tata Memorial Centre (TMC) is a Grant-in-Aid institution of the Department of Atomic Energy, Government of India. It functions through its three Centers, viz., Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC), and Centre for Cancer Epidemiology (CCE). The mandate of the Centre is "Service, Research & Education in Cancer". The hospital registers approximately 70,000 new patients annually, from within and neighbouring countries for either treatment or special investigations. The footfall of patients exceeds 1500 every day for ambulatory care. The treatment to these patients is facilitated through eleven Disease Management Groups (DMG).

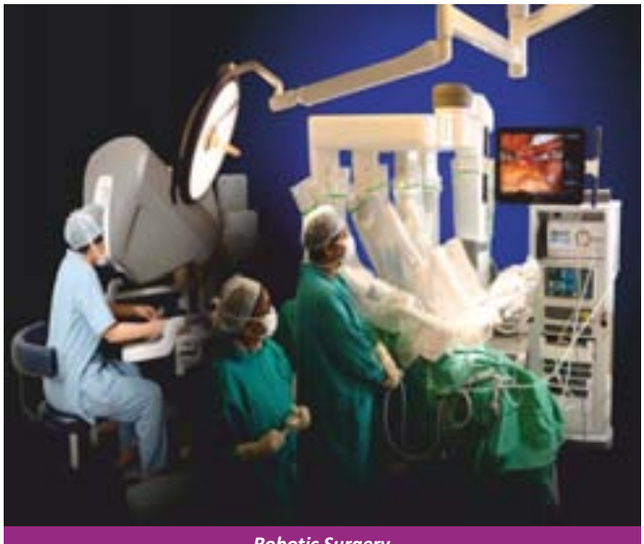
TMC prides itself in providing multidisciplinary treatment to all cancer patients irrespective of their

socioeconomic strata. This comprehensive service straddles Prevention, Early Detection, Treatment using State of the art equipment, Rehabilitation including Palliation and End of Life Care.

Cancer treatment were administered based on established protocols to reduce variance and promote quality for improved outcomes. A concerted effort has been made through the National Cancer Grid to educate caregivers in all participating centres to adopt protocol based treatment. A platform for meaningful discussion and multicentre research across the participating centres and their communities was also provided.

Adaptation of Information Technology has empowered patients and care givers with high availability of health care information. Prompt availability of information has facilitated early institution of treatment and better outcomes. As part of the National Digitization Drive, Smart Card technology has been implemented for cashless transactions and the same has been integrated with both electronic medical record and electronic financial record for enforcing the business rules of the institution.

Surgery remained the bedrock of treatment for solid tumours. Approximately, 6500 major surgical procedures including minimal invasive and Robotic Surgeries were performed during the year.



Robotic Surgery

Proton Beam Therapy

The full-fledged Medical Oncology & Radiation Oncology Departments treated patients solely or in conjunction with their Surgery counterparts. Special facilities for Haematological Malignancies including a Bone Marrow Transplantation Unit; State of the Art facilities for Intensity Modulated Radio Therapy (IMRT) and Image Guided Radio Therapy (IGRT) were available. The establishment of a Proton Beam Therapy at ACTREC will enhance the capability to give high precision radiotherapy especially in children.

Laboratory physicians complemented their Clinical counterparts by providing their inputs and took part in the decision process. The laboratory services are accredited and the Imaging Departments use the State Art of Technology to support these decision processes. During the the current year 45 lakh investigations have been performed using state of art equipment. Some of the services like Molecular diagnostics which needed a high level of equipment and unique expertise were used by patients of other hospitals.

TMH is acutely aware of the financial hardships of the patients in families in completing the course of treatment. The treatment costs for patients from the socioeconomic strata are highly subsidized at TMH with no professional charges levied. TMH walked the extra mile by providing seed money for deserving patients in order to institute treatment promptly which in turn has a positive impact on outcomes. Philanthropic Institutions partnered with TMH in alleviating the financial hardships to patients by way of donations to patient care or equipment.

Rehabilitation, Palliation and End of Life care are an intrinsic part of treatment to ensure quality of life. TMH has provided the leadership by having full-fledged departments providing service to patients and formal education to care givers.

60Co Teletherapy Sources for Cancer Hospitals

Nine 60Co-Teletherapy Sources (CTS) with total activity of about 118 kCi in the range of 164 and 226 RMM were supplied to various cancer hospitals in India by BRIT. Out of the nine CTS sources, one source is exported to Tanzania and another source is kept ready for export to Kenya. Decayed sources were unloaded from the teletherapy units and stored for fabrication of irradiator source. These sources were fabricated at RAPPCOF, Kota using Co-60 produced indigenously in nuclear power reactors.

Cancer Awareness & Prevention

Tata Memorial Centre is in the fore front of promoting awareness of healthy lifestyles and ill effects of tobacco. The initiatives of the Centre and the findings thereof have been adopted for formulating public health policies.

The Centre has both rural and urban outreach program for prevention and early detection of cancer where individuals are screened by using simple and cost effective methods by basic health care workers who have been trained to do the screening. Suspicious cases are referred to base hospitals for treatment.

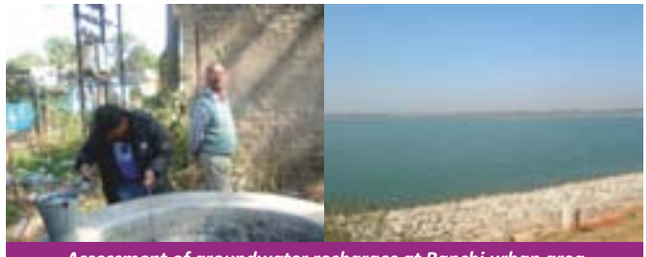
A unique and dedicated Centre for Cancer Epidemiology analysed the data generated in Cancer Registries to establish trends and risk factors. A bio-bank which is a first in our country is being established to archive samples collected from different parts in the country and subsequently analysed for causative factors of Cancer.

DAE is currently establishing three green field Cancer Care Centres similar to TMH in different parts of the country viz. Visakhapatnam, Mohali and Varanasi. These centres when commissioned will complement the work done in TMH and alleviate the cancer burden in their adjoining Communities. In the meantime, basic cancer care facilities are provided in Sangrur and Visakhapatnam.

WATER

Water Purification, Desalination of water & Isotope Hydrology

Isotope hydrological investigation was initiated for Ranchi urban area with the aim of understanding mechanism of groundwater recharge and interconnection of surface water reservoirs with the local shallow and deep ground waters. The studies concluded that rain water is the main recharging source of groundwater in the Ranchi Urban area.



Assessment of groundwater recharges at Ranchi urban area

Surface water bodies contribute marginally to the ground water recharge. It is observed that groundwater fall in three distinct groups.

Studies have been carried out on the behaviour of U in groundwater from the Granitic terrain of Madurai district of Tamilnadu. Total U concentration in groundwater was measured in the hard rock aquifer to understand U distribution. A detailed study was conducted by collecting a total of 124 samples representing different seasons. Higher concentration of U (150 µg/l) is observed in Granitic terrains in north eastern part of the study area. 13% of samples in U exceed the permissible limit of WHO standard. High U coupled with high pCO_2 values of groundwater indicates that bicarbonate enhances the weathering

process and thus mobilizes U in groundwater. The stable isotope signatures of δ18O and δD indicate that the U rich groundwaters are meteoric in origin and the samples of fissile hornblende biotite gneiss region show evaporative enrichment. This study also demonstrates the fact that lithology controls U distribution in groundwater.

BARC has developed the know-how for preparation of Thin-Film Composite (TFC) based Sea Water Reverse Osmosis (SWRO) membrane capable of desalination of highly saline /sea water. These membranes are capable of removing more than 99% salinity from saline water with concentration up to 35000 ppm, i.e., typical sea water salinity

The technology has been transferred to M/s. Permionics Membranes Pvt. Ltd., Vadodara in June 2016. Onsite training was provided to the licensee. The licensee has started manufacturing commercial size spiral membrane elements using BARC technology and 12 numbers of 8040 spiral membrane elements (8 inches dia. and 40 inches long) each having 33-34 m2 of effective membrane area were tested in-house RO plant at BARC and also at SWRO plant NDDP, Kalpakkam. Each membrane element is capable of desalting about 20000 liters of sea water per day at 50-52 bar pressure. With respect to imported membrane element, our indigenous element is capable of giving comparable performance for sea water desalination at competitive price. This is the first time such sea water desalting membranes are manufactured in India using the indigenously developed technology, which in the long run shall help in import-substitution.

Thin film composite polyamide RO membrane in preparation

Rolling of commercial size 8040 spiral membrane element

8040 spiral membrane elements rolled with indigenously developed membrane

INDUSTRIAL APPLICATIONS

BARC continued its support to the Indian industry for troubleshooting, measurement of hydrodynamic parameters, flow visualization and design evaluation in industrial process systems using radiotracer techniques. Radiotracer investigations were carried out in high pressure heat exchanger systems at M/s Indian Oil Corporation Ltd. for identifying the leaking heat exchangers(s) resulting in substantial economic benefits. Radiotracer experiments were also carried out in vacuum distillation tower at M/s Heavy water Board, Thal; cross-flow reactor at M/s Engineers India Limited, Gurgaon, Haryana and effluent treatment plant at M/s Shreyans Paper Industry Limited, Punjab;

Ethyl Acetate production reactor at M/s IOL Chemicals and Pharmaceuticals Limited, Ludhiana, Punjab for investigating detailed hydrodynamic behaviour. 82Br and 131I were used in most of the industrial radiotracer investigations.

Radiotracer based thin layer activation technique was applied to estimate the wear of automobile disc gear material in the presence of lubricants. The gears were irradiated by 13 MeV proton beam in BARC-TIFR accelerator facility to produce 56Co. The wear behavior of the gears was studied for different bio-based lubricants for different load and speed in a tribological setup.

Aerial view of the facility to hygienise sewage sludge using Radiation Technology

The first large scale facility to hygienise sewage sludge using Radiation Technology is expected to be operational by August 2017. The facility is constructed under MoU between Ahmedabad Municipal Corporation and BARC. BARC is providing technical and scientific support for setting up the 100 tons per day dry sewage sludge hygienisation 60Co γ Irradiation facility.

The foundation stone of the plant was laid down by Chief Minister of Gujarat on 30th January, 2016. The facility will be first of its kind in the world to hygienise sludge in a fully automatic process employing 60Co radiation source and converting it to manure using growth promoting bacteria. The technology and Cobalt source are available in our country conforming to make in India and Swachcha and Swastha Bharat initiative.

A polyurethane based foam modified through γ radiation grafting technique has been developed to

Oil-Water separation by modified PU

separate oil/water from layered as well as from emulsified oil/water mixture (with and without surfactant). γ assisted one step grafting of low surface energy methacrylate molecule is used to render super-hydrophobicity and super-oleophilicity to an easily available, inexpensive foam through appropriate surface roughness generation and modifying surface energy.

Due to porous structure, its separating efficiency is very high with grafting induced high selectivity and absorbance capacity. The material is promising for applications viz. oil spill cleaning from water, purification of crude oil, emulsified waste water produced in industry and daily life. The material is scalable, mechanically flexible, extensively reusable and economic.

Indigenous development of dual energy X-ray Baggage Scanning System (XBIS) was carried out in collaboration with Bharat Electronics Limited. XBIS with 640 pixels of low energy detectors and 640 pixels of high energy detectors along with front end and data acquisition electronics was integrated with x-ray source and mechanical subsystems. The machine has been qualified for imaging performance according to international standards. The pixelated X-ray detectors which are the most critical part of the system are developed for the first time in India.

X-ray baggage scanning system

Radioisotope Sources supplied by BRIT

The various engineering products offered by BRIT included the supply of more than 1748 kCi of radioactivity in various forms and for varied uses.

Industrial Irradiator Sources

Eighty eight irradiator sources with total activity of around 1438.17 kCi were supplied in eight consignments to various processing plants within the country. The irradiators to which these sources are supplied are namely, (a) AVPP, Ambernath – 199976 Ci; (b) AIIPL, Vasai – 199998 Ci; (c) Aligned Industry, Bhiwandi – 99998 Ci (d) RPP, Vashi – 213220 Ci; (e) UML, Vadodra – 199990 Ci; (f) GAICL, Ahmedabad – 199990 Ci; (g) MICROTROL, Bengaluru – 199998 Ci and (h) GAMPPL, Hyderabad – 124999 Ci.

A total of 675 kCi of irradiator sources are planned to supply upto 31st March, 2017. These are: MSAMB, Vashi – 350kCi; Aligned Industry, Bhiwandi – 100kCi and Sri Lanka – 125kCi and OGFL, Kolkata – 100kCi.

Radiography Sources

Nearly 789 radiography consignments of Ir-192 and Co-60 with total activity of approx. 37.5 kCi were supplied to various radiography customers in the country. It is planned to supply four hundred more radiography sources up to March 2017.

Custom Made Sources (CMR) and Reference Sources

Custom Made Sources of Co-60, Cs-137 and Sc-46 were supplied on request for Nucleonic Gauges and other calibration uses in 690 consignments upto December 2016. A total of 6.33 Ci of radioactivity was supplied for reference and custom made sources. Three custom made 60Co radiation sources with total activity of 427 mCi were supplied till December 2016. It is planned to supply another five more Co-60 sources with an activity of 500 mCi up to March 2017. One Cs-137 CMR source with a total activity 970 mCi was supplied and it is planned to supply 15 custom made 137Cs radiation sources with 6.5 Ci activity up to 31st March 2017. One CMR source of Sc-46 with 6.9 Ci was supplied upto December 2016.

A contract is to be signed with Los Alamos National Laboratory (LANL), USA for provision of technical support on repatriation of decayed radioactive sources in India back to USA. The sources from five institutes are to be collected, removed from the devices and repatriated to USA. The contract is already forwarded to DAE for their approval.

Isotope Application Services

Isotope Application Services Section of Marketing & Services Division of BRIT offered its valuable, timely and elegant services and solutions to various industries across the nation.

Fly ash disposal studies for Bhushan steel Ltd., Odisha

After querying the coal from mine, void is created. Torrential rains fill the mine void with water. In coal fired thermal power stations huge quantity of fly

Fly ash disposal studies for Bhushan steel Ltd., Odisha

ash is generated. Ministry of Environment and Forest, Government of India, permitted M/s. Bhushan Steel Limited to dispose off the fly ash generated from their power plants into Jagannath coal mine void at Talcher in Dhenknal district of Odisha. This would provide information of its impact on the surrounding environment which should be within the stipulated limits. Radiotracer study was carried out at to understand and analyze leaching characteristics of fly-ash into the groundwater in surrounding areas. Flyash labeled with Sc-46 was used as radiotracer.

A batch of about 3 tons of fly ash mixed with water in agitator was labelled at site with about 5 Ci of scandium in chloride form. The labelled fly ash slurry was dumped in to the water in the mine void.

The radiotracer plume movement in the stagnant mine pit water was monitored. Groundwater samples from the strategically placed bore wells and piezometers were analyzed at RAL, BRIT to study the appearance of radiotracer.

Monitoring of the radiotracer plume movement in the stagnant mine pit water

It was found that there was no radiotracer leaching into the groundwater till four months after injection. The groundwater sampling is continued on a monthly basis. The report on the study was sent to the Ministry of Environment and Forest (MoEF) by BSL for obtaining approval to continue safe disposal of fly ash into the mine void pit.

Gamma scanning of Process columns

(1) In the refinery Bharat Petroleum Corporation Limited Mumbai, temperature difference was observed over the Heavy Vacuum Gas Oil packed bed in the Vacuum Distillation column of 10 meters diameter, which was affecting the product quality. To identify the cause, Gamma scanning was done with the help of auto column scanner. Collimated 200 mCi of Co-60 source on one side of the column and collimated BGO detector on the other side were simultaneously maneuvered to get 6 scan-lines. Interpretation of the data showed that in the upper half of the bed liquid distribution was not uniform. This helped BPCL in saving the shutdown time

Gamma scanning of Process columns

by carrying out maintenance of the liquid distributor above the bed.

(2) In the petroleum refineries, water mixed with hydrocarbon in drainage system is called as sour water from which hydrocarbon is recovered in the sour water stripping unit. In the stripping unit coarse separation of water is carried out in a drum and hydrocarbons are stripped off in an adjoining column. In HPCL, Mumbai, the product quality from the Sour Water Stripper unit was not as expected. To understand the cause, gamma scanning of the SWS column and the preceding surge drum was done. The gamma scanning showed that the separation baffle in the surge drum was damaged and several trays in the SWS were partially damaged. In some sections of the column heavy flooding was observed.

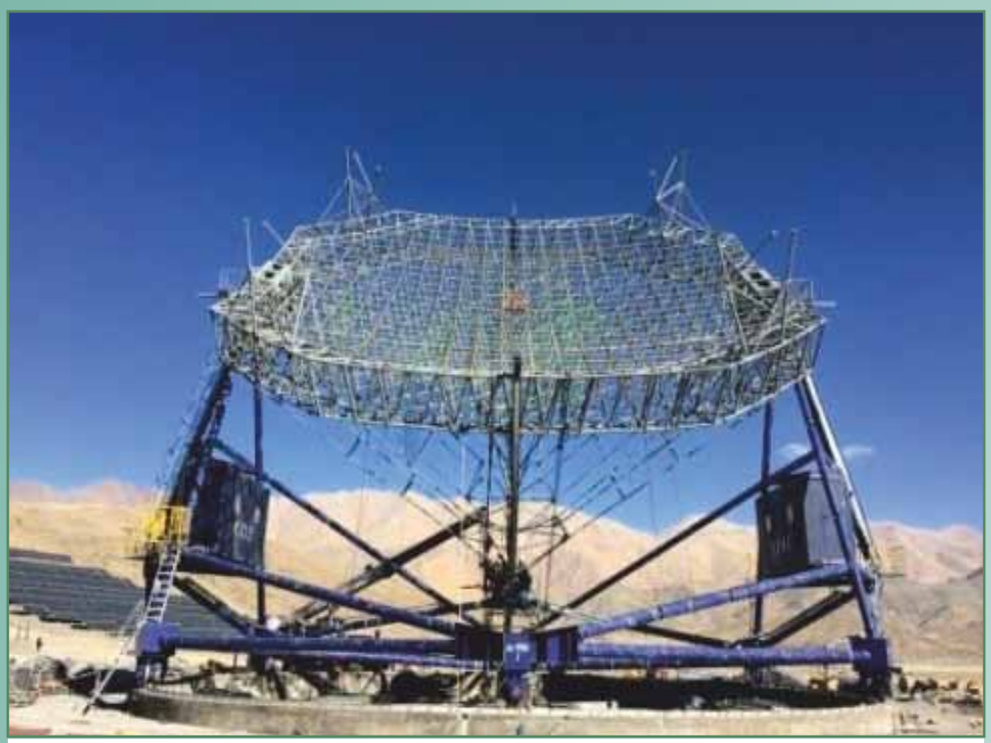
Leak detection study of PET plant, RIL, Dahej, Gujarat

In continuous polymerization plants of M/s. Reliance Industries Ltd. Dahej, Gujarat, CP-1 and CP-2, ingress of process side fluid was observed in to the heat transfer fluid which posed a danger of clogging in the pipelines and has affected the heat transfer performance. Radiotracer study was done by using Tc-99m in organic phase which was extracted on site by using solvent extraction process.

Leak detection study of PET plant, RIL, Dahej, Gujarat

The leak was pin pointed and was confirmed visually during shutdown of the plant. Corrective actions were taken by plant engineers. After successful completion, RIL has now requested BRIT to carry out one more study in the same plant to ascertain that there is no additional leak.

CHAPTER 5



Partially assembled mechanical structure CIMs of MACE telescope as on 30th Nov. 2016

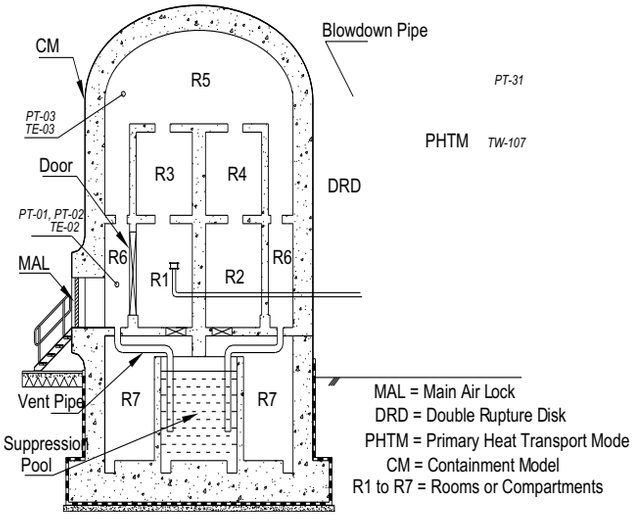
BASIC RESEARCH

One of the WR 2300 copper coated Stainless steel power couplers installed with the CCDTL accelerating structure of linac-4 tunnel at CERN

The Department of Atomic Energy has contributed significantly towards strengthening of basic research in India. The Department pursues basic research in its R&D centres that ranges from Mathematics to Computers, Physics to Astronomy and Biology to Cancers. It also provides grants-in-aid to nine institutes of national eminence. Following were the major activities and achievements of DAE in basic research, during the period of the report.

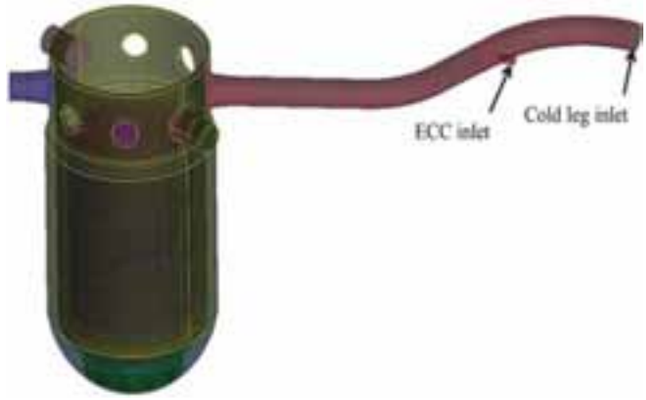
MATHEMATICS & COMPUTATIONAL SCIENCES

As part of experimental data generation for benchmarking and validation of Computational Fluid Dynamics (CFD) codes used for H_2 distribution studies in nuclear reactor containment under severe accident conditions, two scoping Helium(He) distribution experiments were carried out in four selected compartments (R1, R2, R3 & R4) of containment model of Containment Studies Facility (CSF). Helium concentration variation in each compartment and stratification of He in top compartments was observed.



Containment Model of CSF

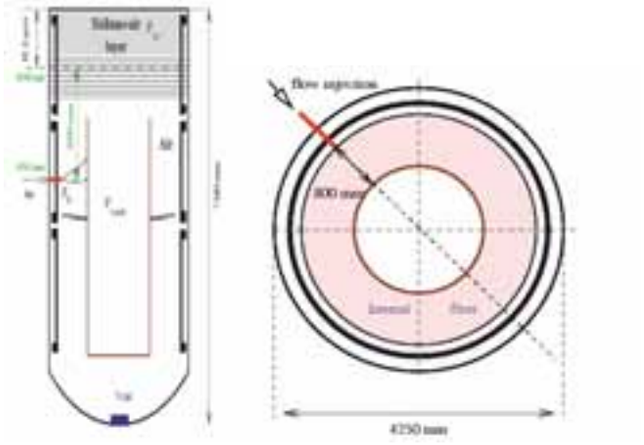
CFD simulations for coolant mixing and pressurized thermal shock (PTS) studies due to buoyancy driven mixing in ROCOM (Rossendorf Coolant Mixing Model) have been performed as validation exercise. ROCOM is a German KONVOI type reactor with all important details for the coolant mixing operated with water at room temperature in a linear scale of 1:5 and having 4 loops with a RPV mock-up made of transparent acryl. Analysis was performed by generating different number of grids in the model. The results obtained with different grids are almost same and the mixing scalar concentration reduces while entering the lower plenum.



Isometric view of ROCOM for PTS with internal details of ROCOM experimental model

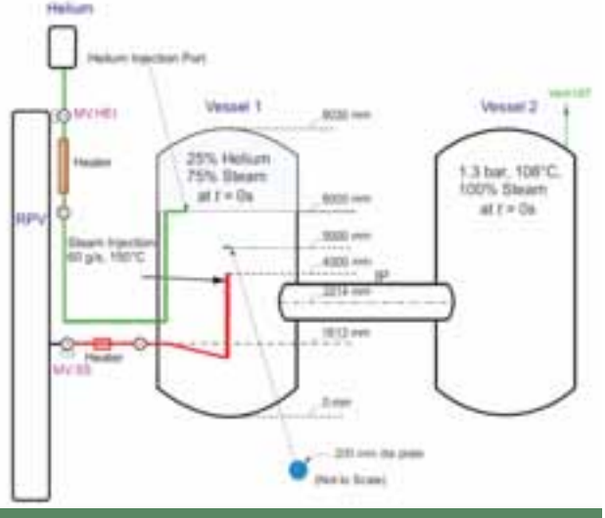
Two thermo-chemical analytical models have been developed for determining the pressure magnification resulting from deflagration of H_2-air mixtures. These methods are based on sound physical background and consider realistic thermodynamic properties. These methods can offer a quick estimate on the pressures that can be expected during accident sequences for NPPs over a wide range of postulated initial conditions.

In the frame of the OECD/NEA HYdrogen Mitigation Experiments for REactor Safety (HYMERES) project, two computer code benchmarks have been organized based on the PANDA HP1_6_2 test and the MISTRA HM1_1 test. In HM1_1 test performed in the MISTRA facility, the effect of an obstruction on the capability of a horizontal, slightly buoyant jet originating from a horizontal pipe to break-up the stratification in a two-layer ambient has been addressed. Blind and open phase CFD calculations were performed for this test and results were submitted in required format to the organizing agency CEA, France for comparison with other participants and experimental data.



HM1_1 Test

Open Benchmark on PANDA Test HP1_6_2 under OECD/NEA HYMERES Project was to study the break-up/erosion of a stratified layer of lighter helium gas formed in post-accident condition by a vertical buoyant steam jet/plume. This exercise has been done to assess the capability of CFD codes to predict the erosion and break-up of stratified conditions that can build-up in nuclear reactor containment after a hypothetical severe accident. 3D transient CFD simulation using code CFD-ACE+ considering complete geometry, initial and boundary conditions have been performed and results in the prescribed format have been submitted to operating agency PSI, Switzerland.



HM1_6 Test

Numerical models have been developed to simulate the wall and bulk condensation in presence of non-condensable gases to simulate the typical post-LOCA steam laden atmosphere of the containment of a Nuclear Power Plant (NPP). The performance of the wall condensation model implemented in FLUIDYN was tested on the CONAN experiments conducted at University of Pisa, Italy. In these experiments, air–steam mixture flows downwards through a vertical channel with square cross section. One vertical wall of the channel is cooled by flowing cooled water on the outer side of wall and the steam condenses on inside surface.

Heavy Water plant, Tuticorin was qualified as per national code IS-1893-2005 after thorough data collection from the plant and by carrying out a Seismic walkthrough. The plant was modelled and subjected to wind and earthquake loads. The work is a major contribution for getting the regulatory clearances.

The School of Mathematics, TIFR continued the research activities in the Mathematical Sciences. Under Algebra and Algebraic Geometry, a partial affirmative answer to a conjecture of V.L. Popov about equidimensional representations was given. It was proved that a positively graded domain is determined by its completion at its vertex. Some new results about quotients of a 3-dimensional smooth affine variety modulo the action of a one dimensional unipotent algebraic group were proved. Complete classification of doubly saturated subgroup scheme of a reductive group with the characteristic of the base field, p, more than the coxter number ${}^{h}G$, was obtained. A notion of a relative canonical reduction for families of principal bundles in higher dimensions was defined and the existence of a schematic Harder-Narasimhan stratification for such families in characteristic zero was proved. A new proof of the classification of algebraic Lauricella functions was given. It was proved that almost every point on ``nondegenerate" varieties in positive characteristic, is not Dirichlet improvable. This uses dynamics of unipotent flows in positive characteristics. A wide ranging and new approach to counting solutions to Diophantine inequalities on homogeneous varieties of semisimple groups was presented. A complete description of the reductions of certain crystalline Galois representations of slopes 1 was given. A universal Torelli type theorem for elliptic surfaces was studied to show that an effective, base change compatible family of isometries between the Neron-Severi groups of two elliptic surfaces arises from an isomorphism of the elliptic surfaces. In continuation of the studies of dominating functions, total dominating functions,

closed packing functions, and open packing functions of the countable graphs, it has been proved that for any real number $r \geqslant 2$ there exists a countable graph whose clique index is r.

At the Centre for Applicable Mathematics, Bangalore, a comparative study between two-scale asymptotic expansion for periodic homogenization and Taylor expansion in the Bloch wave method was undertaken and it was shown that they differ in the fourth order terms for elliptic equations while for the wave equation no such difference was found, this has led to an unambiguous definition of the dispersion tensor. $C^{1,\alpha}$ estimate for non-local elliptic *HJB* equations with critical order non-locality was established. Optimal controllability for hyperbolic conservation laws with discontinuous flux was studied and the solution was obtained by using the backward construction. Role of common midpoint versus common offset acquisition geometry in seismic imaging was studied. Singularities in the in viscid linear theory of sea breezes was studied. Well-balanced schemes for Euler equations with gravitational effects were developed to cover the case of general equation of state and general grid systems. Lagrangian-Eulerian discontinuous Galerkin method for one dimensional compressible Euler equations was developed to improve the resolution of the solution.

Number theory, Algebra and Geometry and Analysis are the broad heads under which important contributions have come from HRI in the past year. New results have been obtained in the area of zero-sum problems with weights. The asymptotic behaviour of inverse Mellin transform of the symmetric square L-function associated to a general cusp forms of any level have been completed. A combined proof the celebrated Gauss's quadratic reciprocity law and the so-called Riemann's non-differentiable function have been given. Some new results on non-linear irreducible characters of finite group automorphisms of finite p-groups and classification being done of all finite groups whose non-linear irreducible characters of the same degree are Galois conjugates. The study of Schrodinger equation on modulation spaces, Hardy-Sobolev inequality for the twisted Laplacian, Maximal operators along hyper surfaces and Fourier integral operators has been involved during one year.

At IMSc, the work related to lattice Boltzmann methods for fluid flow computation has lead to establish a company. This company has recently won several contracts, including from ISRO as well as a Japanese multinational for solving some engineering physics problems. A general agent-based model for the transmission of infectious diseases is being developed at IMSc. This model uses GIS-derived information as well as information from synthetic populations to model the movement and disease dynamics of a large number of individuals. Benchmarking the results to field data and discussions with public health specialists about applications of the model is underway. Prof Meena Mahajan and her PhD student Nitin Saurabh got the best paper award in July 2016 for their work on "Some complete and intermediate polynomials in algebraic complexity theory" at the 11th Computer Science in Russia conference.

The School of Mathematical Sciences at the National Institute Education of Sconce & Research (NISER) continued the mathematical programmes and provide many facilities which included High Performance Computing Cluster.

PHYSICS

At TIFR under Theoretical Physics, it was shown that a self-interacting neutrino gas can spontaneously acquire a nonstationary pulsating component in its flavor content, with a frequency that can exactly cancel the "multiangle" refractive effects of dense matter. It was shown that photon jets can be distinguished from isolated photons. Sterile neutrinos with secret interactions were studied. Sunyaev-Zeldovich effect fluctuations were detected using Planck data in the Coma cluster. This is a first such detection of pressure fluctuations in a cluster of galaxies with important implications for using galaxy clusters as a cosmological probe. A new method for separating the Sunyaev-Zeldovich effect from Carbon monoxide emission from Galaxy was proposed and applied to the Planck cluster catalog. Interaction of X-rays with the Galactic molecular clouds was studied. Prospects for looking for missing baryons in the Universe were studied.

A new universality class of multicritical melting of three-sublattice order of easy-axis antiferromagnets with triangular symmetry was identified and critical exponents were computed. The critical density for the phase transition from the nematic to layered phase in a system of hard rectangles was studied analytically and

by simulations. A theory for optical lattice modulation spectroscopy in spin-orbit coupled Bosons was developed. A cold atom implementation of Bernal stacked bilayer honeycomb lattice with cold atoms was proposed. A new formalism for critical behaviour near nonequilibrium Mott transitions in dissipative open quantum systems was developed in terms of non-Hermitian models invariant under parity *(P)* and time reversal *(T)* transformations. The Berry phase mechanism for anomalous Hall Effect was discovered in a strongly disordered two-dimensional magnetic semiconductor structure.

A comprehensive "White Paper'', quantifying the physics potential of the ICAL detector as obtained from realistic detector simulations was completed. A new variable for analysis of hadronic jets in heavy ion collisions was proposed as a better tool to analyse the hot medium produced in these collisions. An invited review for physics undergraduates was written on QCD critical point. The ratio of the two flow scales in QCD, W_0 and t_0 was found to be universal. Boosted tops in association with jets as a way of pinning down a KK-gluon at the LHC; The Cray XC-30 which delivers over half a Petaflop of computing power was installed in the Hyderabad data center of the Indian Lattice Gauge Theory Initiative.

Thermalization of local operators in integrable conformal models proved. Deconfinement model in AdS/QCD further extended to incorporate dynamical quarks. The dynamics of black holes in a large number of dimensions was demonstrated to reduce to the dynamics of a nongravitational membrane - roughly the event horizon of the black hole. A new definition of the entanglement entropy of a finite spatial region of a lattice gauge theory was proposed. Viscosity of anisotropic fluids using holography was studied. Several aspects of Entanglement Entropy for Gauge defined in our earlier work and explicate its properties were studied.

In Astronomy and Astrophysics, the study of a large range of objects in the Universe, from our nearest star to the composition and geometry of the Universe itself continued. Research areas included Helio and Asteroseismology, X-ray Astrophysics, Astrochemistry and Interstellar medium, Star and Planet Formation, Astrophysical Relativity, Gravitational Lensing & Cosmic Microwave Background, Dark Energy; Quantum Gravity; Gravitational Collapse. Computing facilities consisting of a CPU cluster and 2 GPU clusters have been established. Establishment of data pipe line and setup of ASTROSAT Payload Operation Centre (POC). Developmental activities of improved processing electronics with CZT detectors. CZTI data processing activities and POC related activities are ongoing. Initiated development work with SiPM (Silicon Photo Multiplier) and Multianode PMT (Photo Multiplier Tube). The laboratory model of the IRSIS satellite experiment has been extensively tested in the lab. Characterization of the infrared detector has been completed and spectral data has been obtained and analysed. The infrared fiber bundle has been designed and fabricated. The optical designs, mechanical, cryogenic, electronics and software designs of TANSPEC have been completed. The TANSPEC spectrometer is expected to be commissioned by late 2017. Upgradation of hydrogen cylinder bank with 140 new high capacity and high pressure cylinders and suitable cylinder manifold system. Two new trolleys with manifold system were fabricated at BF workshop. Upgraded the present S-Band tracking system with 70 MHz Tracking Receiver and Down Converter. This new system in three balloon flights (Lab Rats, BATAL and TIFR Engineering Test Flight) with improved payload tracking accuracy with better gain margin was tested. Few GRBs and Instrumentation papers are in process of publishing. A detailed report on the IRSIS laboratory model is being finalized for submission to ISRO. To establish high performance computation facility for doing research in frontier areas of theoretical astrophysics. Publication of results of observations done with the ASTROSAT instruments (CZTI, SXT, LAXPC, UVIT). Fabrication of high altitude balloons to reach 54 km altitude with a scientific payload of 10 kg or more. Far Infrared Astronomy balloon flights for C-II lines using Japanese FPS. Balloon flights for Atmospheric Science and Astrobiology experiments. Test, qualification and developmental activities of improved new CZT detectors. Lab developmental activities for new CZT detectors continued.

At the National Centre for Radio Astrophysics, Pune, meter wavelength Single pulse Polari metric Emission Survey was carried out to study the radio emission properties of normal pulsars. The study concludes: measured widths of the pulsar profiles exhibit the radius-to-frequency mapping; single-pulse

polarization data show interesting trend, viz., Polarization Position Angle (PPA) distribution exhibiting the simple rotating vector model. GMRT search for associated HI 21 cm absorption in high-redshift flat-spectrum sources in the red shift range $1.1 < z < 3.6$ led to one detection of absorption at $z \approx 3.530$ towards TXS 0604+728. This is the highest redshift at which HI 21 cm absorption has ever been detected. The GMRT High Resolution Southern Sky Survey (GHRSS) for Pulsars and Transients carried out at 322 MHz with high time (30 micro-sec) and frequency (0.016 MHz) resolution, led to the discovery of 10 pulsars, 1 of which is a Millisecond Pulsar (MSP), which is among the highest pulsar per square degree discovery rates for any off-Galactic plane survey. Evolution of symbiotic recurrent novae V745 Scorpii and RS Ophiuchi from radio synchrotron emission observed using GMRT lead to the conclusion - emission at a given frequency is visible sooner after the outburst in successive outbursts of both V745 Scorpii and RS Ophiuchi. A database of phase calibration sources and their radio spectra for the Giant Metrewave Radio Telescope has been released with 45 sources at 235 MHz and 610 MHz. An intense solar flare-CME event in 2015 has led to understanding of propagation and interaction effects between the Sun and Earth's Orbit. The GMRT, a world class facility for radio astronomy research at low frequencies, is currently undergoing major upgrades that will significantly improve its capabilities in terms of seamless frequency coverage and sensitivity thereby GMRT maintaining its leading global position in the arena of low frequency radio astronomy. More scientific results from radio observations (primarily GMRT & Ooty Radio Telescope) which are currently under analyses, will be published in journals. The Digital back-end system processing full 400 MHz band-width for interferometric & beam modes will be completed. One more GMRT antenna will complete its Antenna surface refurbishment work.

In Condensed Matter Physics at TIFR, a new multi-mode qubit design which was invented here was tested thoroughly and the device was nicknamed “Trimon”. This design promises to be a new approach for building large scale quantum processors. Multi-mode coupling in graphene drum resonators was characterized and parametric amplification was observed. This work was published in Nature Nanotechnology 11, 747–751 (2016). A new project on cavity-optomechanics using superconducting microwave cavities coupled to Graphene drum resonators started. First device was successfully fabricated and opto-mechanical coupling was observed. It is expected to demonstrate quantum operations on the full three qubit system of the Trimon device along with a detailed theoretical understanding of the device and its extensions. Preliminary testing of a 5 qubit device is planned. Improvement on the cavity-optomechanics experiment by fabricating better devices is also expected. Magnetic properties of Europium based non-centrosymmetric compounds, $EuRhGe_3$ and $EuIrGe_3$ single crystals were studied giving important results; Metamagnetic behavior of $EuNiGe_3$ was explored. Investigated the anisotropic magnetic properties of two new Cerium based Kondo antiferromagnetic compounds $CeRhAl_4Si_2$ and $CeIrAl_4Si_2$. Grown the single crystal of $PrRhAl_4Si_2$ and studied its low temperature physical property properties. Using K refrigerator (the second such facility in Asia) bulk superconductivity in pure Bi single crystals below 0.53 mK under ambient pressure with an estimated critical magnetic field of 5.2 µT at 0 K have been shown. The results have been published in the internationally renowned journal and it has attracted attention in the electronic media and popular press as well. A floating zone furnace have been installed and the process of investigating the magnetic properties of new oxide systems which exhibit interesting magnetic properties is in progress. Investigation of the low dimensional spin systems owing to their interesting field induced critical behaviours is planned. In continuation to the efforts of investigating the anisotropic physical properties of Ce, Eu and Yb based intermetallic compounds, single crystals of such compounds will be grown employing different crystal growth methods. For the generation of Tera Hertz (THz) or Far Infra-Red (FIR) radiation, higher efficiency devices are needed. These devices need to have better emission when bombarded by 800nm light pulses. TIFR has simulated on computer many such schemes to couple the incident light better to the substrate on which we fabricate the devices. This requires reducing the reflected light and increasing the absorbed light better. This is simulated and currently these devices are fabricating. Very high power/energy pulse amplifier laser system is expected to be installed soon and the simulated THz Antenna devices for high power THz generation will be fabricated. Work on various thin films of materials under low temperatures is in progress.

In High Energy Physics at TIFR, astronomical sources like Active Galactic Nuclei (AGN) and gamma ray pulsars were studied with the HAGAR telescope system at Hanle in Ladakh. Long term study of multiwaveband data, including seven years' data (2009-2015) from HAGAR, of nearby blazar Mkn421, revealed log normality behaviour in flux distributions. Work on development of various subsystems of proposed G-APD based imaging camera progressed well. Work on development of calibration device for prototype Large Size Telescope (LST) for Cherenkov Telescope Array (CTA) was nearly completed. Direct detections of gravitational waves from orbiting and merging binary black holes by the LIGO Scientific Collaboration were successful this year. A comparison between dependence of relative velocity of light and sound by experiments in the same configuration confirms both are similar and Galilean to first order in v/c. A second black hole binary was recently detected. The detectors started operation at larger sensitivity. With enhanced sensitivity one may expect up to one event per month. Data collected in GRAPES experiment is being analysed to study comprehensively galactic Cosmic Rays around ”Knee" and diffuse multi-TeV ɣ rays after “ankle" of the cosmic ray energy spectrum. This experiment also investigates the sun, to probe various solar phenomena including coronal mass ejections, flares and total solar eclipses. For the INO (India-based Neutrino Observatory) the industrial production of 2m 2m glass Resistive Plate Chamber (RPC) gaps for the 600 ton engineering prototype of Iron Calorimeter (ICAL) detector has begun. Design of the electronics hardware and software is complete and limited production modules are being tested. The RPC handling trolley has been manufactured in industry and delivered. The white paper on the physics capability of the ICAL detector will be published soon. The INO Ph.D. programme is being organised successfully over the past eight years.

In Nuclear & Atomic Physics at TIFR, high spin states of 132Te, a neutron rich nucleus have been investigated using fission fragment spectroscopy to probe the competition of neutrons and protons in forming the sequence of high spin states near the doubly magic nucleus 132Sn. Experiments with highly charged ions impacting with large molecules like Coronene have revealed giant Plasmon resonance. Accelerator based condensed matter research has led to the first observation of a cross over from itinerant to localized magnetic moment in nano-sized Silver matrix. Sequential decay for multiple charged CO_2 ions has been observed in experiments using a home built state of the art recoil-ion momentum spectrometer. The statistical behavior of random lasing intensity was modeled on exponentially tempered Levy sums, which provides a universal platform for studying random lasing statistics. Systematic development of Anderson localized modes in GaAs semiconductor membranes have been observed. The study covered periodic samples that exhibited photonic modes, weakly randomized samples that revealed weakly localized modes, and a periodic samples with Anderson modes. Molecular dynamics of the dissociative electron attachment to atmospherically important gases like Carbon Monoxide (CO), Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) has been studied. Quantum interference in differential cross section of strong field photo-dissociation of H_2^+ caused due to light induced conical intersection has been observed.

TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera), is used to search for VHE photons from various galactic and extra-galactic sources. Several potential VHE γ-ray sources viz., Crab Nebula, B20806 + 35, Mrk 421, Mrk 501, M87, etc., were detected and recorded during this year. Apart from detection of γ rays from the standard candle source Crab Nebula (used for checking the telescope performance), enhanced γ-ray emission has been observed from Mrk 421 at a statistical significance of 6.3 σ with an excess of 375 ±59 γ-ray events in 97 hours of observation time.

TACTIC gamma ray telescope at mount Abu

Analysis and interpretation of the TACTIC data collected on Mrk 421 during 2012 have been completed. Results indicate that the source was in a high emission state during 15- 26 March, 2012. Near simultaneous data available in other wavelength bands with Fermi-LAT, Swift-XRT, Steward Observatory and OVRO telescope have also been used to construct the Spectral Energy Distribution (SED) of the source. Research carried out for achieving higher sensitivity for atmospheric Cherenkov telescopes indicate that the Random Forest and Wavelet techniques noticeably improve the flux sensitivity of the TACTIC γ-ray telescope like systems.

The correlations between mass distributions of the binary fragments, Total Kinetic Energy (TKE) and neutron multiplicity have been reported for the reaction ^{50}Ti + ^{208}Pb at 294 MeV bombarding energy. In this work, average neutron multiplicities were extracted for different fragment mass splits and TKE windows. A weak increase of the precession neutron multiplicity was found going from asymmetric to symmetric mass splits.

A fission delay time of 45 zs (zepto-second) has been extracted for the symmetric fission. The neutron multiplicity extracted for the symmetric mass split was used to derive the average number of neutrons emitted in the spontaneous fission of ^{258}Rf. The extrapolated value of 4.7±1.4 is found to be consistent with systematics of spontaneous and neutron-induced fission in heavy nuclei and with the results of our previous works for super heavy nuclei with Z=116 and Z=124.

The proton decay probabilities of the ^{56}Fe$*$ and ^{47}Ti$*$ compound systems, which are populated by the transfer reactions ^{52}Cr(^{6}Li,d)^{56}Fe$*$ (surrogate of n+^{55}Fe$\rightarrow$ ^{56}Fe$*\rightarrow$ p+^{55}Mn) and ^{45}Sc (^{6}Li,α)^{47}Ti$*$ (surrogate of n+^{46}Ti$\rightarrow$ ^{47}Ti$*\rightarrow$ p+^{46}Sc) reactions, were measured. ^{55}Fe (n,p) cross sections were then obtained in the equivalent neutron energy range of 7.9 to 20.1 MeV within the framework of the surrogate-reaction method. The experimental cross-section data on ^{55}Fe (n,p) are in reasonable agreement with the evaluation of EAF-2010, while other evaluations TENDL-2014 and ROSFOND-2010 data show some discrepancies. This study demonstrates the possibility of determining neutron-induced charged particle emission cross sections for unstable radionuclides relevant to fusion technology applications by the surrogate-reaction method.

The differences in the fusion cross sections predicted by commonly used CC (coupled-channels) calculations using codes such as FRESCO and CCFULL and experimental data were investigated. A difference was observed between the two predictions for all the reactions involving ^{6,7}Li as projectiles and it is noticeably more for systems involving ^{7}Li. Thus, the conclusion about the enhancement or suppression of fusion cross sections is model dependent.

Projectile breakup cross sections in the ^{6}Li+^{112}Sn reaction have been investigated at two beam energies, 30 and 22 MeV. Cross sections for sequential breakup of ^{6}Li into (alpha + d) via its resonant state of 1+ (5.65 MeV) in the continuum have been measured for the first time along with two other dominant resonant states of 3+ (2.18 MeV) and 2+ (4.31 MeV) at Ebeam = 30 MeV. However, at 22 MeV, the α+d breakup is found to be only due to direct breakup process. Cross sections measured for sequential breakup via two transfer channels, (^{6}Li,^{5}Li) and (^{6}Li,^{8}Be), into α+p and α+α respectively and the above (α + d) breakup channels compared with the results of coupled-channels calculations unravel the reaction mechanisms involving a weakly bound projectile and different processes leading to large inclusive α particle production.

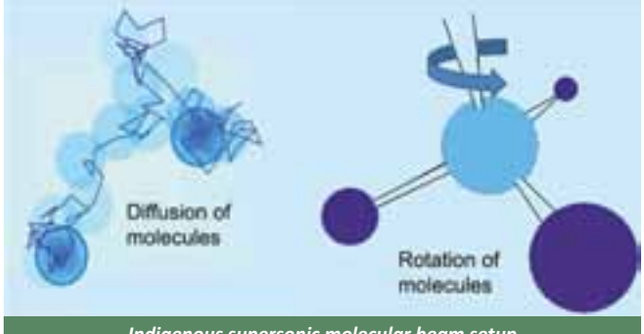
Thin film coatings of Polytetrafluoroethylene (PTFE) over glass were developed by RF magnetron sputtering technique (Power 160 Watts) under high vacuum condition for their application as super-hydrophobic/oleophobic, antireflection and protective coatings on devices and materials. High corrosion and chemical resistance, excellent thermal stability, insolubility in common solvents and high transparency for advanced applications of PTFE make them good choice for protective layers on solar panels. Optical, structural and morphological properties of the films were studied using attenuated total reflectance mode of Fourier transform infrared spectroscopy, UV-Visible spectroscopy, x-ray photoelectron spectroscopy and Atomic force microscopy supported by x-ray reflectivity and ellipsometry. Studies indicate that out of the C-C and CFx (x=1, 2, 3..) bonds in the films, major contributions from $CF_2$and CF_3bonds lead to an F/C ratio of ~1.5 giving hydrophobic nature to the coatings.

Tantalum mononitride (TaN) molecule has been identified as the prime candidate for measurement of nuclear magnetic quadrupole moment-induced Electric Dipole Moment (EDM) in its metastable $a^3{}_1$state with longer lifetime. Several low and high-energy electronic states of TaN produced in a laser ablation-supersonically cooled molecular beam setup have been identified and their precise rotational and vibrational constants were determined using the indigenous supersonic molecular beam setup. The most effective mechanism for populating the $a^3{}_1$state, relevant in eEDM search has been identified.

Indigenous supersonic molecular beam setup

It is a standard practice to trap nuclear waste in glassy materials by vitrification for immobilizing radioactive nuclear waste for long periods of time in the nuclear industry. In this context, it is important to understand the short range structure of the glassy material and the molecular network at the microscopic level for arresting the waste. Neutron diffraction studies were carried out on rare-Earth phosphate glasses with the Liquid and Amorphous Diffractometer (LAD) at DHRUVA research reactor for determining the structural network of the material.

The diffusion of various hydrocarbons in zeolite cages have been studied by using quasi-elastic neutron scattering in DHRUVA National Facility for Neutron Beam Research to understand the catalytic property of zeolites, which have applications in the oil industry. The following figure shows the schematic of diffusion and rotation of hydrocarbon molecules seen in such cages



Indigenous supersonic molecular beam setup

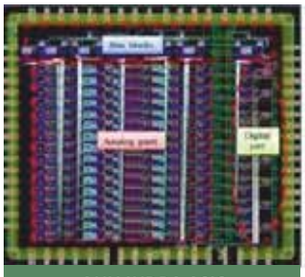
In-situ X-ray diffraction high pressure studies of Lithium rich ceramics Lithium metatitanate (LTO) and Lithium metazirconate (LZO) were carried out with an aim of studying their potential application as tritium breeder materials for thermonuclear reactors. The studies show that they are the least compressible of the known lithium rich ceramics like Li_2O or Li_2SiO_4 and LTO is stable up to 35 GPa whereas LZO shows an iso-structural phase transition at 20 Gpa.

Superconductivity in a crystalline high entropy equi-atomic composition alloy (Hf-Ti-Ta-Nb-V) was observed for the first time. Both resistivity and magnetization data show the superconducting transition temperature to be around 5K and also corroborated by heat capacity measurements. Defect states in wide band gap ZnO were modulated with the help of halide ions to enhance photo catalytic activity of ZnO nanoclusters towards water splitting. The underlying electronic phenomena in a fabricated ZnO-nanorod-based facile photovoltaic device were investigated theoretically and experimentally. This will lead to detection of heavy and toxic metal impurities in conjugated curcumin- an herbal medicine. Study using computational package VASP (Vienna Ab-initio Simulation Package) was carried out on the magnetic state of the material ζFe_2N during the nitriding of Iron or Steel.

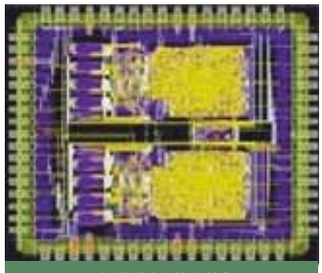
With a view to investigate the different reaction mechanisms, viz., quasi fission, transfer induced fission, etc., operating in heavy ion induced fission reactions, mass distribution and mass resolved angular distribution were measured in $^{28}Si+^{232}Th$ reaction by recoil catcher method using off-line γ-ray spectrometry using ^{28}Si beam from BARC-TIFR Pelletron-Linac facility. Mass distribution was measured at beam energy of 158 and 180 MeV and mass resolved angular distribution was measured at intermediate energy of 166 MeV. Mass distribution for complete fusion fission was symmetric whereas that for transfer induced fission was asymmetric. Contribution from transfer induced fission was in the range of about 16-30%. Mass resolved angular distribution of fission products showed an

increase in the angular anisotropy in the symmetric mass region. This observation suggested pre-equilibrium fission to be the dominant non-compound nucleus fission process in this reaction at the beam energy higher than the entrance channel Coulomb barrier.

ANUINDRA ASIC in 0.35 um CMOS technology has been developed, fabricated and tested. It is a 16 channel, high dynamic range pulse processing ASIC specifically developed for front-end readout of the proposed silicon tungsten calorimeter (FoCAL) as part of ALICE upgrade for High Energy Physics experiments at CERN. ANUPAL-II Time-to-Digital Converter (TDC) ASIC in 0.35 um CMOS technology has been developed, fabricated and tested. The TDCs are based on vernier ring oscillator method with novel precise internal calibration. The ANUPAL-II ASIC is specifically designed to cater to INO experiment that requires 200ps resolution and multi-hit capability.

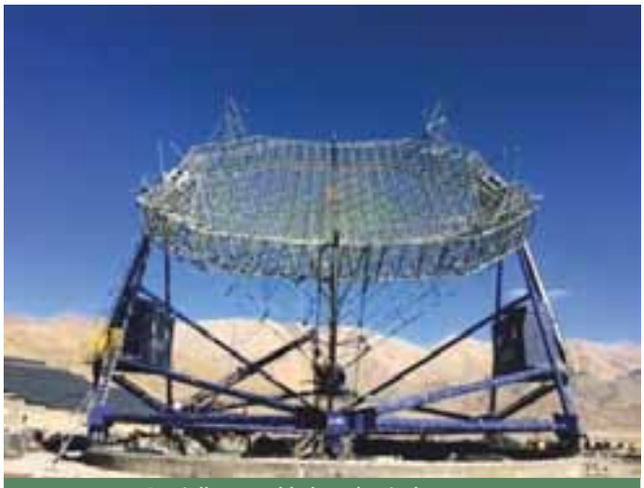


ANU INDRA ASIC



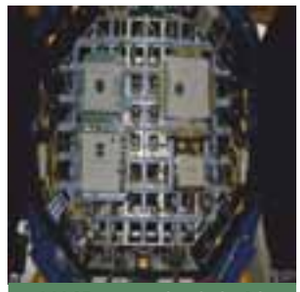
ANUPAL-II ASIC

At BARC, the work on the mechanical structure of MACE telescope is nearing completion. All the sub-systems of 21meter diameter mirror basket have been assembled with 12meter radius bull gear support structure.



Partially assembled mechanical structure CIMs of MACE telescope as on 30th Nov. 2016

MACE camera loaded with CIMs (front side)



MACE camera loaded with (back side)

Substantial progress has been made in testing the high-speed signal processing cards required for the Camera Integrated Modules (CIM) for the telescope. Rigorous testing of 29 CIMs was carried out at ECIL Hyderabad using the test procedure involving telemetry and event data collection and their validation using pulsed and DC LEDs to simulate atmospheric Cherenkov events. MACE integrated camera with 29 CIMs has been tested subsequently. In order to understand various response functions of the telescope like energy thresholds, effective collection areas, detection rates etc., Monte Carlo simulation studies were continued. The results obtained by simulating the response of the telescope to γ- ray, proton and α- particle initiated extensive air showers in the energy range 5 GeV to 20 TeV were published.

Survival of cluster correlation in dissipative binary breakup of ^{24,25}Mg*

At VECC, an experiment has been performed to look for the signature of cluster correlation in binary fragment decay of fully energy-relaxed composites (compound nuclei) ^{24,25}Mg* formed in ^{12,13}C + ^{12}C reactions, by comparing the isotopic fragment yields in two exit channels corresponding to two reactions, where the complementary binary product of one of the exit channels is the well-known α-cluster nucleus. The experiment has been performed at BARC-TIFR Pelletron-Linac facility, Mumbai, using 80-MeV ^{12}C and 78.5-MeV ^{13}C ion beams on ^{12}C target. The inclusive isotopic energy distributions of the emitted fragments ^{6,7}Li, ^{7,8,9}Be have been measured. The ratio of the measured fully dissipative (fission-like) yields of each isotopic fragment obtained in the two reactions has been plotted along with respective statistical model estimates obtained using two statistical model codes, CASCADE and GEMINI++ respectively. The presented data indicated, for the first time, the survival and sustained influence of cluster correlations on dissipative

binary decay of hot composites ^{24,25}Mg* at excitation energy of 2.25 MeV/nucleon. The results have been published in Physical Review C as Rapid Communications.

Excitation energy dependence of the level density parameter in *A* ~210 region

Damping of shell effect in Nuclear Level Density (NLD) and temperature dependence of the smooth part of the Level Density Parameter (LDP) have been investigated experimentally by measuring neutron evaporation spectra in case of ^{4}He + ^{208}Pb and ^{209}Bi reactions. The experiment has been performed using the ^{4}He-ion beams of bombarding energies 28, 31, 35, 40 and 60 MeV from the K130 cyclotron at VECC. The current study was planned to extend the experimental information (which are very limited) on the shell damping factor () and to remove some of the existing discrepancy among various experimental results on the temperature dependence of the LDP. The current study provides crucial information on the damping of shell effect in nuclear level density and on the temperature dependence of the level density parameter. The results have been published in Physical Review C.

Exclusive measurement of isospin mixing at high temperature in ^{32}S

At VECC, Kolkata, an exclusive experiment has been performed to study isospin mixing in ^{32}S. The compound nuclei ^{31}P and ^{32}S were populated at the same excitation energy (E* =40.2 MeV) and angular momentum but through T = 1/2 and T = 0 entrance channels, respectively, using alpha beams from the K-130 Cyclotron. The high energy γ-ray spectra from the decay of IVGDR were measured using a part of the LAMBDA spectrometer. The 50 element multiplicity filter was utilized for precise measurement of angular momentum. The evaporated neutron energy spectra were also measured, in co-incidence with the multiplicity γ-rays, using a liquid scintillator based neutron TOF detector to extract the crucial inverse level density parameter required for statistical model calculations. The results obtained in the experiment suggested that Coulomb spreading width remains nearly independent of temperature and angular momentum. Moreover, isospin becomes a good quantum number with the increase in temperature. However, $\alpha^{2}_{>}$, when extrapolated to higher temperatures, by imposing its value at zero temperature, underpredicts our measured value. These interesting results were published in Physics Letters B.

Magnetic White Dwarfs with masses much above Chandrasekhar limit (Super-Chandrasekhar)

In the present work, Equation of State (EoS) of a completely degenerate relativistic electron gas in magnetic field based on Landau quantization is developed. The mass-radius relations for magnetized white dwarfs are obtained by solving the Tolman-Oppenheimer-Volkoff equations. The effects of the magnetic energy density and pressure contributed by a density-dependent magnetic field are used to find the stability configurations of realistic magnetic white dwarfs.

Core-crust transition and crustal fraction of moment of inertia of neutron stars

A systematic study of properties of hadronic compact stars is performed with EoS for β-equilibrated neutron star matter, obtained using density dependent M3Y effective interaction, which satisfies the constraints from the observed flow data from heavy-ion collisions. This β-equilibrated neutron star matter is able to describe recently observed highly massive compact stars. The core-crust transition density, pressure and proton fraction at the inner edge separating the liquid core from the solid crust of neutron stars are determined from thermodynamic stability conditions. The crustal fraction of Moment of Inertia (MoI) can be extracted from studying pulsar glitches. These results for pressure and density at core-crust transition together with the observed minimum crustal fraction of total MoI provide a limit for the radius of Vela pulsar. Present calculations suggest that crustal fraction of total MoI can be at most 3.6% due to crustal entrainment caused by Bragg reflection of unbound neutrons by lattice ions.

Masses and radii of Compact bifluid hybrid stars: Hadronic Matter mixed with self-interacting fermionic Asymmetric Dark Matter

The masses and radii of non-rotating and rotating configurations of pure hadronic stars mixed

with interacting fermionic asymmetric Dark Matter (DM) are calculated within the two-fluid formalism of stellar structure equations in general relativity. The EoS of nuclear matter is obtained from the density dependent M3Y effective nucleon-nucleon interaction. DM particle mass of 1 GeV is considered. Two-body repulsive interaction of the scale of strong interactions is used for EoS of self-interacting DM. The conditions of equal and different rotational frequencies of nuclear matter and DM are explored.

Comparison of yields of neutron-rich nuclei in proton- and photon-induced ^{238}U fission for RIB

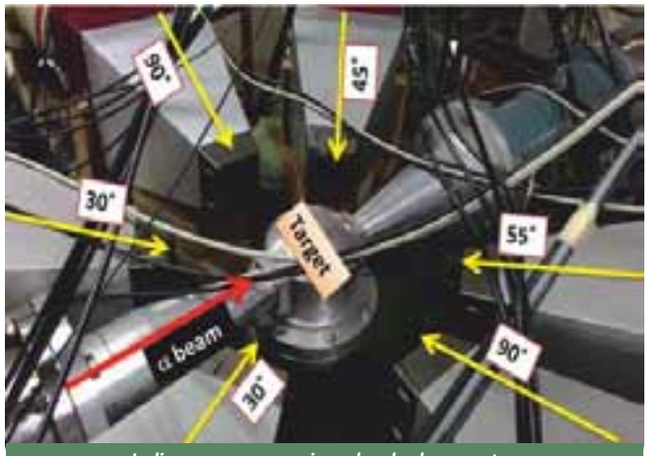
For the first time a comparative study of fission of actinides by protons and bremsstrahlung photons is performed in to provide quantitative estimates of cross sections for RIB. Relative mass distribution of ^{238}U fission fragments are explored theoretically for p- and induced fission. Integrated yield along with charge distribution of the products is calculated to find out the neutron richness in comparison to the nuclei produced by r-process in nucleosynthesis. Some r-process nuclei in intermediate mass range for symmetric fission mode are found to be produced almost two orders of magnitude more for proton induced fission than photo-fission, although rest of the neutron rich nuclei in asymmetric mode are produced in comparable proportions for both the processes. However, production of r-process nuclei by induced fission (bremsstrahlung photons from energetic electron by e-LINAC) is preferred because of better thermal management of target.

Theoretical model of multi-fragmentation

A transformation relation between grand canonical and canonical ensembles in two component Thermodynamical model has been developed. In addition to that also the effect of hyperons on nuclear phase coexistence in strange matter has been studied from 3 components Canonical Thermodynamical model. The bimodality of largest cluster probability distribution in central collision reactions at intermediate energies has been studied from BUU transport model.

First experimental campaign of VECC array for NUclear Spectroscopy (VENUS) with alpha beam at VECC, Kolkata

A moderate array has been setup at VECC, Kolkata, namely, VECC array for NUclear Spectroscopy (VENUS), which presently consists of six Clover HPGe detectors along with the BGO shields for Compton suppression. Recently, this array was setup at the beam line of K-130 cyclotron at VECC, Kolkata, arranging all the detectors in median plane, for its first in-beam experimental campaign. In these first set of experiments, nuclear structure studies of some of the nuclei around A~120 and A~200 mass regions were carried out, which could be uniquely populated with large cross sections using fusion reactions by alpha beams. The setup is shown in Fig.1. A digital data acquisition system from UGC-DAE-CSR, (Kolkata centre) has also been tested with VENUS setup.

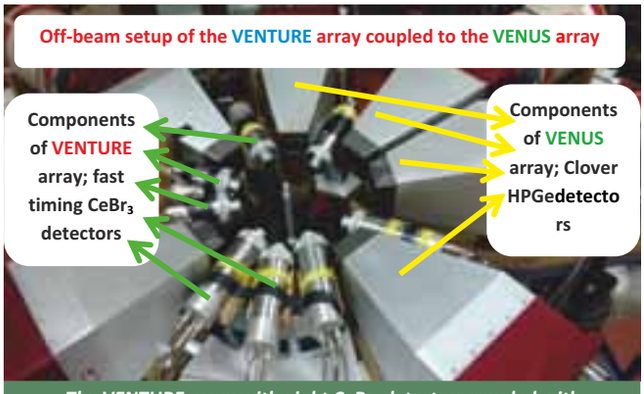


Indigenous supersonic molecular beam setup

VECC array for Nuclear fast Timing and angUlar corRElation Studies (VENTURE)

$CeBr_3$ scintillator detectors, reported to have slightly worse energy resolution compared to $LaBr_3$(Ce) and an improved time resolution are being explored to be a viable candidate for timing spectroscopy and a possible alternative to $LaBr_3$(Ce) detectors, which are limited by their higher hygroscopic nature, self-activity and higher price. The Perturbed Angular Correlation (PAC) measurements have long been used for the measurement of nuclear quadrupole moments and in these works the detectors like BaF_2, HPGe and $LaBr_3$have been used, depending on the lifetime of nuclear levels. The $CeBr_3$ detectors can be a good alternative as well for performing the very precise PAC studies involving nuclear level lifetime ~1 ns to ~10s of ns. Combining the

above two possibilities, an ancillary array of several $CeBr_3$ detectors, named as VENTURE (VECC array for Nuclear fast Timing and angULarcorRElation Studies) has been developed at Variable Energy Cyclotron Center, Kolkata. The array has been used for performing the in-beam prompt spectroscopy and the off-beam decay spectroscopy of radio-chemically separated fission fragments. The array, as shown in Fig. 1, can be used in its standalone mode and also with the array of Clover HPGe detectors, viz., VENUS or INGA and provide a timing characteristics better than the $LaBr_3$(Ce) detectors.



The VENTURE array with eight $CeBr_3$ detectors coupled with the VENUS array of six Clover HPGe detectors

Three $CeBr_3$ detectors of the VENTURE array placed on an angular correlation setup for precise PAC measurements

The main thrust of the research activities in Condensed Matter Physics at SINP has been the study on several manganite samples that illustrates the method of significant enhancement of MR with the reduction of the particle size in nanometer scale. The rare coexistence of a Griffiths phase and a geometrically frustrated antiferromagnetism in the non-stoichiometric intermetallic compound GdFe0.17Sn2 is reported.

Research activities of Surface Physics & Material Science (SPMS) mainly encompassed the growth of low-dimensional (mainly in nanometer length scale 1-100 nm) metallic, semiconducting and organic materials via physical and chemical routes followed by their extensive characterizations with state-of-the-art techniques/tools for achieving tunable mechanical / electrical / magnetic / optical properties relevant in the forefront research areas of micro-nano science & technology. The state-of-the-art characterization techniques, such as a 300 kV transmission electron microscope (TEM) attached with electron energy loss spectroscopy (EELS) and energy dispersive x-ray spectroscopy (EDX), high resolution scanning electron microscope (SEM) augmented with cathodoluminescence (CL) optical detection system, versatile x-ray diffraction (VXRD) system, X-ray photoelectron spectroscopy (XPS) systems along with angle resolved detection capability, ultra-high vacuum based scanning tunneling microscope (STM) and ambient scanning probe microscopes (SPMs) are utilized for structural, compositional, optical, tribological and surface/interface analysis in routine manner. The exploration of the possibility of using low room temperature CNT-based gas sensors prepared on plastic substrates to monitor the presence of ammonia in the environment, where NH_3 concentrations in the low-ppb range are expected. The development of thin film electrodes capable of storing more energy per unit area has become an urgent issue in order to meet the future demands of the electronic industry. The crystallization process for thin high-κ dielectric films and optimal annealing temperature range in the field of high-κ dielectric-based metal-oxide semiconductor (MOS) technology has been investigated. Evidence of buried two-dimensional long range antiferromagnetic (AFM) order has been traced in epitaxial monolayer Cr film deposited on Ag(001) substrate under optimized UHV (ultra-high vacuum) growth condition.

Research carried out at Applied Nuclear Physics involved probing the atomic, nuclear, molecular and nanocrystalline systems using nuclear probes, lasers, X-rays, electron and ion beams. Molecules of biological importance, intermetallic alloys of technological importance and low-dimensional systems, such as nano-crystalline materials are also being studied to explore their properties. Development, characterization and optimization of radiation detectors, model based simulation and cognitive science research to understand the details of visual perception are also being carried out in our laboratories.

CHAPTER 5

The Astroparticle Physics & Cosmology (APC) Division of SINP carried out advanced research in the interface areas spanning High Energy Astrophysics, Cosmology, and Particle & Nuclear physics. During the year under review, members of the Division have carried out research on a variety of topics in AstroParticle Physics observational, experimental and theoretical. The area of research in Theoretical Physics included Particle Physics Phenomenology; Non-perturbative Studies of Quantum Field Theories; Gravity and Cosmology; Strings; QCD at Finite Temperature and Density and Heavy-ion Collisions Phenomenology; Nuclear Theory and Mathematical Physics. Research activities in Plasma Physics Division encompass a variety of theoretical and experimental topics in the field of linear and nonlinear wave propagation.

The Institute of Physics (IOP) is one of the major centers for research in basic science in the Physics stream in the Eastern Part of India. IOP performs vibrant research in the fields of theoretical and experimental condensed matter physics, theoretical high energy physics and string theory, theoretical nuclear physics, ultra-relativistic heavy-ion collisions and cosmology, quantum information and experimental high energy nuclear physics. The main accelerator facilities at IOP are a 3MV Pelletron accelerator an electron resonance (ECR) ion source-based low-to-medium energy ion-beam facility, and a low-energy implanter. These are being used for studies on ion-matter interactions, surface modification, trace elemental analysis, materials characterization, and nuclear physics. One of the important research areas in the Institute is the field of nanoscience and nanotechnology in general and surface and interface studies in particular. The Institute has several advanced facilities for sample preparation and for the study of various physical and chemical properties of nanostructures and bulk condensed matter systems. The Institute is actively involved in the International Collaborations with CERN (Switzerland), BNL (USA), ANL (USA), GSI (Germany), and other laboratories abroad. The Institute is also participating in various research activities related to India-based Neutrino observatory.

The high energy physics group remained involved in pursuing research in String theory, Cosmology and Particle physics. Some of the topics of recent interest are gauge / gravity duality, black hole Physics, anisotropic power law inflation, different aspects of relativistic heavy ion collisions, and dual superconductor model of Hadronization. Connection between phase transition in cosmology and Condensed matter system such as liquid crystal are investigated. In high energy phenomenology, the role of neutrinos in unraveling the mysteries of the universe, cross section processes of one loop which are important for the analysis of LHC data have been studied.

Research areas in Condensed Matter Physics theory spanned mesoscopic systems, statistical mechanics for non-equilibrium systems and biophysics. Some of the topics investigated last year are dynamic phase transition in DNA, fluctuation theorems and phase transitions in driven lattice systems.

In nuclear Physics, research was focused on nuclear structure and nuclear reaction. The mechanism for the formation of superheavy elements in astrophysical objects, nucleus-nucleus reaction and study of cluster decay properties have been pursued. Recently discovered superheavy nuclei and a new mode of fission decay for neutron-rich heavy nuclei has been studied. Measurement of charged particle multiplicity and transverse energy at mid- rapidity and elliptic flow in Pb-Pb and P-Pb Collisions at 2.76 and 5 TeV with ALICE detector at CERN, LHC are reported. In addition, studies on quantum information were also carried out this year.
In experimental physics, 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 Institute of Physics over the years. Some of the topics of current interest are ion beam-induced surface nanostructuring, pattern formation, epitaxial crystallization, and electronic structure studies of multiferroics, manganites etc.

The 3.0 MV pelletron accelerator facilities are being extensively used by University Faculty and

The sample holder and the beam spot taken before doing the actual experiment with the ECR Ion Source of IOP

Students through UGC-DAE consortium. Surface physics and implantation beam lines are being renovated and will be functional soon. A beam time allotment committee has been made. Proposal calls are being called now from BRNS to get the proposals funded to use IOP facility.

At the Harish Chandra Research Institute (HRI), the members of the Astrophysics group have worked in the the field of Gravastars, on study of wormholes, quintessence scalar fields, holographic dark energy models, self-gravitating Bondi flow, non-integrability and chaotic dynamical behaviour of particles in the Kerr metric, analogue gravity phenomena and accretion astrophysics in general.

The condensed matter group of HRI has been focussing on studies of topological phases in quantum matter, new methods to study correlated quantum systems and cluster physics. A new method to study correlated states of matter, at finite temperature and strong coupling, relevant to many real life correlated systems is being developed.Free and surface supported clusters are being studied. Several aspects of topological phases of matter phases, including new layered materials with relativistic electronic band structures such as silicene and germanene are being studied.

A number of important contributions have come from the High Energy Physics group of HRI in the context of new physics search at the Large Hadron Collider (LHC) including possible explanations to recent anomalous events reported by the experiment. The possibilities contained in the data of the newly discovered Higgs boson both in model-independent approaches and in the context of specific models such as supersymmetry or extra dimensions. A good deal of work has also been produced in studies on neutrinos, the illusive weakly interacting particles that contain several unsolved puzzles. In particular, this includes studies in ultra-high energy neutrinos, long baseline physics, and precision measurements in a neutrino detector.

Quantum information and computation is an area of research which promises an efficient method for communication and better computational power than their classical counterparts. The areas of research by the members of the HRI group included quantum correlations and quantum coherence, and their implications in real physical systems, like photonic and ultracold gas systems.

Basic formalism in string field theory and string perturbation theory has been developed. This has provided methods to compute various off-shell quantities in string theory. The formalism also gives an unambiguous prescription to carry out calculations in string perturbation theory. Stokes phenomenon in the context of interpolating functions and N=2 supersymmetric gauge theories has been analysed. The interplay between supergravity theories with maximal supersymmetry and string theory has been explored.

The School of Physical Sciences at the National Institute Education of Sconce & Research (NISER) continued the Physics educational programmes and provide many facilities which included Cryogenic Free Physical Property Measurement System; Low temperature Magneto Resistance Set-up; Plasma Enhanced Chemical Vapour Deposition Set up.

CHEMISTRY

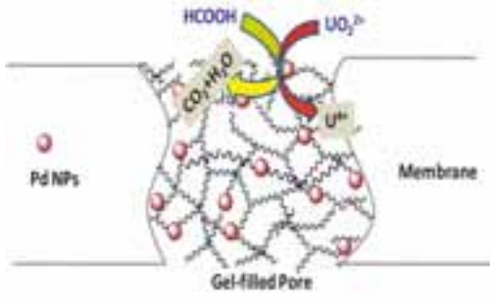
At BARC, positron annihilation and nuclear magnetic resonance spectroscopic techniques have been exploited to understand the phase transition behaviour of water confined in MCM-41 mesopores at different levels of hydration. This study suggested that the level of hydration modified the H-bonding network of nanoconfined water, which in turn, influenced the phase transitions of supercooled water. This study is useful in nanofluidics and drug-delivery systems, in addition to understanding the fundamentals of the phase transition behaviour of water in nanoconfinement.

Studies on the batch sorption and thermodynamic modelling were conducted for Np(V) sorption onto thoroughly characterized bentonites from different origins of India (Kutch, Rajasthan) and Russia (khakassia) to understand the role of iron-containing accessory phases on the Np(V) sorption. The samples were characterized by XRD, Mossbauer spectroscopy, XRF, HRTEM, SEM-EDX and other techniques, and wherever possible, the accessory iron phases were identified and quantified and were seen to suggest a dependence of Np(V) uptake on iron content. These studies illustrate the important role that

accessory minerals, even at very low content, can play in governing Np(V) sorption under natural systems.

Several benzene-centred tripodal diglycolamide (DGAs) and DGA-dendrimers were synthesized for the first time and evaluated for their efficacy in actinide separations. The ligands showed highly favourable extraction of trivalent lanthanides (D_{Am} values were >100 at 3 M HNO_3 with $1x10^{-3}$ M ligand solutions in *n*-dodecane). Though UO_2^{2+} ion extraction was very low (D_U <0.1) under identical conditions, the separation efficiency with respect to Eu^{3+} was quite moderate. From the point of view of actinide ion extraction, these ligands are considered to be comparable with that of the DGA-calix[4]arenes reported earlier.

To develop an efficient, robust and recyclable heterogeneous catalyst, the palladium nanoparticles (Pd NPs) were formed by spontaneous reduction of Pd^{2+} ions with hydrazine covalently attached via glycidyl units to the pore wall of poly(propylene) membrane as shown in the figure. Catalytic activity of Pd NPs did not deteriorate during the 5 cycles and after storing for 3 months suggesting a long shelf-life.



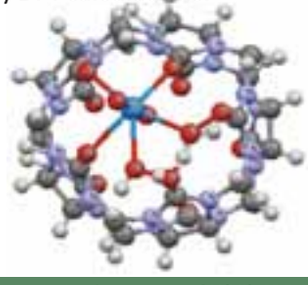
Egg-shell mimicking membrane for hosting Pd nanoparrticles

A high performance liquid chromatographic method using α-hydroxyl isobutyric acid as an eluent was established to separate different oxidation state of Pu such as Pu(III), Pu(IV) and Pu(VI) from each other.

An electrochemically prepared Prussian blue-manganese hexacyanoferrate (PB-MnHCF) nanocomposite on Glassy Carbon (GC) electrode shows very high specific capacitance of 1333±95 F g^{-1} at a current density of 7 A g^{-1} and excellent cycling stability (93% capacitance retention up to 500 cycles) at a scan rate of 50 mV s^{-1} in 0.1 M KNO_3 (pH=2) medium. It also shows selective and sensitive electrocatalytic response towards H_2O_2 reduction and ethanol oxidation. A facile hybrid electrochemical-chemical (E-C) methodology is demonstrated to synthesize Prussian blue on Au electrode from single ferricyanide solution.

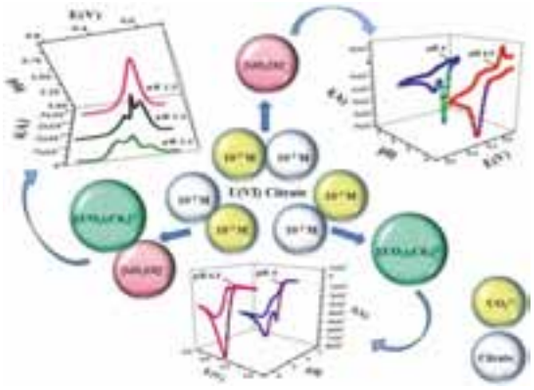
Total Reflection X-ray Fluorescence (TXRF) based X-ray Absorption Near Edge Spectroscopy (XANES) has been used to determine the oxidation states of U in mixed valent U_3O_8 and U_3O_7 uranium oxides. It showed that U_3O_8 is a mixture U(V) and U(VI) oxides in the ratio of 70% and 30 % respectively whereas U_3O_7 is mixture of U(IV) and U(VI) in the ratio of 70% and 30 %.

Macrocyclic ligands like substituted crown ethers, calixarene, calixcrown etc., have been used in nuclear industry for selective separation of metal ions like Cs(I), U(VI) etc. Cucurbiturils (CB[n]) are the new class of macrocyclic ligands with unique structure and have shown affinity for different metal ions depending on their cavity size. The speciation, coordination behavior and energetics of their complexation of these ligands with U(VI) has been studied in solution. Thermodynamic parameters viz enthalpy and entropy, determined by calorimetry and UV-Vis spectroscopy, points toward the partial dehydration of U(VI) in U-CB5 complex. The spectroscopic investigations by NMR and EXAFS support the unsymmetrical binding of U(VI) to CB5 along with encapsulated anion which was rationalized by DFT calculations.



Optimized structure of U(VI)-CB5-FA

Studies on complexation and redox behaviour of U under varying physicochemical conditions in presence of chelating ligands (organic or inorganic) is important from the point of view of their redox speciation and predicting their mobility in aquatic environment. Citric acid, a decontaminating agent for nuclear wastes, remarkably affects the mobility and solubility of U. The Cyclic and Square wave voltammetry have been used to investigate the dominant species of U(VI) Citrate at particular physicochemical conditions on the basis of their redox behaviour.



Redox Speciation of Uranium in Citrate medium

UO_2^{2+} in citrate media exists as UO_2^{2+}, monomer $[UO_2Cit]^-$, dimer $[(UO_2)_2Cit_2]^{2-}$ and polymeric species. Both monomer and dimer are found to be reduced in two irreversible one electron steps with a chemical reaction coupled between them (ICI mechanism) to a stable U(IV) Citrate species at pH $\leqslant$ 5 and via a single reduction step with two electron transfers at pH>5. Using Spectroelectrochemical measurements the clear electronic spectrum of new U(V) species i.e. $[U^VO_2Cit]^{2-}$ in aqueous system has been obtained. The present work is significant for the design and manipulation of redox-based remediation strategies, for understanding the effect of citrate on the migration of uranyl in the environment and for improving predictive modeling of uranyl cycling in soil.

Towards development of new stereo- and regio-selective allylation reactions, Bi-metal-catalyzed carbonyl allylation protocols have been developed. In a weekly acidic Room Temperature Ionic Liquid (RTIL), the reaction proceeds via γ-addition with the γ-substituted allyl bromides with excellent *syn*-selectivity. However, the reaction produces the α-addition product by changing the acidity of the RTIL. A new conjugate of amino bisphosphonic acid and *p*-Bz-SCN-DOTA was synthesized. The ^{153}Sm-radiolabeled product of the conjugate showed good *in vitro* stability in rat serum. Its bio distribution studies in a mice model revealed good accumulation in bones, making it a promising candidate for imaging and therapy of bone metastases. The iron chelator desferrioxamine (DFO), used for treating iron-overload diseases has low bioavailability and can't chelate the intracellular labile iron pool. To increase its bio availability, a DFO-*N*-heterocycle conjugate was designed and synthesized. The conjugate was found to be internalized into the iron-overloaded cells to decrease the labile plasma iron substantially. The bicyclic diaza iminosugars are valued for selective inhibitory property against various glycan-processing enzymes, resulting into important medicinal properties. Hence an asymmetric synthesis of diaza bicyclic iminosugars strategy has been developed with glucose as the chiral template, using aza-alkene cyclo-addition reaction.

At TIFR, novel N-H···N hydrogen bonded complexes were characterized by zero kinetic photoelectron spectroscopy. Achieved first identification and characterization of C-H---S unconventional hydrogen bonded system. Discovered a simple and sustainable method for the synthesis of monodisperse metal nanoparticles supported on the fibrous nanosilica (KCC-1). Novel hybrid materials were synthesized by functionalization of KCC-1 for efficient CO_2 capture. Inorganic vanadates were developed as viable electrodes for super capacitor applications. Novel luminescent Carbon Nanodots have been prepared. Ratiometric fluorescent sensors were developed for detecting phospholipids, phosphoinositides, in live cells that are linked to multiple diseases including cancer, bipolar disorder, and type 2 diabetes. A sensitive fluorescent and colorimetric sensor has been developed for detecting mercury ions in aqueous medium as well as in living cells.

A new method has been developed to determine the shape of the toxic Alzheimer's molecule, using a surface enhanced Raman spectroscopy technique and revealed the main structural features which make the Alzheimer's molecule toxic. An unusual calcium binding protein from *Entamoeba histolytica* that binds and hydrolyzes guanosine triphosphate has been structurally characterized. Structural characterization of an UV inducible protein (UVI31+) uncovered first structural description of a plant chloroplast endonuclease that is regulated by UV-stress response in a single-cell green alga cells. Designed a novel thermostable biocatalysts based on variants of thermostable cytochrome P450 enzyme for specific hydroxylation of long-chain fatty acids and for syntheses of aromatic dyes. The influence of some osmolytes on the fibrillation process of proteins has been unravelled and the effects of selected herbal preparations on the dissolution and inhibition protein fibrillation have been revealed by NMR and other methods. These results

have therapeutic implications. Mechanoresistance of a cell-surface protein of malarial parasite, plasmodium falciparum, was examined for its structural and functional properties.

Strategies have been devised to obtain information regarding the structure of various molecules with high resolution in nuclear magnetic resonance spectroscopy of solids. Structural and mechanistic insights have been obtained for two peptides responsible for Alzheimer's disease. Methods will be devised to obtain geometry information using nuclear magnetic resonance spectroscopy in solids which will be tolerant to various experimental imperfections. Initial magnetic resonance experiments will also be carried out on noble gases, such as, Xenon, the magnetisation of which will be enhanced several fold with optical pumping.

Research in the Chemical Sciences at SINP is wide-ranging and interdisciplinary, and addresses fundamental aspects of science. Overarching goals of the research projects include understanding the excited state dynamics of complex phenomena using ultra-fast spectroscopy and single molecule imaging, finding new functions for old drugs: Non-Steroidal Anti-inflammatory Drugs (NSAIDs), different areas in Nuclear Chemistry, Radiochemistry and Green Chemistry, developing nanotechnology and novel advanced materials for a myriad of applications, unraveling problems associated with devising new, alternative sources of energy, neutron spectrometry and interaction, nano particle dosimetry and radiation safety.

Copper complexes of Oxicam NSAIDs have been synthesized to study their biological applications. They form a new class of membrane anchors that require neither molecular recognition nor strength of interaction between interacting molecular partners, but still can effectively increase membrane fusogenic efficacy over the bare drugs.

A non-enzymatic electrochemical biosensor has been fabricated for cholesterol detection, having a distinct advantage over other conventional enzymatic processes.

A single molecule and ensemble spectroscopic study of protein folding, misfolding, aggregation and DNA-protein interaction have been carried on. Quantum chemical calculations have also been carried out to address some of the fundamental problems based on experimental findings.

The Nanophotonics group is actively engaged in the field of sustainable nano-architecture addressing both their development and applications. Recently the group has developed different architecture of nanomaterials which include tunable gold nano-flowers, silver nano-wires, selenium nano-spheres, intercalated nano-prism, branched gold nano-crystals, and porous silver nano-materials. Nanophotonics group also successfully used these materials in effective drug delivery, Raman sensing of environmental heavy metals, catalysis, therapeutic prevention of viral infection, and in nanoplasmon biochip for bioanalytical detection.

For the first time non-destructive method have been designed by the nuclear and radiochemistry group to determine K content of ancient glass beads which eventually tells about the origin of glass bead. Contribution have made in Radio-Green Chemistry experiments.

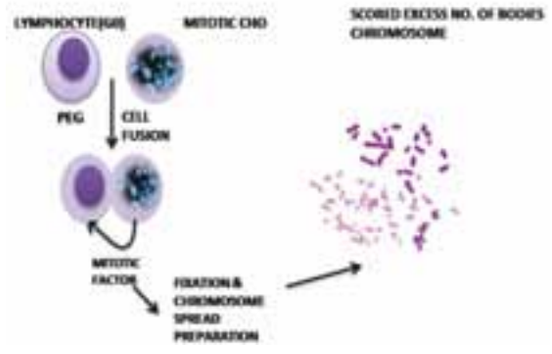
Effect of nuclear mean field and multiple pre-equilibrium mechanism in neutron emission from heavy ion reaction has been studied in the energy range of 10 MeV/amu to 30 MeV/amu.

Some of the major facilities provided by the School of Chemical Sciences at the National Institute Education of Sconce & Research (NISER) inlucded 700 MHz NMR; ThermoGravimetric Analysis (TGA); Differential Scanning Calorimetry (DSC) and Fluorescence Spectrometers (Advanced).

BIOLOGY

High dose accidental exposure cases need to be quickly assessed to plan for appropriate medical intervention and reduce panic. Conventional dicentric assay, though the gold standard assay for biodosimetry, is not suitable for high dose exposure due to cell cycle arrest and severe leucopenia. Mitotic Fusion based premature chromosome condensation technique (PCC-F) is a technique which can estimate doses in a range of 0.2-20 Gy in very short duration (6-8 h after blood

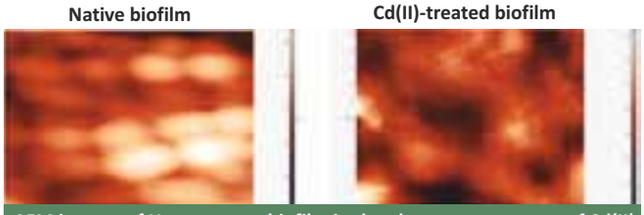
collection). Thus, for rapid biodosimetry of high dose accidental exposure, establishment of premature chromosome condensation technique was planned and accomplished this year. Reproducibility of the method has been tested using multiple blood samples from different donors. Radiation dose response curve has been prepared using ex-vivo irradiation of blood samples. Blood samples were irradiated to different doses ranging from 2-15 Gy using Co-60 gamma source. Study for inter-individual variations in dose response is in progress. Standard operating procedure to perform the assay has been developed.



Protocol for PCC-Fusion method

The BinAB toxin produced by a bacterium is widely used to kill the larvae of Culex and Anopheles mosquitoes and control of the diseases borne by them. For broadening of its biological activity spectrum, a novel product of BinA alone has been synthesized by BinA modification that is more active than BinA/BinB mixture.

A protocol for biofilm formation has been developed using an Indian cyanobacterium, *Nostoc muscorum*. The biofilm adhered to the glass surface within a week and could entrap toxic Cd(II) ions from aqueous solution with good kinetics.



AFM images of N. muscorum biofilm in the absence or presence of Cd(II)

A promoter that is switched on in presence of DNA damaging agents, was cloned and its performance validated using Green Fluorescence Protein (GFP) as a reporter. Regulation of this response has also been established and will be tested for detecting DNA damaging agents.

At TIFR, the role of particular motors (Kinesin-1 and Kinesin-2) regulating the transport of a key protein involved in neuronal function (Acetylcholinesterase) was revealed; TIFR also discovered that Kinesin motors, whose recruitment to lipid droplets is regulated, control fat metabolism in the liver and maintain circulating triglyceride levels during feeding and fasting conditions. This finding also has relevance in Hepatitis-C infections; In a major breakthrough, it has been found, how dynein motors apply forces to carry cargo and that cholesterol is required to cluster these motors on phagosome membranes.

How dynamics of a cytoskeletal protein, F-actin is critical for spermatogenesis and that it prevents abnormal somatic cell penetration by mature spermatids has been found; Evolutionarily conserved developmental signals (Wnt) regulate cell shape through an extracellular metric component has been reported; The key roles of two molecules (aPKC and Lgl) in regulating apical-basolateral polarity in cells have been unravelled; TIFR has set up an in vitro system to follow mechanistic details of cell division for both fission yeast and budding yeast cells, which is largely controlled by cytoskeletal proteins; Discovered the mutual dependence of actin and microtubule cytoskeleton in the control of both pulsed cell constriction and cell delamination.

Neuronal/brain development and organismal behaviour are regulated by elaborate mechanisms and the latter is also known to be altered during the lifespan of an organism, depending on previous exposure to stress. The mechanistic basis of the cirtical role of a transcription factor (Lhx2) in determining neuronal development have been found; The importance of Gq mediated signaling in excitatory cortical neurons to program long-lasting effects of mood-related behavior across the life-span has been unravelled .

Cellular and organismal metabolism plays a vital role in determining survival and is the leading cause of aging and age-related diseases such as obesity and diabetes. Novel control mechanisms that regulate insulin secretion and how early life psychological stress affects muscle metabolism/mitochondria and possibly

cause a pre-disposition to obesity/diabetes, both of which are co-morbid have been found; Unravelled a novel systems level control of gene expression and physiology that is essential to maintain feed-fast cycles.

Developed a model and studied the sensitivity and resilience of early developmental processes to alterations in ploidy(total number of chromosomes); Demonstrated that DNA damages in Drosophila cells trigger cellular death induced proliferation leading to tissue compensation.

The efforts at TIFR have revealed several key aspects of malarial parasite biology and provided potential vaccine targets; The role of a key protein on the invasive sporozoite surface, which will help control the parasite better have been understood. We have also found that a single malaria episode in juvenile mice, renders them to higher anxiety levels in later life.

The various studies undertaken at TIFR's National Centre for Biological Science, Bangalore included the Pathogenic Mutations within the Disordered Palindromic Region of the Prion Protein Induce Structure Therein and Accelerate the Formation of Misfolded Oligomers; Genome-Wide Prediction and Analysis of 3D-Domain Swapped Proteins in the Human; Store-independent modulation of Ca(2+) entry through Orai by Septin 7; Contrasting effects of defaunation on aboveground carbon storage across the global tropics; Role of DARPP-32 and ARPP-21 in the Emergence of Temporal Constraints on Striatal Calcium and Dopamine Integration; Stacking the odds for Golgi cisternal maturation and Chronic but not acute immobilization stress stably enhances hippocampal CA1 metabotropic glutamate receptor dependent Long-Term Depression.
At SINP, the widely prevalent diseases such as leukemia, Alzheimer's and the Prion diseases are being investigated for gaining insights into the diseases. Differential proteomics studies have been performed using clinical samples of cerebrospinal fluid, blood and plasma. Investigations in cellular signalling and its role in cell fate determination *vis a vis* regulation of metabolism were studied using comparative mitochondrial proteome. Epigenomics studies on function and dynamics of transcription factors have been initiated to interpret the epigenetic language in eukaryotic cells. Neurodegenerative disorders like Alzheimer's and Prion Diseases are being pursued to study the roles of various micro RNAs in the disease process. The major focus of research in Alzheimer's has been the study of the downstream pathogenesis mediated through AICD and its adaptor network. Study of the structure and conformation of proteins involved in various cellular regulatory processes remained the main focus of Crystallography and Molecular Biology Division at SINP. Several unique sugar metabolizing proteins have been identified in *Leishmania donavani*, a protozoan parasite that causes Leishmaniases, which are potential drug targets. Works are in progress to elucidate the functional interaction of DNA repair protein (Ku) with the cell cycle modifier polo-like kinase 1 (Plk1). Cloning, expression and purifications of spectrin domains such as the ankyrin binding domain, self-associating domain, SH3 domains etc have been initiated to explore their protein-protein interactions, chaperone activity and membrane binding potential. We are starting a new research area on characterizing the structural dynamics of membrane proteins. Structural dynamics of potassium and magnesium ion channels have been just initiated to decipher lipid-dependent voltage gating mechanisms.

Some of the major facilities that we have recently added to the already fairly rich research infrastructure of The School of Biological Sciences at the National Institute Education of Sconce & Research (NISER) included the X-ray Diffractometer for Protein Structure Analysis

CANCER

The ACTREC facility at Kharghar, Navi Mumbai continued to provide the facilities for Basic/Clinical/Translational Research. The emphasis was laid on therapies which can work well in the local context and are cost effective.

The Scientific and Ethics committees reviewed all the new proposals and approved Research Projects after scrutiny as per law established. The Data Monitoring committee periodically reviewed ongoing research and reports to the Scientific Committee and Ethics Committee which has the responsibility to modify/stop the research activities if called for. The conduct of Research activities are accredited by International Agencies (AAHARP) which emphasize on Patient Safety.

SYNCHROTRON & THEIR UTILISATION

The synchrotron radiation sources at RRCAT, Indus-1 and Indus-2 were operated round the clock as a national facility for the Synchrotron Radiation (SR) user community. Indus-1 was operated at 450 MeV energy, 100 mA current, and Indus-2 was operated at stored current up to 200 mA at 2.5 GeV energy. The undulators U1 and U2 installed in 2015 in Indus-2 were successfully operated at enhanced beam currents in excess of 150 mA. The third insertion device, namely, the APPLE-2 undulator was commissioned this year with demonstration of enhancement in brilliance. It was also operated at a beam current in excess of 100 mA. A number of optimization steps were employed to re-establish operation of Indus-2 at 200 mA with reduced vertical aperture of vacuum chamber at the APPLE-2 undulator location. The machine was run at 2.5 GeV, 200 mA in user mode. Figures 1 and 2 depict the typical user mode operation of Indus-2 at 2.5 GeV energy.

In Indus-2 the ceramic chambers of four injection kicker magnets were replaced with new upgraded chambers which has improved the vacuum in the injection segment from 3×10^{-9} mbar to 5×10^{-10} mbar. This has resulted in improvement in beam life time from 20 hrs to more than 40 hrs at 100 mA beam current at 2.5 GeV beam energy. The lifetime has progressively improved after replacement of injection kicker chambers.

The beam lifetime in Indus-1 also improved after the maintenance of UHV system carried out which involved replacement of gate valve at Indus-1 and a number of titanium sublimation pump filaments in Indus-1 ring. During 2016, Indus-1 and Indus-2 were operated round-the-clock for 340 days. The beam availability to the users was more than 7200 hrs for Indus-1 and more than 5200 hrs for Indus-2.

The Advanced Plane Polarised Light Emitter Undulator APPLE-2, was installed in Indus-2 last year. The effect of undulator action on the orbit stability with low beam current (5 mA) at 2.5 GeV was studied. There was no significant distortion of the orbit during magnet pole gap and phase movement. The basic performance of the undulator was demonstrated using Scanning Wire Monitor (SWM) and beam viewer mounted on the zero degree port of the downstream dipole magnet chamber.

The beam images of the SR coming from the undulator for 0 mm, 0.32λu and 0.5λu phase shifts corresponding to linear polarization in horizontal plane, circular polarization and linear polarization in vertical plane respectively. The observed beam profiles showed a trend that matches well with the theoretical prediction.

The circular polarized synchrotron radiation from this undulator will be used for the study of magnetic materials using by carrying out X-ray Magnetic Circular Dichroism (XMCD) experiments in a dedicated beamline. The photon energy range of interest is 300 eV to 1500 eV including higher harmonics. After commissioning of the APPLE-2 undulator Indus-2 was operated at higher current (2.5 GeV, 100 mA) with vertical jaw movement of APPLE-2 up to minimum pole gap. There was no significant change in beam life time and temperature of vacuum chamber by changing the pole gap from maximum to minimum.

The two planar undulators namely U1 and U2, installed last year in the Indus-2 storage ring were successfully operated at 150 mA, 2.5 GeV. In order to handle the high heat load of synchrotron radiation emitted from these undulators, the cooling water flow rate in the beam dumps was increased from 1.5 lpm to 3.5 lpm. All the components of the front end were re-aligned to ensure proper passage of beam without any obstruction. The safe limit of electron beam position were determined at low current and fed to the Insertion Device Beam Position Indicator (IDBPI) interlock controls. Undulator operation was performed with beam current increase in steps. Tune variations during U1 and U2 undulator gap variation were measured, and it was observed that there was no significant change in betatron tune values during the undulator operation. It was also observed that there was no significant change in the temperature of vacuum chamber, and beam lifetime during the undulator pole gap variation. This demonstrated satisfactory functioning of sub-systems, interlocks and orbit correction schemes. During this experiment the jaws of APPLE-2 were wide open at maximum pole gap.

Four units of 60 A, 25 V power supplies for the quadrupole magnets of transport line (TL-2) have been installed. Four such supplies were installed last year. All the 8 power supplies have been successfully integrated with the new control racks. This complete the upgradation of the TL-2 quadrupole magnet power

supplies. Three power supplies have been developed, installed and commissioned in Indus-2 magnet power supply hall. Eight Fast Orbit Feedback (FOFB) corrector power supplies (third phase) for fast correction of electron beam orbit, and four active shunt power supplies for independent adjustment of Indus-2 quadrupole currents have been installed. The FOFB were recently used in the successful commissioning of Apple-2 undulator.

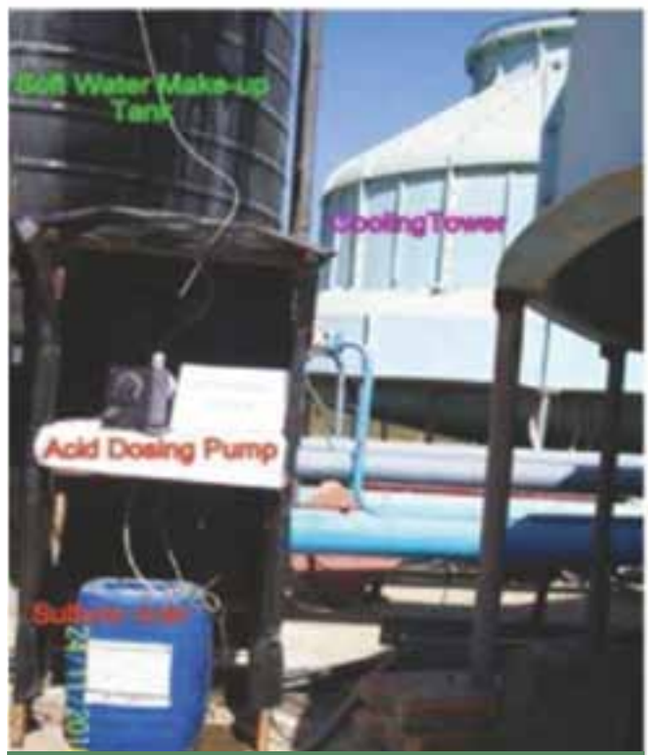
An upgraded fluorescent type Beam Profile Monitor (BPM) has been developed and three numbers of such BPM have been installed in the Indus-2 for the observation and measurement of electron beam profile. The design of BPM includes synthesis of newly designed linear actuation mechanism and ceramic support system, ultra-high vacuum compatibility, thermal and structural analysis of ceramic screen and structural analysis of its housing and support. In order to keep the compatibility with the existing system of operation and control, the upgraded BPM uses the pneumatic system. However to make it fail safe (to avoid fluorescent screen coming in to the beam path in the event of pneumatic system failure), double acting pneumatic cylinders are used.

Beam Profile Monitor installed in Indus-2 ring

Photographs of BPM and bellow assembly during lab test

Upgraded Beam Position Indicators (BPIs) have developed and six units were installed in Indus-2. The upgraded BPIs have improved features like transfer impedance 0.56 Ω @ 505.8 MHz (targeted value > 0.5 Ω), sensitivity 0.06 per mm (targeted value > 0.05 per mm) in both the transverse planes and dedicated vibration isolation support structure. Software development for bunch-by-bunch betatron tune measurement has been carried out to obtain the information about betatron tune of individual electron bunches in Indus-2.

In an accelerator like Indus-2, Low Conductivity Water (LCW) is used for the cooling of accelerator components, power devices in magnets and RF power supplies etc. A weak acid cation bed has been developed and installed for online polishing of cooling tower water. This has brought down the water hardness from 20 ppm to 2 ppm. Further dosing of 98% sulfuric acid at the rate of 120 ml per hour has been started. As a result, scale formation is found to have been controlled.



Acid dosing system

Weak acid cation bed

Residual gas data obtained from Residual Gas Analyser (RGA) from undulator section (U2) of Indus-2 storage ring was analyzed and gas bremsstrahlung simulation study was performed for both air composition and the measured composition of residual gas molecules from Indus-2 ring. The gas bremsstrahlung spectrum and dose in a tissue phantom were studied and composition of the residual gas from the storage ring using FLUKA code.

The absorbed dose rate normalized to pressure in the ring was found to be 1.249 Sv/h- nTorr in case of air composition and 0.392 Sv/h-nTorr in the case of residual gas composition for 2.5 GeV and 200 mA circulating current.

Effect of gas molecules like hydrogen, nitrogen, oxygen, CO_2, CO, air, residual gas from Indus-2 on gas bremsstrahlung spectrum and corresponding doses were also studied. The absorbed dose rate obtained is found to increase with the product of effective atomic number and molecular mass of gases.

Indus-2 has been upgraded with the addition of three undulators (insertion devices). Source term evaluation studies for undulator beam line in Indus-2 were performed using FLUKA Monte Carlo code. The simulation for shield assessment for the beam line was carried out by incorporating relevant beamline components like mirror, mirror chamber and complete optics hutch layout. The necessary front and lateral wall thickness for the hutch was found to be 5 mm and 2 mm thick (lead) respectively to contain the scattered bremsstrahlung photons. Additional 15 cm polyethylene is also suggested behind the bremsstrahlung stop to provide shielding for neutrons generated from the bremsstrahlung stop. The dose rate in the detectors are found to be within acceptable level.
An aluminum wide band (1264.5 MHz -1517.5 MHz) ridged waveguide loaded re-entrant type prototype kicker cavity has been designed, fabricated and tested. A complex geometry of waveguide loaded structure has been realized to get the low quality factor of 5.5 required for wideband application. RF characterization was carried out using a VNA, broadband two four-way splitters, eight cables of identical length and 50 Ω matched loads. Optimized cavity diameter and length are ϕ 162 mm and 230 mm respectively for a central frequency of 1391 MHz and the loaded quality factor 5.5. Tuning was performed by taking machine cuts cavity lip, thereby adjusting the cavity length iteratively along with measurements to arrive at the desired frequency. To take care of harmful Higher Order Modes (HOM), three HOM damping loop type couplers are also designed and mounted. The resonant frequency, bandwidth and R/Q of all modes including fundamental

Half cell of kicker RF cavity

Assemble kicker cavity with couplers

are measured and found satisfactory for the purpose of curing longitudinal multi bunch instabilities of Indus-2.

Modified four numbers of upgraded ceramic vacuum chambers for kickers in Indus-2 have been installed in Indus-2. This has improved the average vacuum of the Indus-2 storage ring and increase in beam life time to more than 30 hrs at 100 mA and 2.5 GeV. The average vacuum in the ring now is 3×10^{-10} mbar as compared to 9×10^{-10} mbar with the old ceramic chambers.

A new injection thin septum magnet with a aperture (10 mm x 28.5 mm) has been developed. The thickness of septum with mu metal shield and 0.25 mm alumina coating has been optimized for radial field homogeneity (10^{-3}) near the thin conductor and low leakage fields outside the septum towards circulating orbit. The magnet was fabricated from 0.1 mm NiFe C-shape laminations with assembly tolerances of better than 50 µ along the 250 mm length. The NiFe cores were annealed at 1100 ºC in the hydrogen atmosphere and oxidized on both surfaces so as to get 10 µm electrical insulation to reduce eddy currents during pulse operation. On excitation with a 50 µs pulse integral field homogeneity (ΔB/B) was found to be 3×10^{-4} and the effective magnetic length was 250 mm. The maximum of the stray field is reduced down to 0.05% of the peak main field. The measured waveforms of stray field are in good agreement with the simulation results.

Thin septum magnet in the measurement bench

The 6 beamlines on Indus-1 and 13 (10 open to users) on Indus-2 are national facilities. More than 600 user experiments were carried out at the Indus-1 and Indus-2 beamlines in the calendar year 2016, leading to about 100 publications in peer reviewed international journals.

Some of the work carried out at the Indus-1 and Indus-2 beamlines are described briefly as under:

Studies on optical properties of low-Z/low-Z C/B4C multilayers have been carried out using synchrotron based soft x-ray reflectivity beamline (BL-3) in Indus-1. These low Electron Density Contrast (EDC) structures have potential to be used as mirrors, monochromators, beam splitters etc. for high intensity radiation. Resonant photoelectron spectroscopy experiments have been carried out using the angle resolved photoelectron spectroscopy beamline on Indus-2 in several systems including an intermetallic alloy FeAl.

The angle dispersive x-ray diffraction beamline (BL-12) was used to study various technologically important materials. Interface properties of NiO epitaxial thin films were studied. Nucleation and growth of the product phase was studied in the Fe_xRh1_{-x} alloy system and a phase co-existence was shown to occur in the temperature range of 300 K to 320 K.

Temperature dependent crystal structure was determine for multi-function materials Co_3TeO_6 and $Co_{2.5}Mn_{0.5}TeO_6$. A strong coupling between the spin and lattice degrees of freedom has been demonstrated in the materials.

Extended X-ray Absorption and Fine Structure (EXAFS) measurements have been carried out on technologically important materials. In a study on CeO_2, it was shown that Sm and Sr doping strongly favors local structural changes favorable for reducing the operating temperature of electrolytes for intermediate temperature (300ºC to 450°C) operation, which is reported for the first time. EXAFS and XANES measurements were performed on Mn-Li co-doped ZnO nanoparticles. Their implications on the photo catalytic properties.

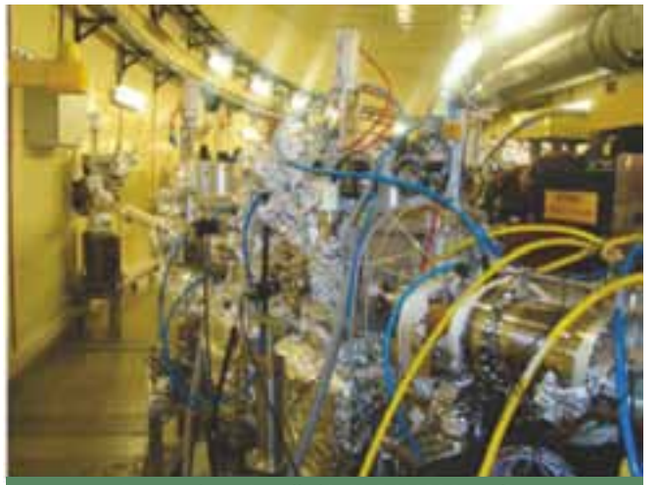
Soft x-ray absorption beamline BL-1 has been used for the study of oxygen absorption in niobium doped TiO_2 which is important for applications such as gas sensors, photo catalysis, electron injection in solar cells and alternative conductive electrode. The role of Nb doping in changing the Ti-O bond and Ti oxidation state was analyzed and correlated with the observed physical and optical properties. The protein crystallography beamline BL-21 has been used to solve several protein structures. Among them, the structure

of Acyl peptide hydrolase enzyme from an extremely radiation resistant bacteria *Deinococcus radiodurans* has been solved and analyzed. The results may be relevant in the radiation resistant mechanism observed in the bacteria.

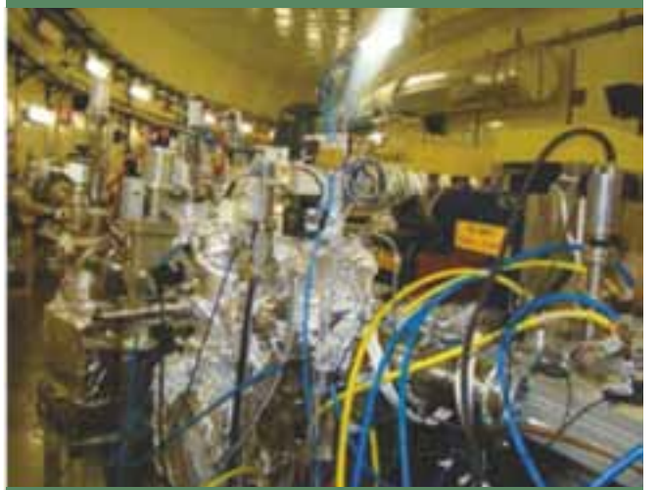
Total reflection X-ray Fluorescence (TXRF) based x-ray absorption near-edge spectroscopy has been carried out at x-ray fluorescence beamline BL-16 to determine the oxidation state of uranium in mixed-valent U_3O_8 and U_3O_7 uranium oxides. The analysis revealed that U present in U_3O_8 is a mixture of U(V) and U(VI), whereas U in U_3O_7 is mixture of U(IV) and U(VI). The present study has demonstrated the possibility of application of TXRF for the oxidation state determination and elemental speciation of radioactive substances in a nondestructive manner with very small amount of sample requirement.

Monochromatic X-rays at an energy of 20 keV at the imaging beamline (BL-4) has been used for the formation of Ag nano-particles by the process of radiation induced hydrolysis. This is a novel technique used for the first time to produce bulk amount of nanoparticles. X-ray lithography beamline (BL-7) has been used for the development of several high aspect ratio structures for focusing x-rays and correcting the x-ray wave-fronts to get better focusing properties of mirrors. A large aperture lens, required for the x-ray diffraction beamline (BL-11) of Indus -2 was fabricated.

Significant efforts have been put in towards the development of new beamlines and their related facilities. These include the installation of the radiation shielding hutch of the Engineering applications beamline, installation of the monochromator of the ARPES beamline, procurement of the gratings and the other optical components for the ARPES beamline etc. The front end (FE) for Indus-2 soft x-ray beamline (BL-26) has been installed and tested. The major components like water-cooled shutter, safety shutter, collimator, vacuum chambers and support/alignment systems are designed, fabricated, tested and installed in Indus-2 ring. A vacuum of the order of 1.0×10^{-9} mbar has been achieved in the front end. Some of the components like pre-mask, water cooled beam viewer, scanning wire monitor etc. of undulator U-3 based x-ray magnetic circular dichroism beamline (BL-20) front end have been designed, indigenously fabricated and installed in Indus-2. The beam viewer and wire monitor



Front end part installed in BL-5 AMOS Beamline

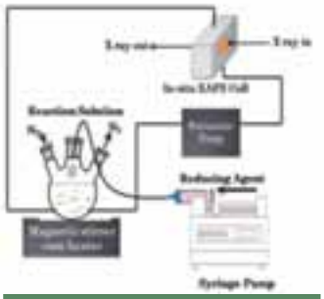


Front end part installed in BL-10 ARPES beamline

are used to provide the shape, size, position and profile of the synchrotron radiation from undulator U-3. A part of the front-ends for "Atomic, molecular and optical sciences beamline" (BL-5) on U-1 undulator and "Angle-resolved photo-electron spectroscopy beamline" (BL-10) on U-2 undulator have been installed. The remaining components of these front-ends like water-cooled shutters, safety shutters, water-cooled masks, beam viewer and vacuum chambers are designed, fabricated and tested for 1.0×10^{-9} mbar vacuum.

At BARC, a computer-controlled flow setup has been designed and implemented at the Energy Dispersive EXAFS beamline (BL-08) at INDUS-2 SRS, facilitating the in situ time-resolved X-ray Absorption Spectroscopy (XAS) measurements on reactions carried out under specialized experimental conditions. A reaction vessel consisting of a three neck flask with two side nozzles connected to peristaltic pump is used for adding, stirring and mixing reactants whereas the XAS cell for the sample is made of Teflon with Kapton

Photograph of in-situ EXAFS setup



Schematic of the experimental arrangement

windows. The setup has been used to probe in-situ nanoparticle growth in a chemical reaction using XAS.

Significant progress was made on the development of Double Crystal Monochromator - II (DCM) for X-ray beamlines at RRCAT, Indore. Design, fabrication, assembly, integration and vacuum testing of major sub-systems were carried out. Software for automated operation was also developed. The calibration of DCM with auto-collimator in the beam line is in progress. Once operational, this DCM can offer an energy resolution of 1.4×10^{-4} in the range 2.5-15 KeV.

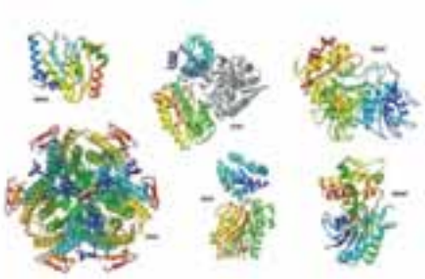
DCM II Design

Photo-Electron Spectroscopy (PES) beamline at INDUS-2 was modified to extend the lower energy range down to 2keV. After carrying out the assembly and testing of various sub-systems, the Photo-Emission Electron Microscopy (PEEM) beamline was commissioned at INDUS-2.

Development of a Toroidal Spectrometer was completed for the Angle resolved Photo Electron Spectroscopy (ARPES)/PEEM for the simultaneous detection of photoelectron ejection angle and its kinetic energy. This facilitates the measurement of Fermi surfaces of the ordered and disordered phases, electronic structure of the material, orientation information, chemical interactions of the adsorbed molecules, scattering processes in the solid targets etc.

Toroidal Spectrometer

Fully operational protein crystallography beamline at Indus-2 synchrotron has been used for Anomalous diffraction experiments with Zn, Mn, S, Br, and Se containing protein crystals. So far, the PX-BL21 beamline has been used by more than 50 research groups from all over the country. There are more than 30 Protein Data Bank (PDB) entries and 15 papers have been published utilizing this beamline. Some of the structures with PDB entries are shown.



Illustrations of some protein structures using the protein crystallographic beamline of Indus-2

CYCLOTRONS & THEIR UTILISATION

K130 Variable Energy Cyclotron

The K130 variable energy cyclotron has been accelerating and delivering light ion beams in round the clock shift basis for doing various experiments in physical sciences. Projectiles like proton of energies 7-18 MeV, alpha 26-60 MeV and deuteron 15-25 MeV is available for performing experiments. Low energy singly charged helium (He+) beam is also available for experiments which are obtained in higher harmonic mode of operation. These projectiles were utilized by in-house experimental groups and users from other institutes across the country. The beam availability from K130 cyclotron for has crossed the target of 3500 hours that comprises of beam development activities and beam on target to perform experimental research. It has been planned to accelerate high charge state heavy ions in K130 cyclotron and utilize these projectiles for experimental research. Hence a major planned shutdown has been taken from middle of January, 2017 for commissioning of axial injection beam line for heavy ion acceleration program. The external electron cyclotron resonance ion source, ECRIS, and the horizontal portion of axial injection beam line has already been commissioned and tested. Commissioning of vertical portion of beam line is in progress.

PLASMA & FUSION TECHNOLOGIES

The various activities carried out in the Institute of Plasma Research (IPR) during the year were broadly classified into two categories namely, programs having immediate societal benefits, and programs with long term societal benefits. In the former one, Facilitation Center for Industrial Plasma Technology (FCIPT) has contributed significantly towards exploiting various plasma phenomena for potential societal benefits

(a) radical plasma nitriding system developed in FCIPT and (b) radical plasma nitrided agricultural tools

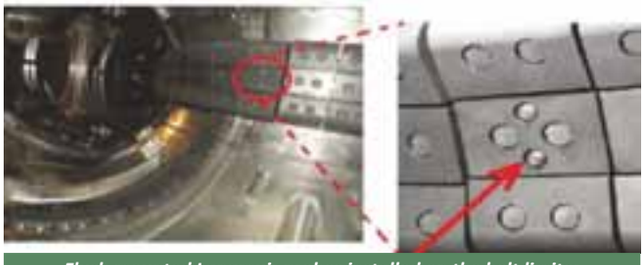
through short term projects and technology transfers to various industries. Technology transfers were carried out for atmospheric pressure plasma jet technology; metal oxide nano powder production technology; plasma pyrolysis technology for organic waste and atmospheric pressure inline plasma processing technology. The wide spectrum of technological umbrella FCIPT owns, can be judged from the variety of subjects it covers viz., bio-medics, waste treatment, power through green technology, space application, nano- technology, material processing, water treatment, coal gasification, high power plasma torch, plasma nitriding of Cut-Tear- Curl (CTC) tea roller for reducing chromium contents in tea leaves etc. These applications show enormous potential for societal benefits. The short term projects undertaken by FCIPT are being funded by national and international agencies and relevant private companies.

In an another significant development, Remote Handling and Robotics Technology Development (RHRTD) group has realized low cost solution for Virtual Reality (VR) facility in the laboratory. This facility will be utilized to develop various virtual and augmented reality applications, having flexibility to integrate with remote handling equipment. The facility provides platform for rapid design reviews for RH equipment and schemes of existing and future tokamaks at IPR. Ongoing program of RHRTD has plans to develop facility for application development of specialized VR applications that are not commercially available and integrate design and analysis tools (like finite element code, multi body dynamics, etc.) into VR. Also, integration of applications from other domains like haptic feedback, image processing and real time physics into VR will be undertaken. A facility for application development and testing for real-time robotic hardware linked virtual and augmented reality will also be developed followed by centralized control facility with

modular architecture for operator training and execution of RH operations. Some of the major contributions of RHRTD during the reported period are namely, 1) development of various VR applications for remote handling and robotics, 2) development of Prototype Articulated Robotic System –II (PRAS-II), 3) development of Prototype Hyper-Redundant Inspection System (Hy-RIS), and 4) development of a prototype gripper assembly, and development of SST-1 compatible In-Vessel Inspection System (IVIS).

The basic research programme in IPR addresses wide variety of physical phenomenon's concerns to earth's atmosphere and fusion devices. Even, few experiments have focus on surface modifications because of low energy beams. Devices like Large Volume Plasma Device (LVPD), SYstem for Microwave PLasma Experiments (SYMPLE), BETA, Helicon plasma device , IMPED and system for Low Energy Ion and Neutral Beams interaction with surfaces, Plasma Torch, Q-Machine, Plasma Wake-Field Accelerator (PWFA) experiments, and dusty plasma devices are contributing to the fundamental studies in plasma. The major benefit of this program is the generation of trained man-power and technical knowhow within country for future ventures.

In long term societal benefit category, fusion plasma activity dominates. In this direction, assembly work of upgraded version of first Indian tokamak, Aditya is completed. Various magnetic field coils viz., Transformer (TR ~ 12.5kA), Toroidal (TF 1.5Tesla) and Vertical (VF~ 3kA) are tested during integrated power testing. The errors in position and fields of all the coils are measured using ECDS. First plasma discharge (plasma current, I_p 80kA and duration, t~15ms) is obtained with APPS operation. This activity will continue for achieving designed plasma parameters in the Aditya-Upgrade. RF power of 750kW will be coupled for second harmonic heating using ICRH in second phase of Aditya up-grade experiments.



Flush mounted Langmuir probes installed on the belt limiter on the inboard side of the Aditya-U tokamak

In Tokamak (SST-1) project, experimental campaign XVIII had obtained Tokamak plasma discharges where plasma currents are in in excess of 112.5 kA in a central field of 1.5T with plasma density 0.8- 1.0 x 10^{13} cm^{-3} and electron temperature in excess of 200 eV are obtained. With these Ohmic plasma parameters in SST-1, the phase-1 milestones of SST-1 was completed (110 KA of plasma current for 100 ms in 1.5 T of central field). Prior to the XIX campaign, the vacuum vessel of SST-1, equipped with plasma facing components was opened for additional in-vessel installations and inspections. The XIX campaign was a preparatory one confirming `quality vacuum', `reduced impurity states', `earlier cryogenic cooling of the magnet system and the cryogenic window', `basic feedback and controls required for the plasma shots', `long pulse data acquisition status' etc., apart from Electron Cyclotron pre-ionization and integrated operations of the associated subsystems. The campaign XIX held during Aug-Sep 2016 was dedicated for establishing all the engineering parameters and obtaining Ohmic plasmas 80 kA for duration > 300 ms. Further detailed physics on magneto hydrodynamic aspects, magneto-static and electrostatic fluctuations and edge turbulences, mode rotation etc. have been planned to be studied subsequently apart from studies of lower hybrid coupling and further improvement of the core plasma parameters. The SST-1 up-gradation update has been presented in the IAEA Fusion Energy Conference in Kyoto, Japan on Oct 18, 2016.

Plan of indigenizing the technology available elsewhere either by collaboration through participation in the experiments or through fundamental developments is continued during this year as a part of 12^{th} Five Year Plan. In this direction, material characterization facility at low temperature (MCFLT) is developed. Commissioning of 30 kA, 30 V DC power supply is undertaken to test indigenously fabricated Nb3Sn and NbTi based large D- shaped toroidal field superconducting coils. Development of indigenous insulation material for future super conducting magnets under neutron influence in collaboration with IGCAR, Kalpakkam have been carried out. A single pellet injection system, SPINS-IND, based on pipe gun technique of propelling hydrogen pellets frozen in a specially designed sleeve cooled to 5 to 10 K using GM cryo cooler is made operational with 95% reliability. An 80 K helium gas supply system was commissioned. The system has a flow rate of 50-210 gm/s, with the

maximum operating pressure of 18 bars. Automation of High Pressure High Temperature Water Circulation System (HPHT-WCS) for feed-back control and data acquisition is completed successfully. Integration of HPHT-WCS with High Heat Flux Test Facility (HHFTF) at IPR is successfully completed. Magnetron Sputter Coating System is used to develop coatings of various materials e.g. Titanium, Carbon, Copper, etc.

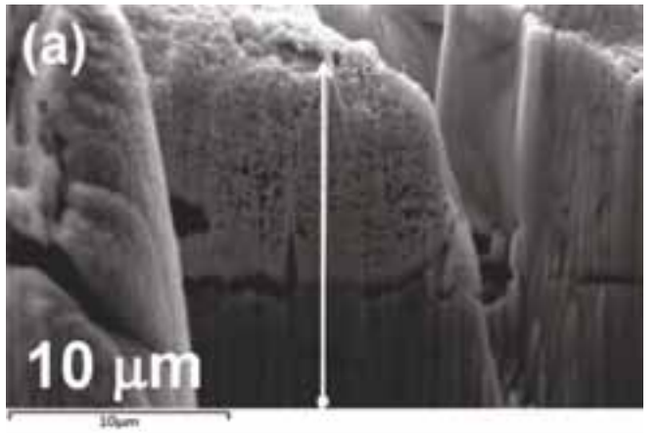
The plasma theory and simulation programme, with latest computational facility, is helping to understand the various experimental results obtained by the institute. Through collaborative work all over the country and abroad, the group is also working to explain various plasma phenomena observed. It also guides the future experiments through simulations without actually spending enormous money on them.

The Guwahati campus namely Centre for Plasma Physics, has contributed strongly through programs like development of a neutron source based on inertial electrostatic confinement fusion scheme, supporting theory and simulation, dusty plasma experiments, divertor simulation study experiments etc. besides helping in main activities of IPR.

MATERIAL SCIENCE

An electropolishing technology has been developed to polish SuperNi42 (Ni:Cr:Mo::57:42:1) alloy fuel tube of LWR for fabrication of ECT (Eddy Current Testing) standard in fuel fabrication (IF3, BARC) by etching wall thickness uniformly. Electropolishing of ID of hollow cylindrical tubes of dia 5.82 mm and length 105 mm to 300 mm was done using an indigenously developed acid electrolyte and polishing condition. Surface finish of the polished surfaces was checked under Field Emission Scanning Electron Microscope (FESEM) and compared with as-received surfaces. For ECT standards, 5 nos. of 105 mm length tubes were electropolished from wall thickness of 5.82 mm to 5.94 mm (i.e. uniform dissolution of 60 micron) and handed over to IF3, BARC for making ECT standard for fuel fabrication for LWR.

Uo_2 coated electrodes were supplied for fabrication of Fission counters for detecting neutrons in various installed reactors in DAE. Detailed microstructural investigation of UO_2 coating using Gracing Incidence X-ray Diffraction (GIXRD), FESEM and



FIB cut cross-section FESEM image of as-deposited UO_2 coating showing thickness of the coating and coating-substrate interface

High Resolution Electron Microscope (HREM) revealed that as-deposited coating is X-ray amorphous in nature with nodular surface morphology containing numerous cracks. However, HERM investigation showed presence of very fine crystallites in the range 2-5 nm with majority amorphous grain boundaries. Energy Dispersive x-ray Spectroscope (EDS) analyses of annealed coating showed formation of UO_2 with U:O1:2. Focussed ion beam (FIB) cut X-section image showed better bonding between coating and substrate; and formation of nanoporous UO_2 coating morphology. GIXRD and HREM confirmed post annealing transformation into nanocrystalline UO_2 coating with grain size in the range 8-12 nm. The composition of the coating was further ascertained by X-ray Photoelectron Spectroscope (XPS) analyses of the as-deposited as well as post annealed coating surfaces.

Tensile Split Hopkinson Bar (TSHB) is an experimental technique that is used to generate material property at high rate of deformation and data is used for design and safety analysis of structure subjected to crashworthiness test viz. compliance to AREB regulatory drop tests of radioactive material

Tensile Split Hopkinson Bar (TSHB) setup

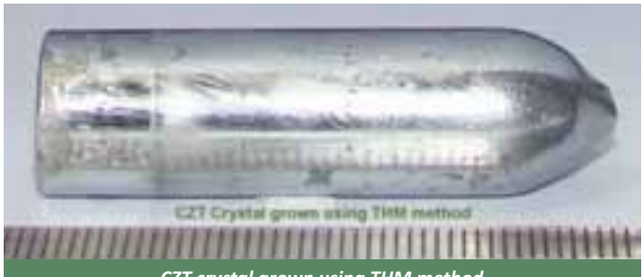
shipping cask and defence applications. The TSHB setup (as shown) is designed, developed and commissioned at BARC.

Strain-enhanced colossal magneto resistance in $Pr_{0.6}Sr_{0.4}MnO_3$ thin films

At IGCAR, thin films of $Pr_{0.6}Sr_{0.4}MnO_3$ were prepared on oriented single crystalline $SrTiO_3$ and $LaAlO_3$ substrates using pulsed laser deposition. X-ray diffraction analysis reveals formation of thin films with c-axis orientation. Thin films exhibit substantially larger colossal magneto resistance than the bulk and the effect is observed to be more pronounced in the film which experiences a larger strain. The resistivity behavior above the metal-insulator transition temperature for the bulk as well as thin films samples follows the adiabatic small polaron hopping mechanism for conduction. On the other hand resistivity in the low temperature metallic region could be explained considering the electron-magnon and electron-electron scattering contributions to resistivity. An appreciable enhancement observed in the magnetoresistance of thin films, nearly 6-8 times larger than the bulk, at low field of 1tesla is encouraging from the application point of view.

CdZnTe (CZT) single crystals for radiation detectors

Room temperature semiconductor radiation detectors based on CdZnTe (CZT) single crystals with energy resolution that is close to that attained using cryogenically cooled HpGe detectors are proposed to be developed. The travelling heater method (THM) facility to grow CZT single crystals is basically equipped with a two-zone furnace. Each resistive heated zone of the furnace is independently controlled through a control circuit and the desired temperature gradient range of 10-50° C could be achieved at 950°C by optimizing the set temperature and implementation of a high precision vertical translational assembly is installed which could move the ampoule/ furnace unit at a very slow rate of 1mm/day. Monitoring thermocouples placed at different points inside the furnace revealed stability to be better than 0.5° C. The THM setup was tested for continuous operation by performing a growth run of CZT crystal



CZT crystal grown using THM method

High piezoelectric response of a-axis oriented AlN thin films grown by reactive assistive ion beam sputter deposition

Textured a-axis oriented AlN thin films were grown on Si(100) substrate forming AlN/Ti/Si(100) layer structure by reactive assistive ion beam sputter deposition to understand the effect of charged native defects on piezoelectric response of AlN thin film by proposing a model for charged vacancy induced enhanced polarization in film microstructure. The results show that the films are highly textured along the a-axis and charged native point defects are present in its microstructure.

Development of an advanced dual beam irradiation facility

An advanced dual beam irradiation facility with an indigenously built 400 kV accelerator was set up. This facility is used for injecting Helium and a 1.7 MV Tandetronaccelerator used for irradiation by heavy ion beam. Also this facility is used to simulate synergistic effects of displacement damage and gaseous helium or hydrogen which is important in the context of development of radiation resistance materials for fast fission, fusion and ADSS systems.

Proton irradiation studies on pure Ti and Ti-6Al-4V alloy

Ti and its alloys are extensively used as structural materials for various support structures of cryogenic systems due to their low thermal conductivity and high tensile strength, in high energy accelerators. The radiation environment of the accelerators may make these support materials susceptible to radiation damage. Ti alloys are sensitive to neutron irradiation, and even a relatively low dose of irradiation may cause in degradation of ductility and fracture toughness. Extensive literature is available on the irradiation

studies of α-titanium alloys. The irradiation effects on (α+β) Ti–6Al–4V alloy are limited particularly at low dpa. In this study, we have carried out the irradiation of pure Ti (α-Ti) and Ti-6Al-4V (α+β alloy) using proton beam from the Variable Energy Cyclotron, Kolkata, India to understand and compare the evolution of defects in both the materials at different doses. The study showed that Ti-6Al-4V can also be considered to be a radiation resistant alloy at least upto a dose of $4x10^{21}$ p/m^2 which is expected to be higher than the normal dose experienced .

Proton irradiation studies on Al and Al5083 alloy

Aluminum and its alloys represent a very important class of structural metals for subzero-temperature applications and are used for structural parts for operation at temperatures as low as -270°C. Among them, aluminum alloy (Al5083) offers a favorable combination of desired properties with high strength to weight ratio for cryogenic application. Among the many important uses, Aluminum alloy has been extensively used for the construction of various critical components of the superconducting cyclotron such as cryostats, trim coil support structure, cooling tubes etc. These structures suffer extensive radiation induced damage caused by the different radiations that are present in the cyclotron. Keeping in view the flexibility of the particle irradiation experiments, we have carried out the irradiation of pure Al and Al5083 using proton beam from the Variable Energy Cyclotron to understand and compare the evolution of defects in both the materials at different doses. The study showed that Al5083 can be used at least up to a dose of $7x10^{20}$ p/m^2, which is expected to be higher than the normal dose experienced by the cryostat and support structures of accelerators during its lifetime (almost equivalent to the dose of $1x10^{16}$ p/m^2 considering 20 years of operation).

At TIFR, Plasmonic quasicrystals were demonstrated with broadband transmission enhancement suitable for enhancing solar cell performance. A novel direct beam shift measurement has been demonstrated which can detect shift in the laser beam position with 50nm resolution. A giant shift in beam position due to surface plasmon polariton mediation when laser beam is reflected by a metasurface has been demonstrated. Electromagnetically induced transparency and its control will be demonstrated in metamterials. From a comprehensive study of Gallium Nitride (GaN) nanowires, grown using a Nickel catalyst it was demonstrated that the growth proceeds by a Vapour-Solid process and not the commonly assumed Vapour Liquid Solid process. The catalyst particle was shown to be a solid at the growth temperature, and a mechanism to explain the length-thickness relationship in such nanowires has also been developed. Synthesis of novel single-crystal semiconducting rhenium-based dichalcogenides ReS2 and ReSe2, have a weak-layer dependence of optical and electrical properties, and hence could be advantageous for optoelectronics. Performed a comprehensive study of their structural, optical and electronic properties, and achieved mobility values 5-8 times better than previously reported.

The compounds with filled skutterudite structure exhibit various interesting properties including different kinds of magnetic order, superconductivity and thermal properties related to alternative technology for efficient usage and generation of energy. At RRCAT, the temperature and magnetic field dependence of heat capacity of two superconducting skutterudite compounds LaPt4Ge12 and PrPt4Ge12 were studied along with their electronic band structure. This study led to the finding that unlike the conventional superconductors having a single energy gap at the Fermi surface, the superconducting skutterudites possess two superconducting energy gaps at the Fermi surface.

The ternary magnetic compound TbFe2Al10 exhibits paramagnetic to ferrimagnetic and ferrimagnetic to antiferromagnetic phase transitions below 18 K. The thermal, electrical and magnetic properties of TbFe2Al10 were studied along with complementary magnetization measurements. The study revealed that there is a sharp rise of electrical resistivity across the paramagnetic to ferrimagnetic phase transition which is related to the occurrence of superzone boundaries at the Fermi surface. TbFe2Al10 also exhibits important functional properties like large magnetoresistance and magnetocaloric effect across the magnetic phase transitions which persist over a wide range of temperatures spanning deep into the paramagnetic phase.

Fourier transform infrared and Raman

spectroscopy measurements were performed on high-purity technical niobium used for the fabrication of Superconducting Radio Frequency (SCRF) cavities. It was found that the presence of a mixture of niobium oxides and other surface impurities appreciably influence the conducting properties of the material causing it to deviate from the typical metallic characteristics. The study will provide inputs for understanding the origin of degradation of performance of the SCRF cavities during actual application.

A giant magnetocaloric effect close to room temperature was observed in an off- stoichiometric Mn-Co-Ge alloy across a first order magneto-structural phase transition. The values of isothermal entropy change are comparable or better than those found in the more expensive rare-earth based intermetallics. An experimental protocol was also devised to achieve reproducible estimates of the entropy change across a sharp first order phase transition. These results could provide useful inputs for establishing an environment friendly technology for magnetic refrigeration.

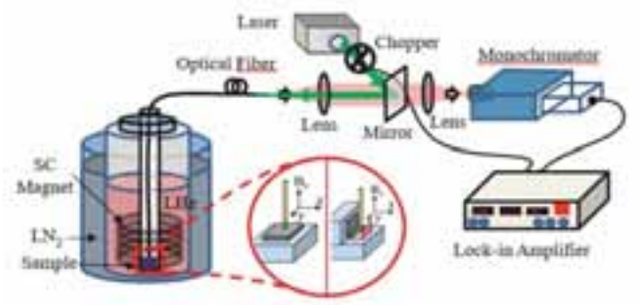
Physical properties like dc magnetization, magneto-transport and magnetostriction of C15 Laves phase 4f ferromagnetic compound $NdRu_2$ were investigated as a function of temperature and applied magnetic field and analyzed in a self-consistent manner. Contrary to expectation, it was found that the magnetic properties of this compound cannot be explained within a simple model based on localized magnetic moment even though Nd based compounds and alloys are usually considered as localized magnetic moment systems. These experimental results in $NdRu_2$ might be related with the hybridization of 4f levels with valence electrons. It is impacted that this work will stimulate experiments as well as theoretical calculations which can provide further insights on the magnetism in rare earth based intermetallic compounds.

The resistive transition of vortex matter in a highly strained $Nb_{75}Zr_{25}$ superconducting alloy was studied. It showed that the models of viscous flow of disordered solids can be indeed applied to vortex matter. The arguments were based on purely elastic energy considerations instead of assuming any particular model applicable to the flow of flux line lattice in the mixed state of a type-II superconductor. The results show that the viscous flow of disordered solids and the flux creep phenomenon in hard type II superconductors could be the manifestation of the same underlying physical principles. These results can be of technological importance for tuning the nature of quenched disorder to achieve desirable critical current densities, and can also lead to fundamental understanding of elastic systems influenced by disorder and driven by external force.

Several high quality single crystals were grown by different techniques for various applications. These include single crystals of Nd doped $GdVO_4$ for laser host applications and Ce doped Lithium Tetra-Borate (LTB) for Thermos-Luminescence (TL) dosimetry. A number of rare-earth doped transparent ceramics, required for laser-host and scintillation applications, have been fabricated by nano-powder technique and subsequent vacuum sintering. Transparency of ~76 % (without reflection loss correction) has been achieved at 1 µm wavelength for Nd doped YAG/Y_2O_3 and Yb,Tb co-doped Y_2O_3. For Yb, Tb co-doped Y_2O_3 ceramics a high intensity luminescence peak at 543 nm (green) was observed under 976 and 929 nm excitation due to Yb -Tb energy transfer up-conversion. Ce doped YAG transparent ceramic was also fabricated and generation of white light was demonstrated using a blue-LED covered with this ceramic. The white light shows tristimulus values of (0.24, 0.40, 0.36). A crossover from bluish-white to greenish-yellow light was observed with an increase in the thickness of ceramic layer from 0.5 to 1.5 mm.

(a) Single crystal of Nd:$GdVO_4$ (b)Tb-Yb co-doped Y_2O_3 transparent ceramic (c) Ce:YAG transparent ceramics (d) White light generation using Ce:YAG.

Dixon ring catalyst with Platinum doped Carbon Aerogel (Pt-CA) developed under MOU between RRCAT and Heavy Water Board for hydrogen isotope exchange was tested for bi- thermal operation in an in-house developed test setup. This is an important qualifying step for Bi-thermal Hydrogen Water (BHW) process used for heavy water production. The test setup consists of catalyst filled one meter long hot and cold columns of 1" diameter maintained under a pressure of 15 bar and at a temperature of 130 °C and 45 °C respectively. Overall extraction of deuterium in hydrogen stream from water, termed as recovery, was evaluated to be 26% at 1.0 lpm of gas flow. The value

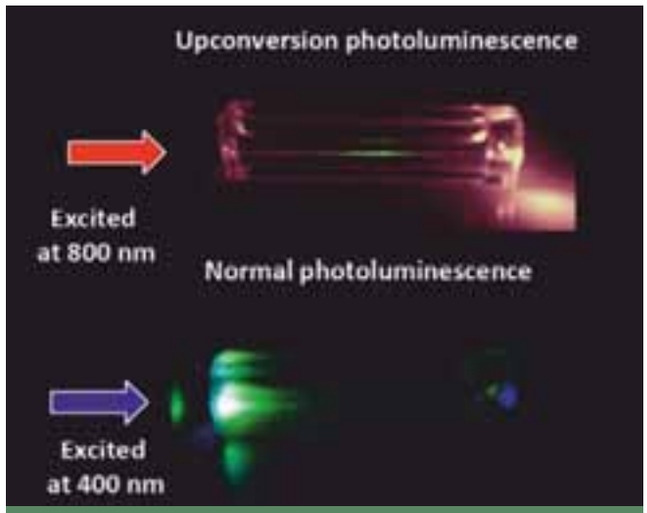


Schematic of Magneto-PL setup at low temperature

compares favorably with sulphide plant with reported recovery of 20%.

The photo-luminescence measurements performed on semiconductor nanostructure under high magnetic fields provide a contactless method to determine exciton properties such as effective mass, binding energy, and Bohr radius. Magneto Photoluminescence (PL) experiments on AlGaAs/GaAs, InGaAs/GaAs quantum wells (QW), InAsP/InP and Type-II InP/GaAs were carried out by applying high magnetic field (8 T) at 4.2 K. The effect of carrier confinement on the effective mass of excitons and estimation of ultra-low disorder, both the interfacial and in-plane disorder, for AlxGa1-xAs/GaAs multi quantum well was estimated by analyzing the line width of magneto-PL data. At the hetero-junctions, interfacial roughness is estimated to be 0.2-1.2 monolayer for Al0.3Ga0.7As/GaAs multi QWs. This nondestructive technique for estimating ultralow disorders and effective mass is especially important since it is not possible to measure such parameters for un-doped multi QW samples by the conventional transport measurement techniques.

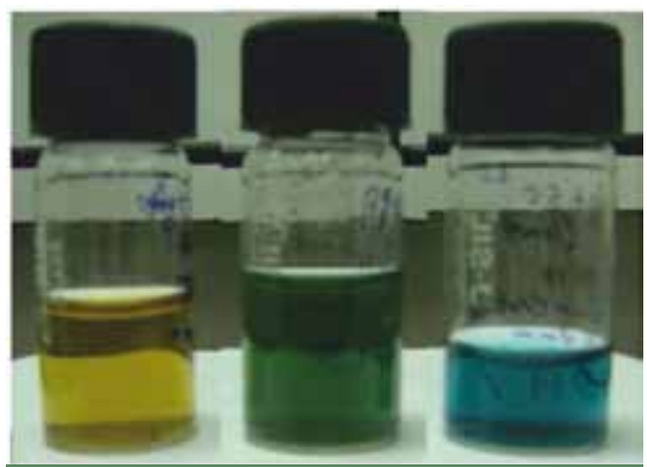
The role of optical invisibility in curtailing the optical limiting efficiency of a nickel/toluene nanocolloid has been experimentally demonstrated for nanosecond laser pulses. The incident laser pulse heats the nanoparticle. Above a certain threshold energy the nanoparticle temperature is high enough to vaporize the solvent around it, creating a bubble. Under the right conditions this bubble can screen the nanoparticle from the incoming laser pulse. A simple yet physically realistic "particle-in-bubble" model has been developed which can quantify the linear and nonlinear absorption as well as the scattering from the sample. Such invisibility could lead to development of invisible photo detectors, densely packed devices, low-scattering near-field optical microscopes, etc.



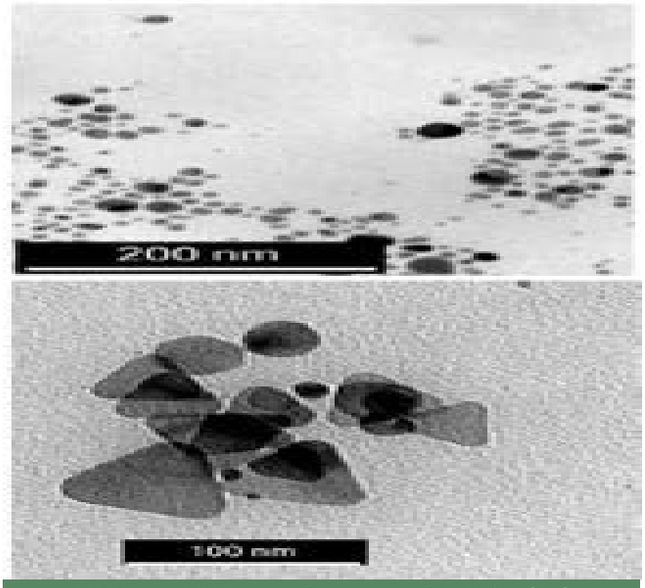
Photograph showing upconversion (top) and normal (bottom) photoluminescence from CdTe nanocolloid

Upconversion photoluminescence from quantum dots is one route to achieve microscopy resolution beyond the diffraction limit. It has been experimentally demonstrated that the upconversion photoluminescence gets strongly quenched in a CdTe quantum dot- silver nanosphere mixed nanocolloid as compared to a pure CdTe quantum dot colloid. In contrast the normal photoluminescence from the same mixture gets enhanced. This is despite a high degree of dilution in the nanocolloid sample. This behavior can be attributed to the modifications in the optical field induced by the plasmon resonance of the silver nanospheres.

A computational model has been developed to elucidate the role of growth environment, impurities/additives, solvents, and their concentration to the crystallization process. It is shown that minute presence of either biuret or biurea can drastically alter



Silver nanoparticle solution after 2, 6 and 12 hrs



TEM images LPPLA-grown silver nanoparticles before (top) and after light irradiation (bottom)

the growth morphology urea crystals. In addition to this, pair creation in intense laser field has also been studied.

Spherical and triangular silver nanoparticles with wideband plasmonic response were synthesized through a process involving Liquid Phase Pulsed Laser Aablation (LPPLA) of silver target in aqueous sodium citrate solution followed by visible light irradiation. The resultant triangular nanoparticles were free from any other extraneous chemical species and exhibited high absorbance in wide wavelength band of about 550-1050 nm. This expected to be useful for trace analysis using surface enhanced Raman scattering, photovoltaic and plasmon assisted photo-catalytic studies.

Using the recently procured glove box system, fabrication and characterization of polymer based photo-voltaic cells was accomplished. Composites thin films of Poly-3- hexylthiophene (P3HT) and Phenyl-C61-Butyric acid Methyl ester (PCBM) were used as photoactive material. The influence of thermal annealing on the device efficiency was established. The open circuit voltage (Voc)of both annealed and un-annealed devices remain almost same but remarkable variation was observed in the short circuit current (Isc) fill factor and upon annealing. The observed variation upon annealing effect is due to changes in the film morphology of photoactive layer.

Inert atmosphere glove box system housing spin coater and thermal evaporator used for photovoltaic device fabrication. Device structure is shown in the inset

To investigate the role of Antiphase Domains (APD) in generation of strain in GaP film grown on different substrates, GaP/Si and GaAs heterostrucure are studied using Raman spectroscopy along with atomic force microscopy. It is concluded that the APD are predominant at the valley region of the surface morphology in GaP/Si, which is the main reason for lower growth rate at the valley region. The information obtained using spatially resolved Raman spectroscopy is very useful for identification of high density APD regions in the III-V semiconductor layers grown on Si/Ge.

INTERDISCIPLINARY AREAS

Handheld low cost 12-Channel Tele-ECG

12 Channel Tele ECG

Peripheral Pulse Analyser

Instrument that operates with the help of a mobile phone/PC via Bluetooth has been developed. The device is ideally suited for rural health care. Technology of this instrument has been transferred to industry and is in the process of deployment at Government district hospitals.

Peripheral Pulse Analyzer to study physiological variabilities for the purpose of disease characterization has been developed. Technology of this instrument has been transferred to industry for commercial production.

During the year, some of the achievements of the TIFR Centre for Interdisciplinary Sciences, Hyderabad were as follows:

Developed of methods to measure qualitative ^{1}H-^{1}H distances which can be used to study human proteins and proteins that are difficult to obtain in large quantities. Using Solid-state NMR spectroscopy it has been able to decipher the secondary structure of the oligomers of a-synuclein A new recoupling method (SS_REDOR) to measure strong dipolar couplings in solids have been developed. This method is a significant improvement over the currently used S-REDOR sequence known in literature.

A nonequilibrium statistical physics model was shown to describe the formation of stacks within the Golgi organelle, and further to suggest quantitative measures that can discriminate in a qualitative manner between competing mechanisms of protein transport through the compartments.

Study of the structure-functional relationship of an unusual Ca^{2+}-binding protein from Entamoeba histolytica.

Establishment of a state-of-the-art mechanobiology laboratory, which will attempt to elucidate how the cells in our body collectively respond to different physical cues, has been initiated.

A state-of-the-art Biophysics lab for multi-scale characterization of amyloid oligomers is being setup.

The novel method for the Synthesis of NHeteroCycliccarbene-stabilised 2 hydrophophasilines, starting from Silicon (IV) – precursor has been disclosed. This method will have potential for the synthesis of different substituted to hydrophophasilines.

For the first time a new susceptibility, pinning susceptibility to directly calculate the growth of amorphous order in experimentally relevant glass forming liquids have been proposed. Considerable progress has been made in understanding cavitation in glassy systems, as cavitation is believed to be one of the main mechanisms for failure for amorphous solids. The initial work on stability of biopolymer in glassy matrix with the hope to better understand bio-preservation is expected to be finished soon.

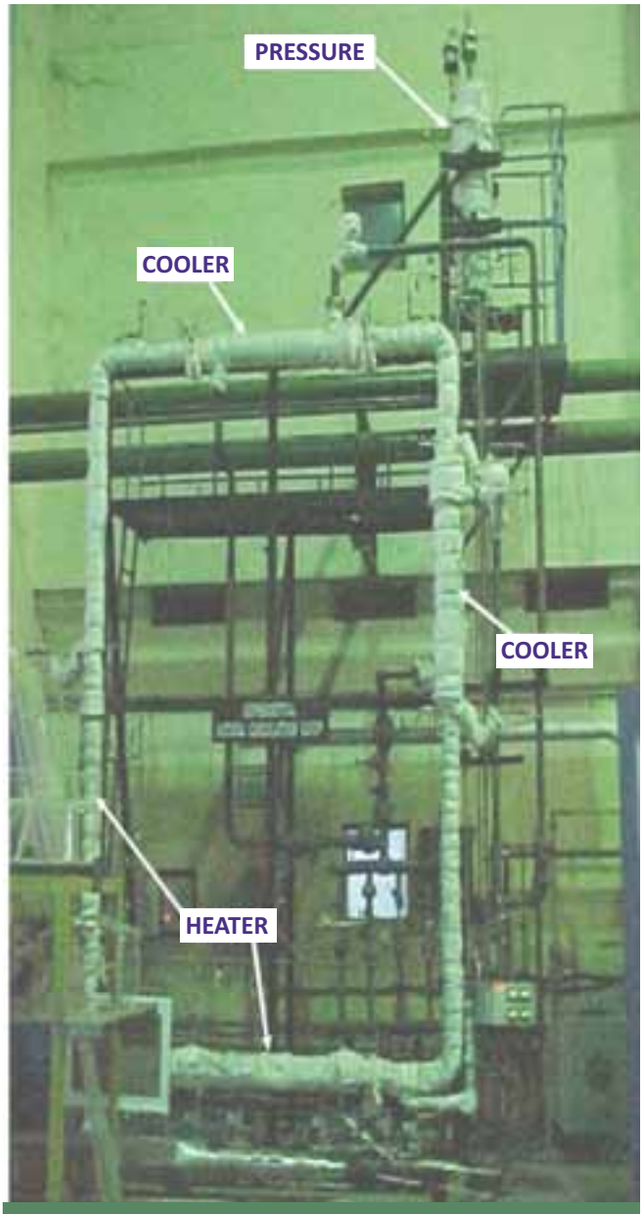
A novel image-analysis based routine for detection of cell cycle stage along with DNA damage responses has been setup.

Computer simulation has been used to elucidate the kinetic pathways of approach of ligand to a solvent-inaccessible cavity of proteins, which is otherwise impossible to obtain from well-known experimental means.

Work on Ultrathin, water-repellent surface chemistry got highlighted in the media. A material has been developed which, when coated on other substrates, can render them both water repellent (superhydrophobic) and oil repellent (oleophobic). For the first time, demonstrated the capability to include the spin scattering term in the original Maki's model, by using Fermi liquid approach to linearize these equation, to extract a complete physical solution. This opens up new avenues to explain some of the recent reports in spin-polarized tunneling measurements using superconducting tips.

A random external potential using laser light have experimentally realised, in a collaborative work. This work may result in technologies where by manipulating lasers one may be able to influence freezing and glass transition properties of colloidal crystals. This may have applications in sensor technology;

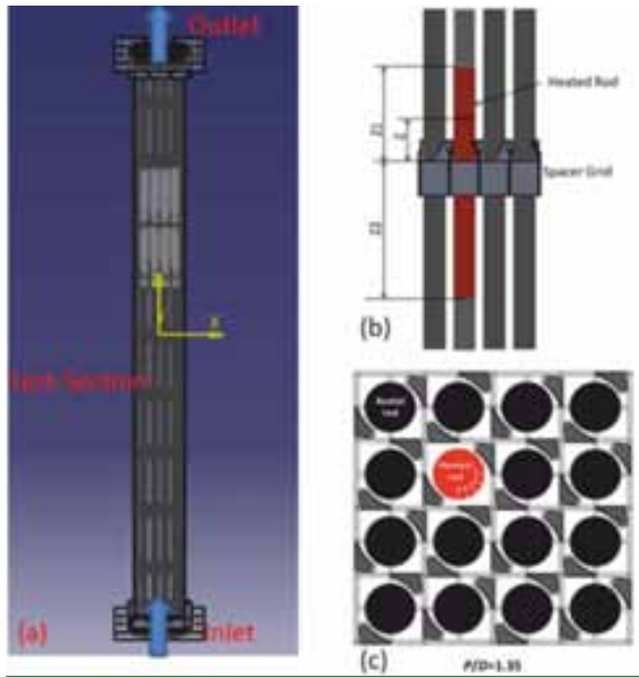
INTERNATIONAL RESEARCH COLLABORATION



Photograph of SPNCL

The Super Critical Water cooled Reactor (SCWR) is one of the six reactors considered in the Generation IV International Forum for safer and financially attractive reactors of the future. The heat transfer and pressure drop characteristic of the supercritical fluids are important for the design of SCWR. In order to accurately predict heat transfer characteristic of supercritical fluid a rectangular uniform diameter, Supercritical Pressure Natural Circulation Loop (SPNCL) is operated at BARC. Carbon dioxide has been used as working fluid in SPNCL as it is a good simulant to water. A Steady state simulation of a 3D model of the loop, with heater at the bottom and cooler at the top, has been carried out employing the commercial CFD code, CFD-ACE+. Steady state mass flow rate and heater surface temperatures have been predicted for different heater powers. After successful benchmarking, simulation results have been used to predict heat transfer coefficient in the heater region and induced mass flow rate in the loop.

CFD simulations of Flow Mixing and heat transfer in 4x4 rod bundle with twist-vane spacer grid have been performed under the IAEA Coordinated Research program "Application of CFD codes for nuclear power plant design. OpenFOAM CFD code is used for the simulation. Experimental results of Korea Atomic Energy Research Institute were used for this CRP project. Two case of simulation were performed, one is isothermal case for flow mixing and second for heat transfer study. The details of the test section used for CFD simulation, the comparison of velocity vector at Z/D=1.4 at central sub-channel downstream of spacer grid between experimental results and CFD and the axial variation of average surface temperature predicted by CFD simulation along with experimental data were shown.



Details of 4x4 rod bundle (a) Test section,
(a)Heated rod and spacer grid (c) Cross sectional view

Power converter for electromagnet developed for FAIR

As a part of the in-kind contribution to Facility for Antiproton and Ion Research (FAIR), Darmstadt, Germany over 500 power converters for electromagnets will be designed, developed and supplied. The first converter of this series, a two-quadrant converter (300 A /±142 V), has been developed based on the design and prototyping provided by RRCAT, Indore at ECIL, Hyderabad. The converter has qualified factory acceptance tests and has been delivered to FAIR for site acceptance tests. Subsequently, production of 50 such power converters will commence at ECIL.

RRCAT has successfully developed, tested and supplied two high power WR 2300 copper coated stainless steel power couplers for CERN's linac-4 project. RRCAT scientists participated in the commissioning of the accelerating structures and the beam diagnostics for the linac 4. The linac-4 has been commissioned by CERN and accelerated H^- ions to the rated energy of 160 MeV.

One of the WR 2300 copper coated Stainless steel power couplers installed with the CCDTL accelerating structure of linac-4 tunnel at CERN

The important development of Superconducting RF (SRF) cavity for high intensity proton linear accelerator under the IIFC collaboration took place at VECC.

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

At TIFR, the CMS Experiment collected data from proton-proton collisions at a centre of mass energy of 13 TeV at the Large Hadron collider (LHC). It was successful in colliding protons at a centre of mass energy of 13 TeV. Data has been analysed to confirm the presence of standard model Higgs boson which was discovered earlier and also many other rare phenomena. It has also set limits on many models beyond the standard model.

At the International Centre for Theoretical Sciences, TIFR works were carried out in Astrophysical Relativity; Complex Systems; Fluid Dynamics and Turbulence; Statistical Physics and Condensed Matter; Interdisciplinary Mathematics and String Theory And Quantum Gravity.

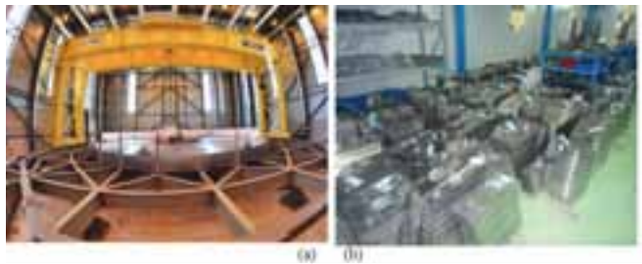
The SINP joined the ALICE Collaboration in 1997 and has been one of the founder laboratories who developed the Muon Spectrometer. The group has made critical hardware contributions which have been fabricated indigenously. These are the Muon chambers for the Second Tracking station built entirely in the campus and the MANAS chips for the readout of the 1.1 million channels which were designed at Saha Institute and fabricated at the Semiconductor Complex Laboratory, Chandigarh. These deliverables performed exceedingly well during the Run-I which has led to 26 research publications in reputed journals. The physics programme of ALICE after the Long Shutdown 2 (LS2) will be devoted to the high precision measurements of hard probes (heavy flavour hadrons, quarkonia, photons and jets). The Muon Forward Tracker (MFT) will allow ALICE to extend the precision measurements of

the heavy quark resonances. The MFT detector will be put upstream of the absorber of the MUON spectrometer i.e. much closer to the Interaction Point (IP) to add the vertexing capability. The Si-tracking detectors of low-material budget will be used in MFT. The basic detection element of the MFT is the pixel sensor which is based on the CMOS monolithic pixel sensor technology. In this International Collaboration, among 12 participating Institutes, the mechanical and electronics technicians/engineers along with the scientists of Saha Institute and Aligarh Muslim University will constitute the Indian collaboration. The activities had been started in the beginning of 2015. The India-MFT collaboration will be focussing on two areas: The Pixel characterization Work and The fabrication of Water-Cooling system of MFT detector. For the CMS Collaboration activities, the CMS group from SINP has ongoing responsibilities for the Run II data taking, in detector performance and calibration studies of the hadron calorimeter, tracker validation, bad channel calibration, and tracking performance studies. The group is also involved in diverse studies of the LHC Phase II tracker development. The international collaboration with SNOLab in PICASSO experiment were continued at SINP.

Under IPR – JET collaborations, both small and big (full-scale) prototype RMP coils have been tested using an indigenously developed power supply. While in IPR-WEST collaborations, IPR scientists/Engineers have developed software modules for the data acquisition (DAQ) hardware of Plasma Control System (PCS, CODAC) and Wall Monitoring System (WMS) required for the startup experiments of WEST tokamak. New specific topic of cooperation (STC) document for Thomson scattering system for WEST has been signed. Discussions on the design and development of XCS (X-Ray Crystal Spectrometer) system for WEST/SST-1 tokamaks as per the previously signed STC are in progress. Under EU-Indo collaboration, MTDD has successfully develop and established technology for manufacturing large as well as small ELM control coils appropriate for large Tokamak such as Joint European Torus (JET) and SST-1. For the CZTS based plasmonics solar cell (Indo-UK program), the experimental work carried out by Indian group was validated and understood by UK group in Loughborough University through theoretical simulations. This work presented a nice understanding of silver nanoparticle growth on patterned substrate for plasmonics solar cell application. Experimental results matches well with theory. This was the first time sticking behaviour of silver atoms were investigated both experimentally and in simulation.

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.



a) base section of Cryostat, manufactured by L&T and b) neutron shielding blocks manufactured by Avasarala Technologies, Bangalore

Six segments of Base section of the Cryostat (a 30m dia and 30 m height vacuum vessel) manufactured by L&T, Hazira, is undergoing welding operations for final assembly at ITER site in France. About 600 neutron shielding block are delivered to Europe and Korea.

A novel concept of “pipe-in-pipe” developed to accommodate thermal expansion in buried pipes is successfully accomplished. Pipe spools dispatched to ITER site in several batches. Prototype Cryoline manufactured at Inox India Ltd. is commissioned at

a) Prototype Cryoline manufactured at Inox India Limited b) acceleration grid Power Supplies (AGPS) designed by ITER-India and manufactured by ECIL c) cold circulators

ITER-India laboratory. Diacrode-based driver & final stage high power RF amplifiers are tested for 1.5 MW output in full 35-65 MHz frequency band in ITER-India lab. These RF amplifiers were manufactured by Thales,

France as per specifications from ITER-India.

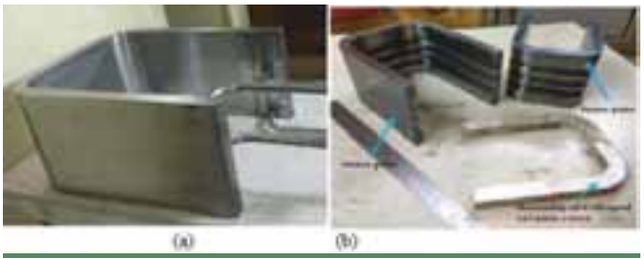
Dual output regulated high voltage power supply manufactured by ECIL on ITER-India specifications is operated continuously at ITER-India lab, delivering 2.8 MW of output power to drive 1.5 MW diacrode-based amplifiers on matched and mismatched loads is now being installed at the Neutral Beam Test facility in Padova, Italy.

Cold circulators successfully tested with highest mass flow rates. Their testing at JAEA also simulated all magnet operating conditions. The circulators were manufactured by BNI, USA and IHI, Japan as per specifications from ITER-India.

India is working for the demonstration of Test Blanket Module (TBM) in ITER and Tritium Extraction System (TES) plays a very important role in realizing TBM development. TES consists of He Purge gas System (HPS) and a scale down HPS system has been designed and installed for concept demonstration and optimum performance data generation. The system has been fabricated, Installed & cold commissioning done for purification of Helium and separation of Hydrogen Isotopes. The setup is being operated with hydrogen for data generation and parametric optimization of full scale system.

Helium purge gas system

Indian Lead Lithium Ceramic Breeder (LLCB) blanket concept will be tested in ITER through Test Blanket Module (TBM) program. TBM Division, IPR is engaged in the Design and Development of LLCB TBM and its associated ancillary systems. TBM systems design and related R & D activities such as development of blanket materials, Helium Cooling Systems, Lead



(a) 10 channels U-shaped FW with ends welded and inlets & outlets of each circuit and (b) prototype demonstration of manufactured U-bent inner and outer plates with CNC C-shape grooved channels and curved ceramic cores

Lithium technologies, Hydrogen isotope technologies and related diagnostics are in progress at IPR, India with the support from BARC Mumbai, IGCAR, Kalpakkam and various research centres and academic institutes within India. Some of the major activities carried out by LLCB Test Blanket System are namely, 1) Development of IPR Interface Code for Shutdown dose rate estimation in Fusion system (IICSF), 2) nuclear analysis of neutron activation system for Indian TBM in ITER, 3) carried out joint benchmarking exercise with China TBM team to establish the common shutdown dose rate (SDDR) estimation methodology, 4) preliminary estimation of occupational radiation exposure during the Indian TBS maintenance activities in ITER, and 5) neutronic mock-up experiments for TBM shield module neutronic design validation. Under TBM fabrication technologies development activities, a 10 channel mock-up of TBM FW (U-shaped) has been fabricated indigenously at vendor site in Mumbai with technology support from BARC. In next phase, half size TBM first wall would be fabricated.

Ceramic pebble development activities have taken a boost as Lithium Titanate Ceramic pebble production capacity has been upgraded to 5 kg of qualified pebble per month. These pebbles have been characterized in different international R & D laboratories. Experimental set up for measuring the effective thermal conductivities by steady state and hot wire method have been indigenously built at IPR. Besides this, an Experimental Helium Cooling Loop (EHCL) facility (450 C, 0.4 kg/s) is being set up at IPR. The performance tests of the circulators were conducted successfully. Development of a compact temperature-level measurement technique for liquid metal applications is undertaken. Long duration test (over 1200 hours) was performed to estimate the reliability and longevity of the sensor assembly in liquid Pb-16Li environment.

CHAPTER 6

MACE camera loaded with Camera Integrated Modules CIMs

RESEARCH EDUCATION LINKAGES

Beam Profile Monitor installed in Indus-2 ring

CHAPTER 6

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 Schools and the Administrative Training Institute (ATI).

The Board of Research in Nuclear Sciences (BRNS) is an advisory body of the Department of Atomic Energy (DAE) provides financial assistance to universities, academic institutions and national laboratories for encouraging and promoting scientific research in the areas of relevance to the mandate of DAE.

The National Board for Higher Mathematics (NBHM) established under the aegis of DAE promotes excellence in higher Mathematics education and research in the country. The Board also provides grants for promotion of activities in pure and applied Mathematics under several schemes including support to research projects, travel grants for participation in workshops, conferences and undertaking collaborative research funds for organizing conferences etc.

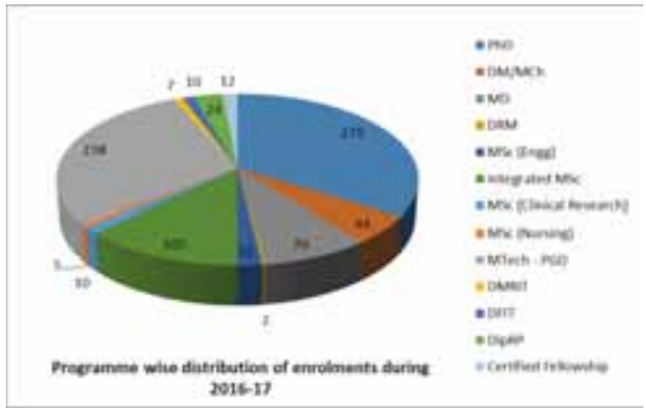
HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a deemed to be University, is a grant-in-aid institute of the Department of Atomic Energy. It nurtures academic programmes of eleven premier institutions of the DAE under a single umbrella making vast research and faculty resources within DAE available for students. It serves as a catalyst to accelerate the pace of basic research and facilitates its translation into technology development and applications through academic programmes viz. Postgraduate degrees/ diplomas and Ph.D. degrees in Engineering Sciences, Physical Sciences, Chemical Sciences, Mathematical Sciences, Life Sciences, Health Sciences, Applied Systems Analysis while encouraging inter-disciplinary research.

Under HBNI, 822 students were admitted in different programmes during 2016-17. HBNI has notified 189 Ph.D., 275 M.Tech-PGD, 98 M.Sc., 63 Post-graduate medical degrees, 44 medical super-speciality programmes (DM / MCh) and 42 Diplomas in Radiation Protection (DipRP), Medical Radio-Isotope Technology (DRMIT), Radiation Medicine (DRM), and Fusion Imaging Technology (DFIT) during 2016-17 (up to February 28, 2017). More than 1600 students are currently pursuing Ph.D. in various disciplines under HBNI.

HBNI has signed a MoU with Jawaharlal Nehru University, New Delhi for academic collaboration.



Training School

While the academic programme of the BARC 59th batch was continuing, screening examination for 9 engineering and 5 science disciplines for the 60th batch was organized successfully at 62 venues in 45 cities. This year Nuclear Engineering was added as 9th engineering discipline. The number of applicants went up to 1,55,472 and 87,270 candidates appeared in the online examination. 3,959 candidates appeared for the selection interview. Recruitment data are given in the form of pi diagrams and bar charts. A total of 284

candidates were selected for OCES/DGFS-2016 as compared to 268 last year. This included 7candidates of DGFS-BARC.

The 60th OCES Batch of BARC TS was inaugurated by Director, BARC as Chief Guest on August 1, 2016. BARC's outreach programme was further expanded by the participation of officers from RRCAT, IGCAR, NFC and VECC in addition to those from BARC. It covered 94 colleges spread across 20states, including north-east.

143 TSOs (105 engineering+12 physics + 2chemistry +8bioscience+16 RSE) and 16 fellows of OCDF 2015 scheme, after successful completion of the training, were placed in various units of DAE. Graduation Function of BARC Training School was held on July 25, 2016 with Vice Admiral (Retd.) Dinesh Prabhakar, DG, ATV Programme, as the Chief Guest and Dr. Sekhar Basu, Chairman, AEC, and Secretary DAE as the Guest of Honour. Chief Guest gave away Homi Bhabha Prizes to the toppers of 12 OCES disciplines of 59th batch and the topper of the 12th OCDF course. All the officers belonging to the 59th OCES and 12th OCDF Batch, along with their parents and spouses were invited for the Function. Hostel night was also celebrated. All TSOs were taken on a guided tour of DAE facilities at Tarapur. During the year, TSOs from other BARC Training Schools visited BARC, Mumbai.

Work for OCES/DGFS-2017 programmes began in October-November, 2016 with the preparation of advertisement to be published in the second week of January 2017. A short advertisement in the Official Language in Hindi language daily newspapers in the Northern Hindi-speaking belt has already been released besides a long advertisement in 26 national and regional dailies in 46 cities and towns. A full page advertisement was published in 'Employment News.' Campaign through DAE facebook page has been launched too. A net job portal – 'www.shine.com' has been engaged to send about 12 lakh emails to the target candidates.

In order to promote DAE activities and thereby attract best talent to our fold, visits to as many colleges and universities as possible during January 20 to February 13, 2017 have been planned under the outreach programme. The Online examination, during March 18-26, 2017 is planned at 45 cities/towns with multiple venues in cosmopolitan cities.

By the end of March, 2016, foundation and core course work along with examinations for OCES 2015 had been completed. It was followed up with technical visits to DAE facilities at Tarapur, placement viva, elective courses, mini-projects, administrative workshop etc. The soft skills workshop for all the TSOs, introduced during OCES 2012, continued for OCES 2015 as well. The 4-month academic course work for OCDF 13th Batch, which started on August 1, 2016 along with OCES 60th Batch, had been concluded successfully. At present, the academic course work of 2nd semester of 60th Batch is underway, and by end of March, 2017, the semester examinations would be completed. During the present year, a total of about 150 of over 170 courses consisting of foundation, core and elective courses were taken by TSOs. About 600 faculty of practicing scientists and engineers were invited from various Divisions/Units of DAE for conducting the courses. Mini-projects this year were allotted to TSOs in consultation with their prospective Divisions/Units. About 140 Scientists and Engineers supervised the project work of the TSOs.

Summer training (1 to 2 months) and academic projects (2 to 12 months) for BE/B.Tech/M.Tech/ ME/Engg Diploma/MSc/MCA students from all over the country were conducted. During January –December, 2016, 1606 students from different institutes visited BARC for training/project.

Soon after formal joining (on August 1, 2016) of different Divisions/Units of DAE by the graduate TSOs, the process of undergoing of M.Tech project work got underway in consultation with the respective Head of Division/Unit. The allotment of MTech Projects to all the eligible fresh officers from OCES 2015 has been

completed and finalization of M.Tech. enrollments is being done for 85 candidates.

After successful completion of 8th set of QUEST course, 9th set of Quest course is announced, under which application have been invited and received for 3 advanced courses. All the courses are scheduled to commence in February 2017.

Health, Safety and Environment Group of BARC conducts One-year Diploma in Radiological Physics Course (post-M.Sc., programme) under the aegis of Homi Bhabha National Institute (HBNI). It also conducts various training cum certification programmes on radiation safety in medical, industrial and research applications of radiation sources for societal benefits. These courses are mandatory as per AERB regulations. HS&EG also conducts Workshops and Exercises aimed at training of various organizations such as Defence, Paramilitary, NSG, Forensic, Civil Defence, Police, and Fire Services on Preparedness and response for Nuclear Disaster and Radiological Emergencies.

At IGCAR, thirty seven Trainee Scientific Officers of the tenth batch have completed their training in six disciplines and were placed in various units of DAE. In the present academic year, thirty six Trainee Scientific Officers are undergoing training at the Training School. In the current batch, 25 Research Scholars have been inducted, to pursue their doctoral programmes in the frontier areas of engineering and basic sciences. Employees, who are pursuing higher studies under the aegis of Homi Bhabha National Institute, are also undergoing coursework at the Training School.

Human Resource Development was continued at AMD with in-house (70 officers + 9 Scientific Assistants + 13 Technicians + 11 Work Assistants) and external (22 officers) trainings in institutes like ATI, ASCI, IIPI, NIAS, TSFA, NFC etc. 40 students from various universities and institutions were imparted internship, field / laboratory training in AMD. 62 students from universities made study visits to AMD Headquarters and Regional Centers.

Human resources development activities at RRCAT were continued and contributed in a significant way towards development of quality manpower in the form of imparting training to Trainee Scientific Officers (TSOs) in the discipline of physics, electrical and electronics, providing one year pre-doctoral course work towards the successful completion of Ph.D. degree of HBNI, Mumbai. In addition, RRCAT provided guidance to M.Tech/M.Sc. students to carry out their one year/six months project work towards the partial fulfilment of their degrees. In the 16th batch, 5 TSOs have completed the one year orientation course in the field of Accelerators and Lasers and have been placed in various units of DAE. In the current 17th batch, 5 TSOs are undergoing training. 5 TSOs who passed out previously from various BARC training schools and joined RRCAT as SO/C have been awarded M.Tech. degree. Number of Ph.D. scholars who have completed the one year pre-doctoral course are 9 and currently 7 Ph.D. scholars are undergoing the course work. During 2015-16, 8 scholars have been awarded Ph.D. degree by HBNI. A total number of 110 students from various universities/institutions have completed their M. Tech project work at RRCAT

At TMC, the formal education in medical and para medical disciplines in Oncology were conducted leading to the award of Post Graduate Degree/Diploma/Certification in the respective fields. Fellowships were also awarded for advanced training in select disciplines. In the year 2016, the total no of candidates who graduated were 156.Informal Education in the form of trainees and observers weree accepted from National and International agencies with the objective of refining their skills.

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 Resources 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 consist of 11335 strong and dedicated workforce with 3644 engineers and scientists, 5869 technical employees, 1540 non-technical executives & staff and 282 Auxiliary support staff who spearhead the activities of organization. During the year, as a part of annual induction program of young talent to NPCIL, 4 Medical Professionals and 99 direct recruits in scientific and 16 in non-technical categories (Group A) were recruited through centralized recruitment process. In the career progression front, during the year 321 employees in Scientific and Technical categories and 246 (32 executives and 214 non-executives in non-technical categories were elevated to the next higher grade. Training and Development initiatives covered competency development for fresh as well as experienced manpower across hierarchy. Besides, well developed internal training programs, customized management development programs with the involvement of professional training institutes and experts were organized for higher levels. Harmonious Employee Relations were maintained across NPCIL. To minimize the grievances of employees a structured mechanism for redressal of grievances (GRAMS) at all levels.

Performance Linked Incentive Scheme (PLIS) linked to various production targets and construction milestones finalized by way of tripartite settlement between Management, Employees and conciliation Officers is in operation and has been proved very successful and instrumental in improving the production by boosting morale of employees and executives. In addition, NPCIL (High Performers Annual Award) Scheme is in place for encouraging employees to work towards achievement of organization goals in an efficient and effective manner.

NPCIL fully complies with the Government of India directives on implementation of Official language. NPCIL has been relentlessly making all efforts towards continuous improvement in the progressive use of official language among all its units, projects and HQs. NPCIL's efforts in propagation of official language have been receiving commendations and awards at various forums.

As in the past, the 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. At present, IOP, Bhubaneswar has 43 Ph.D. students, 19 Post-Doctoral Fellows and 4 visitors. On the occasion of 40th Year Academic Excellence of IOP, it was observed that a total of 122 students were awarded degrees of which 86 has been established as top class researchers/faculty members in various national and international institutes. This year eleven scholars have joined the pre-doctoral programme while eight doctoral scholars received their Ph.D. degrees.

Administrative Training Institute

ATI Administrative Training Institute, started functioning with the motto “Prashikshaneshu Dakshprayate – Training Empowers” on 2nd July, 2007 . ATI has been able to organize over seven hundred Sixty Five programmes for over 21000 participants, till date. ATI's another major achievement is “training at doorstep” of different units. This could be achieved because of the robust Training Management Information System (TMIS) in place. This takes care of major training activities right from drawing calendar, preparing schedules, nomination data, confirmation, faculty database, feedback, budget and expenditure management etc.

Administrative Training Institute (ATI) offers wide range of programmes starting from induction to post retirement and periodic in-service programmes,

CHAPTER 6

subject specific workshops ensuring depth and range.

Against 96 programmes scheduled for the financial year 2016-17, ATI has conducted 65 programmes till January, 2017. This includes one Experience Sharing Workshop for Registrars/Financial Advisers of Aided Institutions, two programmes on Gender Sensitization & Equal opportunities in Govt. Service, Two Mandatory Induction Programmes for Work Assistants, One Mandatory Induction Programme each for newly recruited Administrative staff and newly recruited Security Guards.

Some of the major highlights of the ATI training programmes included One Capacity Enhancement Workshop for Administrative/Accounts Staff of Aided Institutions at NISER/IOP, Bhubaneshwar; Programme for retirees on Pension and Retirement Benefits; Workshop on Contract Labour & Outsourcing; Art of Effective Living and Effective Living & Leadership Programmes at Initiatives of Changes, Panchgani . All the programmes were well received.

Professional training for the Security Staff of the Department is another important programme which has been well received. This programme involves field visits to DAE units. A passing out parade is organized for instilling pride in their work.

Professional liaison and coordination by ATI has helped in strengthening network with the premier training institutes and faculty members. This helped in ensuring quality, variety and freshness in the programmes

Passing out parade function of the participants of the Mandatory Induction Training Programme for newly recruited Security Guards during September, 2016 to 28th October, 2016

SPONSORED RESEARCH

Board of Research in Nuclear Sciences (BRNS)

Board of Research in Nuclear Science (BRNS) is an advisory body of DAE. Besides funding research projects, BRNS provides financial assistance to organize symposia/ conferences/ workshops on topics of relevance to the programmes of DAE. BRNS also awards projects to young scientists to initiate them in a career of research and Dr. K. S. Krishnan Research Associateship to identify and encourage highly talented young scientists and technologists. The DAE Graduate Fellowship Scheme (DGFS) is meant for inducting Graduate Level students doing M.Tech. at the IITs. 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 honourable services of Scientists and Technologists who have distinguished themselves at national and international levels.

During the year 2016-17, 144 new research projects were sanctioned and a grant of ₹ 785 Lakh was disbursed December 2016 under R&D head. BRNS also singed a MoU for the “Development of Technology for large sized Nd-doped phosphate laser glass blocks & discs with edge cladding based on 15 L scale glass melting facility”. The MoU was signed between CGCRI, Kolkata, RRCAT and BRNS.

Under DAE Graduate Fellowship Scheme (DGFS), fellowship was offered/awarded to Four M.Tech. Students studying in IIT Mumbai and IIT Kanpur. Sixteen new students were inducted under DGFS-Ph.D programme, bringing the total number of Ph.D. students under this scheme to 98. Total 17 number of students completed Ph.D., since the inception of this

scheme.

Financial support to the tune of ₹ 164 Lakh was extended for conducting 103 seminars, which were conducted by professional organizations on various topics of relevance to DAE. Out of them 14 symposia were solely organized by the DAE fraternity and they were fully funded by BRNS. 85 fellowships were offered under the Raja Ramanna Fellowship Scheme (Senior Scientists Scheme) & 3 Homi Bhabha Chairs were awarded.

Promotion of Mathematics

NBHM the National Board for Higher Mathematics (NBHM) was established under the aegis of DAE in the year 1983 with the objective of promoting excellence in higher mathematics education and research in the country.

NBHM has been in charge of the Mathematics Olympiad activity for talented young students at higher secondary (the plus two) level. This activity is conducted with the help of the Homi Bhabha Centre for Science Education (HBCSE). Selection for participants of the Indian Team to International Mathematics Olympiad (IMO) is decided in two steps – (1) The Regional Mathematics Olympiad (RMO) and (2) the Indian National Mathematics Olympiad (INMO) at the national level. Selected students from INMO are offered further summer training in mathematics through a Nurture programme for the succeeding 4 years and provided scholarships and cash prizes.

This year the 57th International mathematical Olympiad (IMO) 2016 was held at Hong Kong, from 6 to 16 July 2016. The six-member Indian team secured 1 Silver and 5 Bronze Medals at the IMO-2016.

The 5th European Girls Mathematical Olympiad (EGMO) 2016 was held at Bușteni, Romania from 10 to 16 April, 2016. The two-member Indian team secured One Bronze Medals at EGMO-2016.

NBHM is conducting Madhava Mathematical Competition for the undergraduate students. This competition is designed so as to generate interest in mathematics in early years of college. NBHM is in process of creating suitable infrastructure, in the form of human resources, for this purpose.

NBHM gives grants to various mathematical centers engaged in activities of promoting higher mathematics. The Chennai Mathematical Institute that runs a high quality undergraduate programme in mathematics is a regular recipient of grants from NBHM. The Kerala School of Mathematics, Calicut, The Institute of Mathematics and Applications, Bhubaneswar and the Bhaskaracharya Pratishthana, Pune, are the other institutes getting grant from NBHM based on various programme proposals.

Taking proactive role in spotting talent in the country, the Board provides scholarships and fellowships to the students, selected through nationwide competitive tests, to pursue studies at masters and Ph.D. levels. The Board also offer post doctoral fellowships positions to the young mathematicians after their PhD degrees through the selection process.

During the summer vacation, active training programmes are also organized outside the regular educational framework at the undergraduate level, called Mathematics Training and Talent Search. Supplementary training activities are also undertaken for selected students at postgraduate level, in a coordinated fashion, under the Advanced Training in Mathematics (ATM) programme.

The Board also provides grants for promotion of activities in pure and applied mathematics, under several schemes, including support to research projects, travel grants for participation in workshops, conferences, and undertaking collaborative research, funds for organizing conferences etc.

NBHM has been providing grants to mathematics libraries around the country, enabling

them to purchase the latest books and journals in mathematics. Around 96 such libraries take advantage of this scheme of NBHM and update their collections of Journals / Books in mathematics. NBHM also distribute selected books to various postgraduate institutions under its book distribution scheme.

Financial support was provided to 43 national and international conferences held in India, 7 research projects. Travel grants were provided to 30 mathematicians to enable them to participate in conferences held in India and abroad. The faculty support was provided to the universities in the form four Visiting Professors this is to strengthen the research and teaching potential at the institute. Post Doctoral Fellowships were awarded to 24 new researchers and 32 candidates were selected for the pursuance of NBHM PhD programmes. One RTI query was received and answered during this period.

The new Web-based interactive system for communication, evaluation of proposals and administrative purpose is ready. The tenders have been floated and technical specifications sent by the vendors are under examinations at present.

Olympiad Programme

The Olympiad programme was conducted successfully with all 25 students trained at HBCSE securing medals, including 11 gold medals at international Olympiads. Over 200 teachers participated in various Olympiad related Exposure and Resource Generation camps. Academic and organizational support to conduct the International Olympiad in Astronomy and Astrophysics held at NISER, Bhubaneshwar, Orrissa were provided. Training workshops for school science and mathematics teachers (approx 20 workshops of between 1 to 5 days each, over 500 teachers) were conducted. Two (15 day) workshops for science teacher educators and education officers from Sri Lanka (60 participants) were also conducted.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

As part of addressing the large-scale computational requirement, a multi-purpose parallel high-performance computing cluster, delivering a sustained numerical performance of 180 Teraflops was commissioned at IGCAR and the cumulative high performance computing power crosses the 200 Teraflops. The supercomputing cluster facility is effectively utilized by scientists and engineers for mathematical modeling and computational simulation studies, pertaining to various domains of fast breeder reactor technology.

Various software applications were developed and deployed in an endeavour to push E-Governance at RRCAT. These included digital signature based casual entry permit, material gate pass management etc. RRCAT web site was upgraded to latest platforms and webpages for CHSS beneficiaries, suppliers and pensioners were also added. A vehicle movement monitoring system based on UHF technology has been deployed at Guard House security. Integration of Kshitij-4 high performance computing cluster with centralized resources was accomplished and it was released to users for regular use.

NPCIL has implemented many major IT enabled work processes in the area of Maintenance Management, Material Management and Work Management in NPPs, Human Resource and Finance management and continuously improving the software applications based on the feedback from user community.

Following major IT applications were developed and deployed:

Online Recruitment

Corporate portal for the recruitment of various posts across NPCIL featuring end-to-end recruitment solution consisting of registration by the candidate, online application, short listing, interview call letter, selection of interview date/venue, document verification, interview results, etc. has been developed.

System for Management of Vigilance Complaint

System for Management of Vigilance Complaint was developed and deployed in the company's Internet web site. Also, for internal working, Vigilance Clearance Management system developed and is in use.

Corrective Action Management System (CAMS Ver.3)

Corrective Action Management System (CAMS Ver.3) comprising of Corporate Review, Follow-up Review, Job Observation, Low Level Event, Recommendations and Safety Related Deficiency Management along with Integrated Work Management System (iWMS) was developed in-house for use in NPCIL Stations for monitoring and implementation of various recommendations from various review processes.

M-governance

As part of m-governance, mobile phone based telephone directory has been developed and distributed to employees.

CHAPTER 7

Thin film composite polyamide RO membrane in preparation

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES

12 Channel Tele ECG

CHAPTER 7

The spin-off technologies generated out of the core programmes of the Research and Development organizations of DAE were developed and transferred to industries for commercial exploitation. Over a period of time, a number of technologies have been transferred to industries.

DAE organizations also entered into scientific collaborations with public and private sector organizations. This interaction has given beneficiary organizations a technological edge.

TECHNOLOGY TRANSFER

The knowhow for detecting operating health of turbine blades in thermal power plants was transferred to BHEL & NTPC by BARC. This advanced system can be implemented on turbine of any type of power plants. The system successfully detects early symptoms of defective blades. Two different designs of Seismic Switches for Nuclear reactors have been developed and the technologies have been transferred to ECIL after carrying out various qualification tests. The technology of a high voltage Capacitor Charging Power Supply (CCPS) has been designed and the technology has been transferred to ECIL.

The technology of He MS Leak Detector was successfully demonstrated and is ready for transfer to industry. Incubation MOU for the development of Residual Gas Analyzer was signed with L&T.

An incubation technology for an oral BRP formulation is being transferred to a private Indian entrepreneur for its clinical trials as a prophylactic as well as a therapeutic radioprotector.

The know-how for preparation of Thin-Film Composite (TFC) based Sea Water Reverse Osmosis (SWRO) membrane capable of desalination of highly saline /sea water has been transferred to M/s. Permionics Membranes Pvt. Ltd., Vadodara in June 2016.

Handheld low cost 12-Channel Tele-ECG Instrument that operates with the help of a mobile phone/PC via Bluetooth has been developed. The device is ideally suited for rural health care. Technology of this instrument has been transferred to industry and is in the process of deployment at Government hospitals. Peripheral Pulse Analyzer to study physiological variabilities for the purpose of disease characterization has been developed. Technology of this instrument has been transferred to industry for commercial production.

At IPR, the “Atmospheric pressure plasma jet technology” has been transferred to M/s Aditya High Vacuum Pvt. Ltd., Ahmedabad on 23rd June 2016. FCIPT has developed state of art atmospheric pressure plasma jet using dielectric barrier discharge. Dermatologists at Institute of Post Graduate Medical Education and Research (IPGMER) Hospital, Kolkata have used this Plasma Jet for the treatment of fungal infection on human skin.

Plasma Jet on feet infected with Tinea Cruris

“Metal oxide nano powder production technology” has been transferred to M/s Plasma & Vacuum Techniques, Ahmedabad on 8th July 2016. FCIPT has developed a plasma based instrument that can produce metal oxide nano powders in bulk quantities.

“Plasma Pyrolysis technology for organic waste” was transferred to M/s Bhakti Energy, Rajkot on

Dr. Shashank Chaturvedi, Director, IPR(centre) and Mr Ashok Vora, Bhakti Energy (right), exchanging Technology transfer documents

29th August 2016. FCIPT, IPR as a part of its contribution to Swatch Bharat Mission is expanding the use of Plasma Pyrolysis technology for the waste disposal. This technology was also transferred to M/s G P Green Energy Systems Pvt. Ltd., Kolkata on 7th December 2016.

"Atmospheric pressure inline plasma processing technology" has been transferred to M/s Arshad Electronics Pvt. Ltd., Mumbai for treatment of textile and plastic film treatment on 9th November 2016.

COLLABORATIVE PROGRAMMES

At BARC, a bio-degradable oxocatalyzed polyolefin food packaging film was developed in collaboration with Institute of Chemical Technology, Mumbai. Indigenous development of dual energy X-ray baggage scanning system (XBIS) was carried out in collaboration with Bharat Electronics Limited.

INTELLECTUAL PROPERTY RIGHTS

DAE-IPR Cell constituted by the Department, works as a nodal agency for all Intellectual Property Rights (IPR) related matters including filing of patents within India and abroad for all the Units including Public Sector Undertakings and Autonomous Institutions under DAE. During the financial year 2016-17, five DAE-IPR cell meetings were held. DAE filed seventeen new patent applications which includes; two application under PCT (Patent Co-operation Treaty), five in India, four in USA, three in Europe and one each in Australia, Canada & Japan.

During this period, eleven of the previously filed patents have been granted to the Department. These includes; six in USA, four in India and one in Europe. Following are the list of patents granted:

- A method for non-intrusive on line detection of turbine blade condition – by BARC (in USA)
- A method for large-scale synthesis of optically stimulated luminescence grade polycrystalline ceramic material – by BARC (in USA)
- A flexible magnetic membrane based actuation system and devices involving the same – by BARC (in USA)
- Process for Development of a High resistance Austenitic Stainless Steel – by IGCAR (in India)
- A novel method of Synthesis of Rhodium Metal Foam using room temperature ionic liquids – by IGCAR (in India)
- Niobium based superconducting radiofrequency (SCRF) cavities comprising niobium components joined by laser welding – by RRCAT (in USA & Europe)
- A process for producing ultrapure titanium dioxide from titan ferrous ore and slag sample – by IREL (in India)
- A decentralized information flow security model for multilevel security and privacy domains – by TIFR (in USA)
- Ceramic Filler, Method of preparing the Ceramic Filler and Applications as

Resonator and Laminate thereof – BRNS Project by RRCAT & MEITY (in USA)

- Fire Retardant Intumescent High Density Rigid Polyurethane Foam for Specialty Applications – BRNS Project by BARC & IIT, Kharagpur (in India)

During the same period, the following four patents were licensed to six companies:

- A method of making a supported dry asymmetric polyamide membrane for membrane filtration (BARC)
- A spiral wound dry polyamide element for membrane filtration and a method of making the same (BARC)
- Ultrafiltration Membrane water purification device (BARC)
- A penetration enhancing flux formulation for Tungsten Inert Gas (TIG) welding of austenitic Stainless steel and its application (IGCAR)

During the year, 153 patent applications were referred to the Department by the Controller General of Patent, Intellectual Property (IP) India, to screen for the applicability of section 20 (1) of Atomic Energy Act, 1962, i.e., whether the application is related to or useful for atomic energy, and give its opinion. Directions of the Department were communicated to the Controller of Patents in India.

As a part of Training School curriculum, IPR subject has been introduced at BARC Training School at AMD, Hyderabad, and at IGCAR Training School, Kalpakkam. Regular lectures on IPR are also delivered at the BARC Training School, Mumbai. A one day Intellectual Property Awareness program was conducted for scientists at BARC and RRCAT, under the ages of Administrative Training Institute at their respective institutes.

CHAPTER 8

Students Rally as part of Swachchta Pakhwada

INFRASTRUCTURE

Tamirabarani : Tower Block of 120 Nos IIIC Apartments

CHAPTER 8

CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible for providing infrastructure support to various Units of Department of Atomic Energy (DAE) including its aided institutions. DCSEM is involved in planning, designing & execution of various construction works for Housing, Schools and Hospitals, Laboratories, Institutional Buildings & infrastructural facilities to support the scientific & technological programmes of DAE. The Directorate is also responsible for operation and maintenance of various services, Estate Management and Security for the housing colonies of DAE at Mumbai.

During the report period, the major works completed by DCSEM at Anushaktinagar, Mumbai were the construction of High Level Ground Reservoir (HLGR) water tank of 40 lakh litres capacity in the western sector; Multilevel car parking for 156 cars near Vikram Sarabhai Bhavan (VSB) and other miscellaneous work such as the development work for CISF Quarters for (II-B & IV-D) along with PH services.

40 lakh litres capacity tank

Car Parking near V.S.Bhavan

Various works of DCSEM at Anushaktinagar, Mumbai under progress included the construction of Building and ancillary structures for Sewage Treatment Plant for 15 lakhs litres capacity including civil, internal PHE works adjacent to existing sewage treatment plant at Western Sector; Restoration/renovation of old houses which are more than 20 years old Phase-II; Up gradation of services under 12th plan; Construction of 356 nos. residential quarters,; Hostel for trainees of BARC/HBNI Phase - I&II; Construction of extension of V.S.Bhavan; Building for Fission based 99MO Production facility for BRIT adjacent to ISOMED in BARC; Construction of cultural centre and the construction of 312 flats of type V-E at Mandala.

Sewage Treatment Plant at Western Sector in Anushaktinagar is nearing completion

The progress of the major construction works by DCSEM for other units/ Autonomous units of DAE were as follows:

The Phase-I construction of Global Centre for Nuclear Energy Partnership (GCNEP), which includes SNSS & Guest House Block 'A' building along with associated Electrical works at Kheri Jassaur near Bahadurgarh, Haryana is nearing completion. The construction of First Research and Technical (FReT) Block for TIFR, Hyderabad is under advanced stage of completion. The construction of Office Complex (Phase-II) for AMD for exploration and Research at Southern

Guest House : Block 'A' of GCNEP

Region, AMD complex, Nagarbhavi, Bengaluru is also under progress. The construction of Facilities for Research in experimental Nuclear Astrophysics (FRENA) laboratories for SINP at Bidhannagar Kolkata is under progress. The construction of R&D Laboratory for AMD and Eastern Regional Regulatory Centre for AERB building at VECC Kolkata is in progress and the construction work of 100 bedded hospital and ancillary building for TMC at Vishakhapatnam, Andhra Pradesh is also in progress.

Major work orders issued during the report period included the construction work of 312 flats for type V-E at Mandala, Anushaktinagar; the construction of Substation Building for 312 flats of type V-E including Civil, Electrical & PH works at Anushaktinagar; the construction of Substation Building including Civil, internal Public Health and Electrical works for VECC at Rajarhat, New town, Kolkata.

The Engineering Services Division of DCSEM maintains all the residential flats and shops etc. (10169 nos.) and public buildings of the Department in Mumbai including execution of up gradation works required for the buildings. These Division is also responsible for the operation & maintenance as well as upgradation of electrical power distribution, lifts, water supply, sewer lines, sewage treatment plant, fire fighting system etc. of township at Anushaktinagar, Mumbai.

The Estate Management Section of DCSEM continued to manage the estate of DAE and allotment of all the residential flats of different categories, shops in Anushaktinagar township, public buildings and the security for the DAE Estate in Mumbai. It also continued to manage the departmental canteen at VS Bhavan, Guest Houses of Dhruva, Neetibaug at New Delhi and Zerlina & Anand Bhavan at Mumbai.

During the year, schemes worth ₹ 238.35 Crores were executed as per BE 2016-17 for various DAE units including projects for DCSEM worth ₹ 110 Crores.

PURCHASE & STORES

Directorate of Purchase & Stores (DPS) is one of the service organizations of Department of Atomic Energy. The directorate was set up in the year 1973 with a mandate for managing the material management requirements of various constituent units of the Department. The mandate includes procurement of right material, at right price and at right time for various programs of the department. It has been the continuous endeavour of the directorate to meet all the requirements of research and development as well as industrial units of the Department. The Directorate also concludes various contracts for procurement including service contracts, procurement contracts, consolidation, transportation and clearing contracts. The technical liaison mission of DPS at Atomic Energy Wing, Embassy of India, Paris provides technical support for procurement of sophisticated machinery. It also supports department for execution of bilateral co-operation in nuclear industries, scientific studies and nuclear regulations.

IT Infrastructure Development

The Directorate made continuous efforts for implementing the latest information technology tools for increasing efficiency to the best of its ability. A new e-tendering portal has been launched where the central and the regional purchase units floats tenders. Six high-end servers are used for connectivity, authentication and data processing jobs for stores and indenting officers of all the stores units situated at Trombay.

CHAPTER 8

Implementation of Policies of the Government

Tenders are floated on e-tender portal for ensuring transparency and equal opportunities to all vendors and for effective implementation of government policies, viz., public procurement policy, preference to micro and small enterprises and domestically manufactured goods, drugs and medicines. Tender fee and earnest money deposit is waived for the micro and small enterprises in accordance with government policies.

Vendor Development

During the year, the Directorate arranged three vendor meets of which two meets were exclusively for micro and small enterprises. The mandate of the Department, different items procured and features of the e-tendering platform were presented to the vendors. Feedback was obtained from vendors on the e-tendering portal for incorporating modifications in the e-tendering software for convenience in usage by vendors. A distinct e-mail account was created to receive problems/grievances/complaints from vendors. The issues raised were addressed by senior officials of the Directorate and replies were sent to the vendors.

Import of Uranium Fuel for Nuclear Reactors

Nuclear trade has been opened up for Indian civil nuclear facilities. The Directorate has been entrusted with the responsibility of procurement of uranium in various forms due to the experience gained over the years on procurement of various categories of items by the Directorate. During the calendar year, DPS has procured uranium ore concentrate consignments from M/s. Cameco Inc. Canada and M/s. JSC NAC Kazatomprom, Kazakhstan and natural uranium fuel pellets from M/s. JSC TVEL, Russia. Negotiations are being carried out for procurement of uranium ore concentrates from Australia.

GENERAL SERVICES ORGANISATION

General Services Organization, Kalpakkam takes care of the common facilities such as Housing, Medical, Transport, Water Supply, Civil, Electrical, Telecommunication, Solid waste collection and disposal etc in the Atomic Energy Townships at Kalpakkam and Anupuram where employees of the DAE Units at Kalpakkam, viz – IGCAR, BARCF, MAPS and GSO reside. GSO provides infrastructural support to the Kendriya Vidyalayas, Atomic Energy Central Schools, Atomic Energy Higher Secondary School and accommodation for the CISF personnel. GSO attends to liaison works with State Government Departments for supply of water and with BSNL for telecommunication network to the Township.

Some of the significant achievements of GSO during the year 2016-17 are mentioned below:

Civil Work

In-house Architectural & Structural engineering design services have been carried out for the works relating to 100 bedded hospital at Anupuram; Additional Classrooms for various schools (KV-1, AECS-1, AECS-3) at both the townships and CISF 2B tower block.

During this period 62 Nos of NIT were released and Work orders for 44 Nos works has been issued for₹ 13.40 Crores under various project heads. Work order for the following major works that were issued during the year include construction of 140 Nos. Dormitory accommodation for C.I.S.F. personnel in DAE Township, Kalpakkam for Rs. 3.97 Crore; Widening of Bituminous road between Anupuram Main gate (Gate -1) and Neikuppi gate (Gate-2) with storm water drain and pathway in DAE Township, Anupuram for ₹ 3.36 Crore; Construction of Additional Class rooms and Toilet Block for KV-2 in DAE Township, Kalpakkam for ₹ 1.76 Crore; Construction of Additional Class Rooms for KV-1 in DAE Township, Kalpakkam for ₹ 1.34 Crore; Construction of

120 Nos. of Type III-C and 480 Numbers of Type IV-D Residential Quarters in DAE Township Anupuram for ₹ 1.82 Crore; Construction of Four wheeler parking shed for IV-D quarters in DAE Township, Anupuram for ₹ 1.37 Crore; Construction of 5 Nos. of Additional Class rooms in Atomic Energy Central School-III at DAE Township, Anupuram for ₹ 1.14 Crore and Special repairs to Night latch/window Grills and providing Grill door for NB and II-B row type houses in DAE Township, Kalpakkam for ₹ 1.28 Crore.

The construction works of Thamirabarani – Tower Block housing 120 Nos. IIIC apartments; Four Nos. of IVD Houses for CISF Personnel and Two Wheeler Parking Sheds for Efficiency Plus Tower Blocks were completed.

Tamirabarani : Tower Block of 120 Nos IIIC Apartments

IV D Apartments for CISF Personnel

Electrical & Telecommunication

Augmentation of the electrical & telecommunication infrastructure and refurbishment of aged systems was carried out. Various activities completed during this period included the Supply, installation, Testing and Commissioning of Solar Water Heaters in SRI Hostel cum Guest House at DAE Township, Anupuram; Supply, Installation, Testing and Commissioning of a 365 kVA Diesel Generator set at DAE Townships, Kalpakkam and Anupuram; Transportation, Laying, Testing and Commissioning of 11 kV Underground Cables and other associated works in DAE Township, Kalpakkam; Internal Electrification of Transition Switching Station, Ring Main Sub-station-6 and other associated works at DAE Township, Anupuram; Providing Street and Area Lighting in 240 Efficiency Plus Tower block services roads at DAE Township, Anupuram; Providing Power Supply to Fire Fighting System and Street & Area Lighting System for 120 Nos. type III-C Quarters at DAE Township, Anupuram and Rewiring of 50 Nos type II-B Residential Buildings (Phase -II) at DAE Township, Kalpakkam.

Computer

Centralized Network and Server Facility was set up. This facility will cater to the total IT requirement of GSO. It will include the Internet and Intranet Network Connectivity related equipment, Application Servers, Network Security related equipment, ATS-KTS link related equipment etc. In the first phase of the work, upgradation of the OFC Backbone was completed and fifteen Rack Servers were procured, tested, installed and configured. Videos surveillance of the GSO Annex Building was completed. Audio-Visual System Integration was designed, procured, installed and commissioned at the auditorium in the GSO Annex Building.

Mechanical

Enhanced Fire Safety measures have been implemented at DAE Hospital by providing Fire water main and facility for Fire Tender movement around the Hospital. Comfort conditions have been ensured for the patients in female ward of DAE Hospital by erection of new air conditioning system. Maintenance and repairs of strategic special nuclear material carrying vehicles was carried out on 32 occasions during the nuclear fuel

transfer to/from visit to Kalpakkam from various DAE units during 2016. Autoshop was upgraded to test, diagnose and repair the automobile air-conditioner system with the new BOSCH AC diagnostic recovery machine with the existing manpower. In-house designed insulators were installed at starter circuits in all the buses/trucks, to prevent electric short circuits due to mechanical failure (accelerator lever link). Fall protection clamps were introduced to all the heavy vehicles like Buses & Trucks to prevent the toppling of vehicle in case of Propeller shaft failure during running.

Swachh Bharat Initiatives

Swachhta Pakhwada campaign was conducted from 18.04.2016 to 02.05.2016. The following activities were successfully conducted.

Rally by School Students

A mass rally was conducted at Kalpakkam township on 18th April 2016 to create awareness on cleanliness among township residents. Nearly 100 Students from Class IX of Atomic Energy Central School 1, Kalpakkam actively participated in the rally.

Students Rally as part of Swachchta Pakhwada

Cleaning Activities

On 22nd April 2016 cleaning campaign was organized by GSO through an NGO called Exnora Green Pammal at Anupuram Township. The complete cleaning was carried out at various places. On 26th April 2016 a cleaning campaign was conducted at Government Primary School Complex, Kalpakkam and the complete school campus was cleaned with the help of volunteers.

Cleaning of Tamil Medium School, Kalpakam

Technical Talk on Swachh Bharat Mission

A Technical Talk on "My Waste My Responsibility" by Smt. Mangalam Balasubramanian, President, Exnora Green Pammal, was organized by ESG, GSO on 29th April 2016.

CHAPTER 9

Missile Check Out Facility for AKASH Missile

PUBLIC SECTOR UNDERTAKINGS
(FINANCIAL PERFORMANCE)

Portable RCIED Jammer (EC-SPJE-400)

CHAPTER 9

Financial performance of DAE's public sector undertakings namely, the Nuclear Power Corporation of India Ltd., Uranium Corporation of India Ltd., Indian Rare Earths Ltd. and Electronics Corporation of India Ltd. are given below. Operational highlights of these public sector undertakings, except ECIL, have been covered under the relevant major programme heads. Gist of the operational performance of ECIL is given here.

NUCLEAR POWER CORPORATION OF INDIA LTD.

The expected net Profit After Tax (PAT) for the year 2016-17 is about ₹ 2180 Crore The net profit after tax for previous Financial Year 2015-16 was ₹ 2707 Crore NPCIL bonds continued to be rated at AAA (Highest Safety) by CRISIL and CARE.

URANIUM CORPORATION OF INDIA LTD.

The performance of all major units of the company during the year 2015-16 remained quite satisfactory. The total income of the Company during the year 2015-16 was ₹ 1024.63 crore as against ₹ 890.24 crore in the previous year. The Company has registered a Profit Before Tax of ₹ 158.06 crore in the year 2015-16 as against ₹ 11.33 crore in the previous year. Performance of the Company in terms of MoU signed with DAE is expected to be "Good" for the year 2015-16.

INDIAN RARE EARTHS LTD.

During the year 2016-17, the Gross Sales Turnover anticipated is ₹ 459.94 crore (provisional) against ₹ 362.36 crore of previous year. Anticipated Profit Before Tax (PBT) in 2016-17 is ₹ 30.67 crore (provisional) compared to PBT of ₹ 111.23 crore in 2015-16.

The Monazite Processing Plant (MoPP) was commissioned after obtaining operational clearance from AERB in May, 2015 and it has started the production activity. Ramping up of the Capacity is under progress.

Commissioning trials for producing separated high pure rare earths at RED, Aluva using mixed rare earth chloride from MoPP are on. Sustained production to meet the specified quality is in progress.

ELECTRONICS CORPORATION OF INDIA LTD

Electronics Corporation of India Limited (ECIL) is engaged in the design, development, manufacture, supply, installation and commissioning of electronic equipment for Atomic Energy, Defence, Aerospace, Security, Information Technology and e-Governance sectors. The company has emerged as a leader in providing total solutions in strategic electronics and has varied multi-disciplinary competencies. ECIL has been consistently paying dividends over the past few years and is poised to leverage huge growth in strategic electronics.

ECIL has built a strong technological base by associating itself with prestigious R&D institutions of DAE, DRDO, DoS and academic institutions like IIT. The initial thrust of ECIL was to meet the Control & Instrumentation requirements of the Nuclear Power Program but later on the expected scope of self-reliance pursued by ECIL enabled the company to develop various products to cater to the needs of Defence, Space, Civil Aviation, Telecommunication, Banking, Police, Paramilitary forces, Oil & Gas, Power, Health, Agriculture, Steel and Coal sectors and various user departments in the Government domain.

ECIL has evolved as a multi-product company servicing multiple sectors of Indian economy with emphasis on import substitution and development of products and services that are having economic and strategic significance to the country.

Performance

Against the MoU target of ₹ 1650 crore for production and net sales, the Company achieved a production of ₹ 863.20 crore and a net sales of ₹ 850.07 crore up to December 2016.

The sector-wise significant achievements during the year 2016-17 are as follows:

Atomic Energy

- The company shipped its first consignment of Ultra Stable Power Converters to Germany for the International Science Program called Facility for Antiproton and Ion Research (FAIR).

Ultrastable power convertors

Defence

- Seeker accorded CEMILAC certification with the completion of SFT (Safety of Flight Test) for Seeker hardware and IV (Independent Verification) & V (Validation) of seeker software
- Captive Flight Trials (CFT) of seeker for performance test

Universal Electronic Fuzes

- ECIL reached a one million mark in the production of Electronic fuses for Armed Forces with zero lot rejection

Aerospace

- Antenna System for Strategic applications
- Inauguration of MHRD 32 DTH channels transmission through 11M & 9.3 M Ku band Antenna at BISAG

Missile Check Out Facility for AKASH Missile

Security

- Integrated Security Systems for strategic installations
- Mobile Communication Jammers
- Cyber Security Equipment

M7: Multimode Digital Radio

Portable RCIED Jammer (EC-SPJE-400)

IT, e-Governance & OTHERS

- Electronic Voting Machines and VVPATs for the General, State and Local Body elections
- Supervisory Control and Data Acquisition Systems for oil and gas pipelines
- Computerization of Sales Tax Operations in Maharashtra
- IT Education for various state departments.

Research & Development

The in-house R&D Programmes are guided and supported by the Technology Development Council (TDC) leading to several new products and enhancements being introduced into the market.

New Products Introduced

Following new products were introduced during the year:

- Developed prototype GEM foils required for VECC used in their modern advanced detectors
- Laundry Monitoring System
- SiPM / Scintillator based Detectors
- Prototype plastic Scintillator based Portal Monitoring System (PMS)

Laundry Monitor

Plastic Scintillator based Portal Monitoring System (PMS)

Tie-ups and Agreements

- The Company has entered into a Memorandum of Understanding with VIASAT for supply of Antenna for Antarctica
- The Company has entered into a Memorandum of Understanding with BARC for supply of RMP components
- The Company has entered into a Memorandum of Understanding with Rajasthan Atomic Power Station (RAPS 3 & 4 and 5 &6) for AMC of C&I system
- The Company has entered into a Memorandum of Understanding with Space Application Centre (SAC), Ahmedabad for supply of Ku DBS Feed

Gyros

Actuators

Radiation Detectors

LVDT

CHAPTER

10

Interaction with students at the 20th National Science Exhibition, Kolkata

OTHER ACTIVITIES

NPCIL was conferred with Vigilance Excellence Award 2016 from Vigilance Study Circle, Hyderabad

SCIENCE RESEARCH COUNCIL

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

BARC-SAFETY COUNCIL

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

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

CRISIS MANAGEMENT

The Crisis Management Group (CMG), a standing Committee of senior officials of the Department of Atomic Energy (DAE), is responsible for coordinating the Department's emergency preparedness and response activities to any radiation emergency in the public domain. Such 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 with inherent design features, the possibility of any accident in a nuclear facility or during transport which might lead to a radiation emergency in the public domain is highly remote. However, in order to handle any unforeseen situation, formal emergency response systems are in place and are tested regularly to ensure that there would be no radiation hazard to the public. All radiation facilities are regulated by an independent regulatory authority however, in case, an unlikely event does occur and leads to a radiation emergency in the public domain, a response system is in place to tackle such situations, by mobilizing the expertise of the Department of Atomic Energy in the field of radiation measurement and protection and medical treatment of radiation injuries. The objective is to make these specialized technical supports available to public officials who would be handling various types of emergencies related to radiation / involving radioactive materials in the public domain. The CMG also provides its expertise in various forums in the field of nuclear / radiological emergency management at both National and International levels.

The Crisis Management Group formally meets to review the crisis management plans at different facilities, to discuss on issues related to radiological incidence occurred if any, in the country and provide necessary guidance on matters related to radiological safety in the public domain to avoid the recurrence of such incidence.

The Emergency Response System of DAE is also available to respond any request from public official in the event of the reported presence or suspected presence of radioactive material. For this purpose, guidelines have been circulated to all 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. These are equipped with multiple modes of communication and are in constant contact with various nuclear facilities in the country, with Ministry of Home Affairs (MHA) as well as with the International Atomic Energy Agency (IAEA) in Vienna.

During the year 2016, India not only ensured its participation in all IAEA conducted International exercises (popularly known as ConvEx exercises) but could also successfully meet all the Convention

requirements identified under the Early Notification and Assistance Conventions (ENAC). India's participation was facilitated by Crisis Management Group (CMG) of Department of Atomic Energy and its

Sl. No.	Exercises carried out during the year 2016	Number of exercises
1.	Communication Exercises	401
2.	Fire Emergency Exercises	78
3.	Plant Emergency Exercises	46
4.	On-Site Emergency Exercises	19
5.	Off-Site Emergency Exercises	02

Emergency Control Room (ECR) which is also the National Contact Point for nuclear and radiological emergency.

During the year, Crisis Management Group (CMG) as the Competent Authority could successfully mechanize and submit "India's Offer of Assistance" to Georgia for Medical Treatment of one radiation affected patient, when for this real-life case, "Request for Assistance" was formally received from IAEA.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and heavy water plants periodically carry out variety of emergency exercises. The numbers of exercises carried out during the year 2016 are listed in the following table:

During the year, on 9 Oct 2016, CMG ensured DAE's effective response to the reports of suspected leakage of radioactive material from consignment at New Delhi International Cargo Terminus.

During the year, CMG has also ensured DAE's participation in Ministry of Home Affairs (MHA) conducted mock exercises on radiological emergency at Bengaluru, Mumbai and Delhi airports.

INTERNATIONAL RELATIONS

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

In addition to participation in the annual General Conference of the IAEA in September 2016, India actively engaged in nuclear security issues through the Nuclear Security Summit process, the Global Initiative to Combat Nuclear Terrorism, and India's own Global Centre for Nuclear Energy Partnership (GCNEP). Following the announcement made by the Prime Minister of India at the Nuclear Security Summit in Washington in April 2016, India made a voluntary contribution of US$ 1 million to the Nuclear Security Fund of the IAEA. India participated in the IAEA's International Conference on Nuclear Security in December 2016 in Vienna and hosted an Internal Assessment Group (IAG) meeting of the Global Initiative for Combat Nuclear Terrorism (GICNT) in February 2017 in New Delhi. As part of high level exchanges between India and IAEA, the Director General of IAEA Mr. Yukiya Amano visited India during 14-16 March 2017.

Cooperation at the multilateral level in peaceful uses of nuclear energy and advancement of nuclear S&T was also promoted through active participation in the European Organisation for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER), and the Nuclear Energy Agency of OECD. India became an Associate Member of CERN on January 16, 2017.

As part of India's continued engagement in civil nuclear cooperation with major partners, an Agreement

between the Government of India and the Government of Japan for Cooperation in the Peaceful Uses of Nuclear Energy was signed on November 11, 2016 during the visit of Prime Minister of India to Japan. The Agreement will enable India to benefit from Japan's advancements in civil nuclear domain and its extensive supply chain, and would open up opportunities for collaboration between Indian and Japanese industries to advance India's civil nuclear programme. On December 9, 2016, the Government of India and the Government of the Socialist Republic of Vietnam signed an Agreement on Cooperation in Peaceful Uses of Atomic Energy which provides a renewed framework for our civil nuclear cooperation with Vietnam. As part of our on-going developmental partnership and capacity building programme with Bangladesh, specially designed training courses were organised by GCNEP and NPCIL for nuclear energy professionals from Bangladesh in the areas of civil nuclear science and technology.

The Prime Minister during his visit to Tanzania and Kenya in July 2016, announced presenting India's indigenously designed and developed radiation therapy machine, "Bhabhatron II" with digital Simulator for cancer treatment in the two countries. As part of partnership with Africa, following on the announcements at the India-Africa Forum Summit of October 2015, DAE has offered 70 fellowships in cancer therapy to healthcare personnel from African countries at the Tata Memorial Centre, Mumbai, up to 2020.

During the period 2016-17 the Global Centre for Nuclear Energy Partnership (GCNEP) conducted 12 programs (one International Training Course, one Training Program for Bangladesh Delegation and eight national programs & workshop) in nuclear security, radiological safety, nuclear security culture and public awareness. There was active technical exchange between USA and UK under MOUs with these countries. One workshop on "Nuclear Security Culture" was organised with UK.

On GCNEP's construction progress front, the School of Nuclear Security Studies (SNSS) and one wing of Guest House building civil construction is completed. Five schools Labs are being setup and furnishing of Guest House is in progress. It is expected that the centre will start operating from its Bahadurgarh site during mid-2017.

The activities of the Centre were carried out from leased premises (Transit Office), by conducting off-campus Training Programs/ Workshops in the areas of Nuclear Security, Radiological Safety, Safeguards, Radiation Technology Applications for Food Security, and Public Awareness. A team of 10 engineers and one security officer has been posted at transit office. The newly constructed SNSS Building is ready to occupy and after receiving statutory clearances during mid-2017, all operation will be carried out from the centre. The outsourced security services, catering and facility management services, IT Infrastructure and other essential services will be in place by that time.

1st Training Program for Bangladesh Delegation, under the umbrella of Global Centre for Nuclear Energy Partnership (GCNEP), was conducted from 20th to 22nd Dec 2016 at Hyderabad, INDIA. This program was conducted as a part of consultancy services to neighboring countries. The delegation consisted of a batch of 13 professionals from various organizations from Bangladesh viz. Armed Force Division, National Security Intelligence, Boarder Guard, Fire Service & Civil Defense, Criminal Investigation

Faculty & Delegates of Training Program

A session in progress during the program

Department, Ministry of Home Affairs, Ministry of Science & Technology, Bangladesh Atomic Energy Commission, Artillery Brigade Bangladesh. Most of the delegates were the members of Bangladesh National Physical Protection System Working Group.

The purpose of the course was to familiarize delegation with current concepts and technologies in the area of physical protection of nuclear power plants so as to enable them to plan overall nuclear power plant security programs in their country. The objective of the training course was to provide participants with the general understanding of approaches on Physical protection of Nuclear Power Plants against theft and sabotage covering mainly the design, evaluation and response modules for physical protection.

NPCIL has been a member of many international organizations such as World Association of Nuclear Operators (WANO), Candu Owner's Group (COG), Institute of Nuclear Power Operations (INPO) and World Nuclear Association (WNA) and participating actively in their programmes with the objective of enhancing the safety and reliability of its nuclear power plants.

NPCIL is one of the founding members of WANO, which was established in 1989. It is currently a member of two regional centres of WANO located in Tokyo and Moscow. WANO's mission is to maximize the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices. All the 450 nuclear power plants operating in more than 30 countries of the world are its members. NPCIL representatives are in the governing board of WANO Tokyo and Moscow centres. During the year, WANO follow-up review of NAPS was carried out. WANO Peer Reviews of TAPS-1&2 and RAPS-5&6 are scheduled to be carried out in March 2017. The above reviews will be carried out using WANO Performance Objectives & Criteria. In these reviews, a team consisting of experts from various countries will review the station's programmes, practices and procedures and will benchmark them against the best international programmes and practices bringing out strengths and areas for improvements. These reviews also provided us opportunity to learn international good practices. During this report year, WANO Tokyo Centre facilitated discussions through videoconferences with other WANO members on some of the issues identified during the WANO Corporate Peer Review of NPCIL held in the year 2015.

WANO organized two Technical Support Missions (TSMs) on the topics for which NPCIL had requested specific assistance from WANO to learn from international practices and experience to strengthen its own programmes. Two more TSMs are planned before the end of the year. So far, WANO has organized more than 50 TSMs in India as per the request of NPCIL. Many persons from NPCIL participated in the important meetings, seminars and workshops and gave presentations. A team from RAPS-1&2 is scheduled to visit Pickering NPP in Canada under WANO's Benchmarking programme. Many experts from NPCIL participated in the peer reviews of overseas NPPs/other WANO members and had the opportunity to discuss various issues related to improvement in plant performance with experts from other countries. NPCIL continued to submit Performance Indicator data and WANO Event Reports (WERs) to WANO.

NPCIL participated in some of the COG meetings held through audio and video conferences. In addition, COG representative visited NPCIL and discussed issues of mutual cooperation. One expert participated in COG workshops held in Canada. NPCIL participated in the information exchange programme of COG and had access to its website, which is a warehouse of useful operating experience information related to PHWR plants.

NPCIL is participating in INPO's International Participants Programme. Many senior officers at stations and HQ have been provided access to INPO website, which contains high quality operating experience information and other documents.

NPCIL participated in various meetings, workshops, seminars organized by IAEA. NPCIL continued to provide information for IAEA PRIS database.

MANAGEMENT SERVICES

Management Services Group (MSG) manages the Information Technology facilities in DAE headquarters. During the year, DAE-wide Integrated Management Information System (DIMIS) was launched. The system was installed in a central data center accessible to DAE and all its constituent units through it wide area network Anunet.

Screenshots of DIMIS, DAE Integrated Management Information System

During the year MSG also steered the implementation of e-Office in DAE. E-Office is a Government of India initiative under its e-governance

Make-shift Computer Centre for eOffice Hands-on Training in DAE

mission. The application aims to create a paperless office with the introduction of electronic filing system. DAE is implementing e-Office using its own data center resource. Hardware and software for implementing e-Office has been installed; extensive hands-on training has been carried out for the employees of the Department by setting up make-shift computer labs. Digitization of files is being taken up within Sections in a phased manner. Digital Signature Certificates have been provided to the prospective users of eOffice.

MSG is contributing to the technical aspects of the implementation of DBT (Direct Benefit Transfer) in the Department. MSG has launched the DBT App, a web-based Management Information System, for the Units and Institutions of DAE to facilitate information exchange related to the schemes of the Department on the DBT portal.

E-Office workshop

DAE's web site is maintained by MSG. It has links to all DAE and its constituent units. DAE's website is a repository of parliament question and answers, press

releases, acts, rules, agreements, orders, publications, achievements of the department, and provides downloadable forms for the benefit of the public. MSG also manages various applications relating for administration and accounts activities in DAE Secretariat.

VIGILANCE

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

The functions of Vigilance section during the year included the following:

Submission of 22 monthly/quarterly/annual returns to various authorities such as Central Vigilance Commission (CVC), Department of Personnel and Training (DoPT), and Central Bureau of Investigation (CBI).

Processing of 12 new cases of Disciplinary cases of Group 'A officers and retired Government servants.

27 complaints were downloaded from CVC portal and 4 complaints received through PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides, 4 complaints from CBI have also been processed. 56 cases have been closed with the approval of Competent Authority after necessary investigation and status uploaded onto the CVC portal. 38 complaints have been received directly in the Department. After confirming the authenticity of the complainant, carried out necessary investigation and with the approval of Competent Authority 32 complaints were closed.

Vigilance clearance given for various purposes to 2,453 Group 'A' officers as well as staff in the Secretariat.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2016" was observed in DAE during October 31st to November 05th, 2016 on the theme of "Public participation in promoting Integrity and eradicating Corruption". The week commenced with administering vigilance pledge by Secretary, DAE to all officers and staff on 31/10/2016. During the week, various competitions such as Quiz, Slogan writing, Poster drawing and Essay writing competitions were held in which officers and staff of DAE actively participated. Shri K Selvraj, General Manager & Chief Vigilance Officer, Dena Bank delivered a talk on 05/11/2016. The key note address was delivered by Shri Sanjeev Sood, Joint Secretary (I&M) and Chief Vigilance Officer, DAE. Shri S. Mervin Alexander, Joint Secretary (Admin & Accts.) and Shri R A Rajeev, Joint Secretary (Finance) had also shared their experience on the occasion of

DAE Staff participating in the Vigilance Awareness Week

Chief Guest and Senior officials of DAE on the dais during Vigilance Awareness Week

Vigilance Awareness Week, 2016. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 05.11.2016. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance awareness is one of the important parameters of good Corporate Governance. At NPCIL, a number of initiatives were taken and innovative methods were adopted in spreading awareness and imparting knowledge to employees. Vigilance Seminars, Interactive Sessions at various sites and HQs are regularly organized by the Vigilance Directorate.

An initiative of organizing 'Outreach Programmes in vigilance awareness in Schools & Colleges' was taken by NPCIL as per directives of Central Vigilance Commission (CVC) in the months of October & November 2016. CVC assigned 'Greater Mumbai', 'Tirunelveli' & 'Kalpakkam' District to NPCIL for conducting these activities. NPCIL conducted outreach activities in total 20 colleges including 2 colleges in Mumbai, 2 colleges in Palghar district, 3 colleges in Tirunelveli District &3 colleges in Kalpakkam. In addition, 10 more colleges located at other cities / towns nearby NPCIL power plants were also covered.

Vigilance Awareness Week with the theme of "Public participation in promoting Integrity and eradicating Corruption" was observed in NPCIL. A number of programmes viz. Seminars, Debate Competitions, Quiz competitions, Elocution Competition, Essay writing competition, Slogan writing competition , Short Film Competition, Poster Drawing, Street play & Speech competition etc. were held at NPCIL HQs & its sites.

This year, Central Vigilance Commission (CVC) had envisaged a web based system of e-Integrity Pledge for citizens as well as corporates. CVC entrusted the responsibility of developing the concept to NPCIL & National Informatics Centre (NIC). Accordingly, NPCIL Vigilance developed the concept and presented the same to Hon'ble CVC, senior officials of CVC & NIC.

A short film competition was conducted for all the units of NPCIL. These films were also screened at all units and liked by everyone. These documentaries were produced in-house by employees of NPCIL. It is very effective to communicate anti-corruption message. A Vigilance Song 'Chandan Se Mehekte Rehna' an in-house production was released by CMD, NPCIL during Vigilance Awareness Week (VAW) 2016. "Online Daily Vigilance Quiz" competition for employees was launched by Padma- Vibhushan Dr. Anil Kakodkar, Former Secretary, DAE on 02.11.2016 at HQ, Mumbai. The online Vigilance Clearance Management System (VCMS) has been extended for all employees of NPCIL. Online System for Management of Vigilance Complaints (SMVC) has been further refined and is in place.

Corporate Vigilance Excellence Award for the year 2015-16 was conferred to NPCIL by The Institute of Public Enterprise (IPE), Hyderabad. The award is given for the best practices adopted by the Public Enterprises for vigilance function. Vigilance Excellence Award 2016 was conferred to NPCIL by Vigilance Study Circle, Hyderabad Chapter.

NPCIL was conferred with Vigilance Excellence Award 2016 from Vigilance Study Circle, Hyderabad

OFFICIAL LANGUAGE IMPLEMENTATION

DAE and its Constituent Units, PSUs and Aided Institutions continued to carry out their activities to promote the use of Rajbhasha Hindi in various

disciplines of Nuclear Science and Technology. Some of the efforts made in this direction are highlighted below:

The total strength of Hindi staff in DAE and its constituent Units, PSUs, and Aided Institutions is 125.

DAE have inspected its units ECIL Head Quarters, Hyderabad and AMD Head Quarters, Hyderabad. In addition, various Units/PSUs/Aided Institutions viz. BARC, RRCAT, NFC, AMD, IGCAR, VECC, HWB, GSO, DCS& EM, AERB, NPCIL, IRE, ECIL, UCIL, Bhavini, TIFR, TMC, IPR, HRI and IOP have inspected their Subordinate Offices and Sections.

The Committee of Parliament on Official Language have inspected AMD, New Delhi; NPCIL, Mumbai and TAPS, Tarapur.

Under the Official Language Rule 10(4) of Official Language Rules, 1976, 40 offices have been notified so far.

Chief Guest and Sr. Officials of DAE on the Dais during he Hindi Day celebration at DAE

35 Seminars/Talks in Hindi on various topics, mostly related to Nuclear Science were organized and the Souvenirs on the proceedings of the Seminars/Talks were also brought out in Hindi.

All Gazette Notifications, Cabinet Notes, Annual Reports and other documents furnished to the various Committees of the Parliament, and the Agreements and MOUs were prepared bilingually.

2862 officers and employees were imparted

17th All India Official Language Seminar Organized on 31st May 2016

Shri Sanjeev Sood, Joint Secretary, DAE distributing prizes on the occassion of World Hindi Day, 2017

training in Hindi Noting and Drafting in Hindi Workshops (141 workshops were organized). 307 officers and employees under the Incentive Scheme for doing original noting and drafting in Hindi, 21 Typists under the Incentive Scheme for Hindi Typing and 29 Stenographers under the Incentive Scheme for Hindi Stenography were awarded.

333 Officials, 04 Typists and 13 Stenographers were imparted training in Hindi, Hindi Typing and Hindi Stenography respectively & eligible candidates were given cash awards and other incentives for successfully passing Hindi, Hindi Typing and Hindi Stenography examinations.

Hindi books worth Rs. 7,97,692/- were purchased.

Quarterly meetings of OLICs were held regularly and the progress of implementation of Hindi was monitored closely through Departmental OLIC meetings. The Quarterly Progress Reports and

Minutes of the meetings of OLICs of all Units/PSUs/Aided Institutions were also reviewed regularly. Hindi Week/Fortnight/ Month was organized in all offices.

DAE and its 25 establishments have their Websites in bilingual form and these are updated regularly.

Presently, there are 22,730 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.

23 House Magazines and 13 News Letters were brought out by various establishments of DAE.

NPCIL complies with the instructions issued by Government of India time to time on implementation of Rajbhasha “Hindi”, every year four Hindi workshops are organized by NPCIL HQ as well as at all sites. In this series, 4 one-day workshops were organized at NPCIL HQ. A solo singing competition was organized as a part of Hindi Day celebration.

A Rajbhasha Samman evum puruskar Vitran Samaroh was organized at HQ on 19th December, 2016. This function is organized every year at HQ and the region wise winner units are honored with "CMD Rajbhasha Shield". Every month a Hindi competition is organized at NPCIL Headquarter. During a year, 12 competitions were organized. The personnel of HQ participated enthusiastically in the competitions.

Some of the honours received by NPCIL included the Rajbhasha Shield of DAE continuously for the ninth year (2008-2016); NPCIL HQ has been honoured with the award for the year 2015-16 for its excellent implementation of Official Language in the category of large enterprises from Town Official Language Committee for Mumbai based Enterprises and NPCIL has been honoured with Rolling Shield in the category of large enterprises for the year 2015-16, by an NGO-"Ashirwad", which is working for propagating &publicizing Rajbhasha Hindi in Mumbai. NPCIL has received prizes from this institution for 7 times in the past 10 years.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

Scientific Information Resource Division (SIRD), BARC is continuously being upgraded / equipped with the state-of art facilities and technology infrastructure to provide seamless access to information to BARC scientists and engineers in their day-today R&D activities and also extends its facilities to other DAE institutions.

A total of 581 books and 4306 e-books for Central Library and 394 books procured, processed and sent to BARC Tarapur and BARC Vizag Library. Trace Win and Gen LINWIN softwares were procured for Ion Accelerator Development Division. A total of 771 scientific and technical reports and 100 bound periodicals have been added to the collection. SIRD currently subscribes to 1116 periodicals, 11 Standards and 14 Databases. J-Gate, a platform to search the journals, has started for all scientist and engineers from Nov. 2016. The IEEE/IEL Consortia for four DAE Units (BARC, IGCAR, RRCAT and VECC) was initiated and successfully completed for the IEEE electronic resources. Three ancillary sites of BARC (RMP Mysore, FEMS Visakhapatnam, and EBC Kharghar) are now able to get access to the full electronic resources available on IEL Online, a web platform where IEEE resources are accessible. Back files of four journal packages (RSC, AIP, ACS, IOP) have been purchased and made accessible to the BARC community.

In order to deliver information on the desktops, and provide seamless access to various sources of information, activities like content

management, designing and maintenance of various knowledge portals namely BARC official website in public domain, Online Information Gateway for e-resources Lakshya, Library Portal Saraswati and SIRD portal on BTS have been carried out. In addition, Photography-cinematography, Library management Software, RFID base library automation, XII plan project, Customized Software development to meet specialized needs has been managed and implemented.

Inauguration of HooA facility

To ensure maximum utilization of subscribed Library E-resources, a Cloud based solution that provides access to online resources in a 24x7 from Home, Office or Anywhere (HOoA) has been developed. This facility was launched by Shri K. N. Vyas, Director BARC on August 15, 2016 at Central Complex.

Saraswati, the digital portal of SIRD is now available to entire DAE community through secure VPN ANUNET access. Portal has been updated for digital resources, reports, newsletter, Books/Reports on display. Digital institutional repository, under E-Sangrahay, holds more than 12500 articles and 200 theses from the year 2006 onwards. More than 275 scientists & engineers across DAE are using email based NUCNET facility. A secure VPN based access of Saraswati for ANUNET is being used by BARC out-stationed employee. Exclusive access of Saraswati to the designated employee of Heavy Water Board, Anushaktinagar have been implemented and in operational. An anti-plagiarism web based service has been subscribed. Unified access of Internet (Lakshya etc.) and Intranet (Saraswati etc.) in the central library is being used heavily by users, especially the trainee and DAE staff. Discovery services have been designed for Lakshya to provide a simple search box to search 7000+ E-Books from library's resources with a single query. To reduce the manual entry and error free data, bibliographic records of E-books in Machine Readable Catalogue format have been imported to ILMS Libsys with DOI and abstracts. This has enhanced searching experience in OPAC intranet.

BARC website analytics shows that 52.8% are returning users and 47.2% as new users in a year. It also witnessed a total annual sessions 2,601,378, 1,254,862 users visited with total 5,182,179 page views. BARC website has been recently optimized for quality contents, search ability and enhanced with high quality photographs of the facilities. With new web page layout for BARC Technologies (Entrepreneur's Corner), a multi fold user visit have been noticed. Career, symposium, recruitment and tender sections are updated on daily basis.

Under Apex project R&D-XII-N-49 "Enhancement of Digital Knowledge Resources and Human Resource Development" a subproject titled "Archival Centre for BARC and Enhancement of Infrastructural Facilities" is being executed with a total XII Plan Layout of Rs. 4.0 crore including spill over of Rs. 2.0 crore for next plan.

SIRD is continuing its contribution to enhance the content of Anu Sangrah database. BARC Newsletters from 2010 to latest issue has been uploaded to this portal.

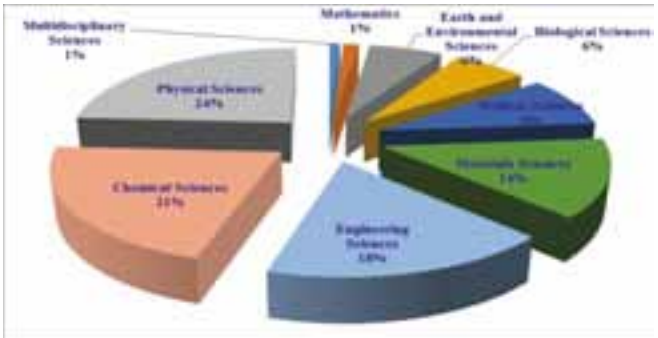
Special events, conferences, visit of delegates and scientific facilities developed by BARC and its units are captured, indexed and hosted on the intranet. For easy access & downloading, photo gallery and Video clips for important functions have been hosted at multimedia library at Intranet.

Library Circulation Unit continued to provide user friendly services to scientists and engineers of BARC and other DAE units. Scientific Information

CHAPTER 10

Resource Division continued its efforts to interact with other National and International organizations to identify and acquire the information which is not readily available in our library to satisfy the varied information requirements of our scientists and engineers. Publications of BARC scientists and engineers are displayed every month at the Display Unit of the Central Library. These publications are also listed in the monthly publication 'Scientific Information Resource Bulletin'. The full text of these publications are simultaneously made available on SARASWATI-the Library Intranet. In order to meet the immediate photocopy needs of our scientists and engineers, the library continued to provide photocopy service to our scientists and engineers and provided ten (10) self-operating photocopiers for the purpose.

A total of 8527 publications were published during 2012-2016 as per Scopus database. The highlights are given below.



Subject-wise Distribution of Publications of BARC during 2012-2016

International Nuclear Information System (INIS) operated by International Atomic Energy Agency (IAEA) maintains a database of bibliographic references to literature on peaceful uses of Nuclear Science and Technology. Scientific Information Resource Division (SIRD), BARC is the nodal agency for all activities related to INIS in India. In the year 2016, India has contributed 3302 bibliographic records to the database. Document delivery services are provided to various member countries of INIS and 35 documents were sent in 2016. NEA Data Codes were requested for BARC scientists and engineers. The section identified 867 nuclear related news from daily newspapers and added to the news archives maintained by SIRD. Bibliographic sheets of 16 external technical reports were made and the digital copy of the reports were sent to INIS for including in the Non-Conventional Literature collection of IAEA.

SIRD's Foreign Languages Section provides translations of French, German, Russian, Spanish, Portuguese and Japanese scientific and technical documents as well as interpretation services and language courses for all the units of DAE. Over 2000 pages of translated text were provided this year, 2 French language courses were held for scientists proceeding to ITER and interpretation services were provided for BARC and NPCIL. Foreign Languages Section also brings out a monthly compilation of SIRD divisional activities – Scientific Information Resource Bulletin (SIRB), 12 issues of which were brought out this year.

Printing and Binding Unit continued to provide printing of restricted reports, reprints, invitation cards, visiting cards etc., by using offset and screen printing processes. Binding of collected scientific publications of various Divisions, reprints, tender documents, restricted reports etc., was carried out.

The Scientific Information Resource Centre (SIRC) of DAE Secretariat continued to the provide library & information services such as Circulation, New Arrivals Services, News Clipping Services, Reference & Information Services, Reprography Services etc. New books, Periodicals & Journals and other reading materials were added to the resource collection of SIRC. SIRC continued to provide the online access to Scientific Journals of Elsevier. The online subscription of law journals were also catered. Publication and printing of statutory documents such as 'Annual Report', 'Outcome Budget' and internal publications such as 'Accounts at a Glance', 'DAE Diary', "DAE Essay Contest Announcement" etc. were handled and completed at SIRC. Publication and printing of various public information literature such as 'Nuclear India', 'Parmanu', 'DAE Perspective', etc. were also continued.

PUBLIC AWARENESS

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

The 104th Indian Science Congress was held at S.V. University, Tirupati during January 02-07, 2017. The focal theme was `Science & Technology for National Development'. The Science Congress was inaugurated by Shri Narendra Modi, Hon'ble Prime Minister of India. DAE and other constituent units participated in 'The Pride of India (POI) Expo' – a mega science exhibition showcasing he cutting edge technologies, leading scientific produ cts and services, path breaking R&D initiatives, schemes and achievements of India's foremost and leading public and private sectors, government departments research labs educational institutions, corporate defence etc.,

Visitors at DAE pavilion during the 104th Indian Science Congress, Tirupati

DAE participated in an exhibition in collaboration with Nehru Science Centre (NSC) which was held on National Technology day – May 11, 2016. DAE put an exhibition on the Life and Times of Dr. Homi Bhabha.

`Govt. Achievements and Schemes Expo' and concurrent show` Food & Technology Expo-2016' was held during July 22-24, 2016 at Pragati Maidan, New Delhi. DAE participated in this event and the main objective of the event was to bring government departments, intuitions, boards PSUs etc., on one platform and provide them the opportunity to showcase their technological innovations, products/service and form fruitful market alliances.

Farmers and industrialists interacting with the DAE officials during Food & Technology Expo-2016, New Delhi

A two day seminar on `Applications of Radioisotopes and Radiation Technology' in `Industries, Agriculture & Healthcare was held at Amity University, Noida during August 5-6, 2016. This was organized by NAARRI a body of professionals that is promoting the peaceful uses of Atomic Energy. DAE participated in this seminar and put up an exhibition on the achievements of DAE in the area of applications of Radioisotopes in Healthcare, Food & Agriculture, Industry, etc.

The 20th National Science Exhibition with the theme `Vision of India for a New Era' was held during August 10-14, 2016 at Kolkata. The focus of the exhibition was to highlight the different Departments

Interaction with studenst at the 20th National Science Exhibition, Kolkata

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.

CHAPTER 10

Bharat Utsav 2016 a week long celebration that highlights India's contribution of Science, Technology & Innovations in various sectors and advancements in Basic Sciences, Energy including New & Renewable Environment, Earth Sciences, Space, Defence, Water Resources, Medicine, Agriculture, Information Technology & Communications, Biotechnology, Transport to inspire the students and general public was held on August 16-24,2016 at Hyderabad, Telangana State in which a number of Indian Scientific & Research organizations participated. DAE displayed their outstanding contributions and achievements in various areas along with NFC, AMD & ECIL.

DAE participated in the `India-IAEA Exhibition India-IAEA Joint Partnership in Peaceful Uses of Atomic Energy' during the 60th Regular Session of the IAEA General Conference held at Vienna, Austria during September 26-30, 2016. To commemorate the Sixtieth Anniversary of the IAEA, amongst other things, an exhibition focusing on major events, projects and achievements by member states on the uses and contributions of atomic energy, to peace and development, was organised within the framework of the General Conference. Twenty two member states including India, participated in the exhibition. The theme of the exhibition was Índia - IAEA Partnership in Peaceful Uses of Atomic Energy'. The Indian pavilion displayed information on a spectrum of activities on the peaceful uses of atomic energy including India's involvement in the formative years of the IAEA with the contributions of Dr Homi Jehangir Bhabha as one of its founder members; the Indian Nuclear Power Programme; Clean Technologies for Societal Applications (comprising vitrified Caesium pencils, nuclear desalination and hygienisation of sewage sludge) ; Cancer Treatment; Nuclear Agriculture and Radiation Processing of Food; India's contributions to the Regional Co-operative Agreement and Global Nuclear Energy Partnership for Nuclear Security. The pavilion also displayed a model of the indigenously developed radiotherapy machine, the Bhabhatron II for

The Indian Pavilion at India-IAEA Exhibition India-IAEA Joint Partnership in Peaceful Uses of Atomic Energy' during the 60th Regular Session of the IAEA General Conference held at Vienna, Austria

cancer treatment, a dummy version of vitrified Caesium pencils for use in Blood Irradiators and samples of radiation processed food material. A short documentary film titled Índia - IAEA Partnership in Peaceful Uses of Atomic Energy' was also screened.

The 8th edition of India Nuclear Energy Summit 2016 was held during October 20-21 2016 at the Nehru Centre, Worli, Mumbai. This was concurrent with the International Exhibition – India Nuclear Energy 2016 being held from October 20-21. DAE participated in this seminar supported by HWB and NFC. The summit was designed to showcase the opportunities, address challenges and evolve strategies, vision in order to propel sectorial development.

DAE participated in the `Agrovision' agriculture summit along with the officials from BARC, held during November 11-14, 2016 at Nagpur. Farmers and businessmen in the Agro industry visited the pavilion.

National Metallurgist Day (NMD) organized by Indian Institute of Metals was held at IIT Kanpur during November 11-24, 2016. DAE participated in this event along with officials from Materials Group, BARC & IGCAR to highlight the achievements in the field of Metallurgy.

DAE took part in a two day Seminar organized by National Association for Applications of Radioisotopes & Radiation in Industry NAARRI at Thapar University, Patiala during November 28-29, 2016. The audience for this event comprised students at the graduate and PG level, factuality members, indistrialists. It was also a good platform to create

awareness about the programmes of the department.

A workshop cum Expo on Rural Technology & Innovations was organized by Centre for Studies of Popular Science at Shahjanpur, UP during December 01-03, 2016. DAE participated in this event to educate and enlighten the rural public of DAE's societal applications especially in the area of agriculture healthcare and water. Rural public in the neighbourhood and school students benefitted from this exhibition.

Indian International Science Festival 2016 organized by Ministry of Science & Technology and Earth Sciences and Vijnana Bharati at New Delhi during December 7-11, 2016. DAE participated in the festival as the objective of the science festival was to expose the fruits of science and technology to the masses ad to build a strategy to instil scientific temper among people. RRCAT, AMD, BARC, HWB also participated in the event. The event was inaugurated by Dr Harsh Vardhan, Hon'ble Cabinet Minister for Science and Technology, Earth Sciences.

A seminar on Peaceful Uses of Atomic Energy organised by United Schools Organizations of India was held during February 9-10,2017 DAE participated in this event facilitating interaction with science teachers across various schools across India including a few teachers from atomic Energy affiliated schools. Experts from various units of DAE delivered popular lectures on all the department's activities.

DAE participated in an exhibition organised by the Goa Science Centre, a grand festival of Science & Technology called Science Fiesta. The Science Fiesta was held at Goa during February 25 – 28, 2017. Members of the general public, students at the high school, college level and academicians visited the pavilion. NPCIL also participated in this event.

To communicate undeniable merits of nuclear power to various sections of the society, Nuclear Power Corporation of India Limited (NPCIL) has been carrying out a gamut of public awareness activities over a period of time conveying the facts on nuclear power in a simple and transparent manner. Public awareness 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.

NPCIL's public outreach includes regular interaction with the persons living nearby Indian NPPs; visits to villagers, students, media persons and other members of public to nuclear power plants; organizing awareness campaigns on nuclear power for various target groups like media personnel, policy and decision makers, people's representatives, state officials, students and teachers, medical professionals and the public at large. Besides, NPCIL is also in the process of setting up a number of nuclear galleries at the science centers across the country to provide factual information in an interesting and interactive manner on nuclear power and other associated aspects.

Use of exhibitions, seminars, scientific meets, distribution of public awareness publications, advertisements in print and electronic media, screening of animated films in vernacular languages, enhanced interaction with press and media, e-public awareness campaigns to name a few were also adopted to scale up outreach activities.

NPCIL has also been partnering with several expert agencies like National Council of Science Museums, other regional Science and Technology Centers, PR agencies and Department of Science and Technology etc.

NPCIL has been reaching out to an average of around 2.9 lakh people per month as a result of these multi-pronged initiatives.

During the year following outreach activities were undertaken by NPCIL:

Web based Public Awareness

NPCIL web site has been providing large amount of information on nuclear energy and about the activities and achievements of the corporation. A link for public has been provided for seeking information on visit to a nuclear power station or for a visit to their premises for a presentation which is being utilized by a large number of people. Apart from that lots of information about various aspects of nuclear energy was shared through various social media platforms like Facebook, YouTube, Twitter, etc.

Publications

Several Lakhs copies of various informative & educative public awareness publications on various aspects of nuclear power were distributed among general public, students, teachers, eminent persons etc. Thousands of copies of these PA publications were distributed in regional languages also in the state where NPPs are located and other states also.

Halls of Nuclear Power

The permanent exhibition on Nuclear Power "Hall of Nuclear Power" was inaugurated at Chennai and opened for general visitors. The already functional 'Halls of Nuclear Power' at Mumbai and Delhi have around 8 Lakhs and 6 lakhs of visitors yearly. A MoU is signed with Pathani Samanta Planetarium – Bhubaneswar, under the Government of Odisha, for the establishment of first Hall of Nuclear Power at the eastern part of India. Creation of similar centers at other places are also under process. Public, particularly students and academicians visit this permanent gallery throughout the year and get benefitted. Further, setting up of Halls of Nuclear Power are planned at various prominent locations across the country.

Nuclear Power Plant (NPP) Models.

The semi-dynamic NPP models have proved to be one of the best tools to educate / inform general public about nuclear power plant operation and its safety features. The concept of miniature NPP models takes the ease of information sharing to a new level through stunning liveliness, interactivity and relevant synchronized voice narration that accompanies the information delivery. The see-through construction of the models allows the viewer to have a peek inside the plant itself. The model explains the functioning of a nuclear power plant in a simple and interesting manner with running commentary on various conventional as well as nuclear systems while the corresponding sections of the model light up to add dynamism to the presentation. Various nuclear safety features are also incorporated in the model to build confidence in viewers that our nuclear power plants are absolutely safe. The first ever models of Plant Layout and Reactor & Turbine 700 MWe were fabricated and installed at Kakrapar, Rawatbhata, Chutka Madhya Pradesh Atomic Power Project, Gorakhpur Haryana Anu Vidyut Pariyojana. Similarly, models of PHWR units are also fabricated and installed at various Science Centres for public awareness.

Exhibitions

NPCIL participated as part of Public awareness activity by organizing Exhibitions at various locations across the country to educate, inform and impart factual information associated with nuclear power and radiation.

Following are some of the significant exhibitions organized during this period:

NPCIL participated in the International level exhibitions like India International Trade Fair (IITF-2016) with Ministry of Power pavilion held at New Delhi, which is one of the notable exhibitions where nearly 6 lakhs visitors were benefitted in NPCIL stall, the pavilion was awarded Silver Medal for Excellence in Display category in IITF – 2016. The above platforms were also utilized for the promotion of "Halls of Nuclear Power" at Nehru Science Centre, Mumbai, Tamil Nadu Science & Technology Centre, Chennai and National Science Centre, New Delhi by displaying a special panel on it.

NPCIL stall at India International Trade Fair (IITF)

Pamphlets on Hall of Nuclear Power were also distributed to the students & others. India Nuclear Energy (INE) - 2016 at Mumbai and All India Marathi Vigyan Adhiveshan – 2016 at Thane are some other important exhibitions where NPCIL participated.

A 2-week long exhibition was organized by RR site in Kota Dussera Mela during which several other activities such as short lectures, film-shows and quizzes were conducted. Around 2.2 lakh visitors, which included VIPs and government officials as well as elected representatives were imparted awareness about nuclear power.

Public Awareness Seminars

Organizing lecture series and participation in seminars as well as panel discussions on safety of nuclear power plants, radiation etc. are the ongoing PA activities. Total such 123 lecture programs have been organized. Presentation was made on 27.4.2016 at NPCIL HQs to around 200 officials of DAE/HWB on the occasion of Swachchta Fortnight highlighting the initiatives taken by NPCIL in preserving the environment and maintaining cleanliness and housekeeping in line with Hon'ble P.M's mission.

Awareness programmes in schools and colleges

NPCIL, took several initiatives to reach out to students and teachers and educationalists

Kendriya Vidhyalaya Students and Teachers Adoption Programme

A long-term, sustained campaign has been initiated in Kendriya Vidyalayas all over India to sensitize students and teachers to the positive aspects of atomic power. Campaigns have been initiated and conducted in Maharashtra, M.P and other states covering 20 Kendriya Vidyalayas.

In addition, several under-privileged schools imparting education in Hindi and local languages were addressed by NPCIL. These include 6 schools of NDMC.

College Lecture Series

Over 50 lectures covering several thousand college students have been organized. These include seminars delivered at major scientific and technical events of various colleges.

Doctors' Meets

Four Doctors' meets were organized in various medical institutions sensitizing around 260 medical doctors to the effects of radiation and epidemiological patterns of radiation-induced diseases such as cancer around nuclear plants to eliminate fear of radiation from the minds of the medical fraternity.

Media Students Adaptation Programme (M-SAP)

NPCIL has always maintained excellent professional relations with press and media to provide valuable inputs to create story line for various sections of society. As a special initiative, NPCIL has devised an exceptional programme to nurture the young journalists from leading mass communication institutes and universities by arranging their visit to our nuclear power plants to have first-hand experience under the very unique programme M-SAP. So far many visits of media students from various institutes and universities across the country have been organized to our nuclear power plants along with detailed briefing on benefits of nuclear power. NPCIL conducted a one-day seminar followed by Jaitapur Nuclear Power Project site visit and press-meet next day for a batch of 50 P.G students of

the Department of Journalism of Mumbai University who had gone on an educational visit.

Capacity-building for outreach

Around 60 resource-persons of NPCIL were trained during this period by the expert faculty in the various training programmes on media and public communication organized at Rawatbhata, Rajasthan and Ghorakpur, Haryana sites.

Atom on Wheels (AoW)

Atom on Wheels Programme, a very unique public awareness activity, is specially designed for the villagers and people who are living near by the upcoming nuclear power plants across 6 states in the country to allay prevailing apprehensions related to radiation and to develop the positives understanding on nuclear energy. Under this programme, around 1500 villages with approx. 10-12 Lakhs of people is targeted to be covered in the duration of two years. This year till December 2016, 540 villages and approximately 2 lakhs villagers in Madhya Pradesh and Gujarat have been covered.

Atom on Wheels

Media / Public Relation (PR) Facilitation Programme

In order to increase the reach about the merits of nuclear energy to various sections of the society, nationwide campaign on media and PR facilitation has been launched. Under this programme many activities are organized in schools and colleges, pan India in 8 states. Lots of articles and positive news, focusing on multiple aspects of nuclear energy are planned to be published in Newspapers across the nation. This year till December 2016, around 480 positive news-clippings appeared in various newspapers across the country and around 25,000 students participated in various Public Awareness programmes organized in prominent cities.

The second edition of the six week Orientation Course on Accelerators, Lasers and related Science and Technologies (OCAL-2016) was conducted during. RRCAT participated in three national events by setting up exhibits. An open house was organized to commemorate the National Science Day. More than 1500 students and teachers of 110 schools from Indore and nearby places and nearly 2000 members of public visited selected RRCAT laboratories. This year a gallery 'Make in India' science and technology was also established to showcase the indigenous scientific and technological achievements of DAE and RRCAT. This was well appreciated by all visitors. During 2016, several visits of school and college students, teachers, and professionals from other organizations were organized where the visitors were taken around the RRCAT laboratories. This include the Vigyan Manthan Yatra for 125 students from various schools of M.P. selected by Madhya Pradesh Council of Scientific and Technology.

SOCIAL WELFARE

Corporate Social Responsibility, Sustainability and Rehabilitation & Resettlement

From the inception of nuclear power programme in the county, the units of NPCIL have been implementing social welfare activities for the benefit of local population living within sixteen (16) Kilometre radius of plant site. With issuance of Department of Public Enterprises (DPE) guidelines on CSR for Central Public Sector Enterprises (CPSEs) in 2011 and enactment of the Companies Act 2013, NPCIL has started structured programme as per the act.

Under CSR programme, NPCIL is taking up the

Primary School Building at Juna and Dr. Homi Bhabha Anumathak Sankritik Bhavan at Uttar Buniyadi Kanya Vidyalay, Bedkuvadur near Kakrapara

Mid-day meal hall at Kurnipet and School Buildings at Kalache near Kaiga

activities in the five identified thrust areas as education, healthcare, infrastructure development, skill development and sustainable development.

Support to education is extended through implementation of projects such as construction of school buildings and classrooms, hostels, school boundary wall, augmenting school teachers, scholarships to students and development of Anganwadis. Educational items are provided to the school children for motivational purpose. Based on need, transport facility is provided for the school children and teachers.

Under healthcare category, primary health centres, mobile medical van services and medical camps are operated and construction activities are taken for extension of hospital buildings. During this year, 326 eye operations have been carried out and another about three hundred and fifty such operations are expected by March 2017.

Total, 3871 Person with disabilities were provided with special assistive device under project called 'ASAN' for livelihood earning. Another 500 Persons with Disabilities will be provided with assistive devices by March 2017.

Construction of roads, bridges and culverts, community halls, bus stop sheds, Over Head Tanks and drinking water facility, R-O Plants etc. were taken up under infrastructure development.

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

MOU signed in MAPS with L&T for providing vocational skill development training to the underprivileged/ unemployed youth

Swachha Bharat Mission

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

As a part of Swachha Bharat Mission, during this year total 1478 toilets and 244 urinals have been constructed in nearby villages and schools by NPCIL and construction of another 30 toilets are expected to be completed by March 2017. In addition to this, contribution amounting ₹ 17 Cr. to Swachh Bharat Kosh and ₹17 Cr. for Clean Ganga Fund is also being deposited to the concerned Government body.

CHAPTER 10

EMPLOYEES' WELFARE

Employee' Health Care

To provide specialised and personalised health care to its employees and the members of their family even after retirement, the Contributory Health Service Scheme (CHSS) was introduced in the Department in the year 1962. The Revised CHSS scheme came into effect from 01/02/1998.

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

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 with the vision to provide quality education to students and an environment in which every student discovers and realizes his/her full potential. AEES currently administers 30 schools/ Junior colleges at 14 centres located all over India and provides education to over 27,000 students. AEES provides education to economically backward children living around its establishments through its Societal Enrichment and Education Programme (SEEP). This programme is meant for the bright children from the rural/tribal areas.

The Constitution of India gives the right to free and compulsory education to all children in the age group of six to fourteen years, as a Fundamental Right. The same was implemented in AEES, in the year 2015-16.

AEES has achieved significant results in its pursuit of excellence in academic as well as other than academic fields during the year. The enrichment of the school libraries, computer aided education, improved sports facilities, play equipment, in-service training programmes for teachers, multimedia programmes and enrichment programmes for students have helped the institution to set new benchmarks in excellence. Construction of auditoria, additional classrooms and the setting up of computer, mathematical, social science and language laboratories, have greatly contributed to the strengthening of infrastructural facilities in our schools.

Board (Xth and Xiith) Exam Results of AEES Students

2246 students appeared in the CBSE Board examination (Class X) in March, 2016. 27 schools achieved more than 90% pass percentage, out of which 19 schools had a 100% result. The pass percentage was 98.49%. 489 students secured CGPA 10 points. 1700 students from 15 AEC Schools and 1 Junior College appeared for the Class XII examination in March, 2016. The pass percentage was 92.29% and the overall Excellence Index stood at 68.12. 11 schools achieved more than 90% pass percentage out of which AECS Kudankulam produced 100% result.

Total 22 students secured admission in IITs, 3 in BITS, 1 in IISER, 26 in NIT/AIEEE, 5 in IIIT, 26 students secured admission in one amongst the Top 100 engineering colleges suggested by National Institutional Ranking Framework, MHRD, India. 43 students secured admission in Medical College.

Co-Scholastic Achievements of AEES Students

11 students were awarded the National Talent Search Scholarships for the NTSE conducted by NCERT. 4 students were awarded the Kishore VaigyanikProtsahan Yojana (KVPY) scholarship, a National Program of Fellowship offered in Basic

Sciences instituted by Indian Institute of Science, under DST.

19 students from AEJC Mumbai, stood in top 1% of the Maharashtra State Board Examinations, 2015 and were offered a scholarship of Rs. 80,000 per year for 5 years under INSPIRE Internship.

58 students of Class X along with 15 mentor teachers participated in the 16th AEES Junior Science and Mathematics Olympiads were held at AECS-1, Mumbai conducted by AEES in collaboration with HBCSE. AECS Turamdih emerged as winner of the National Level "Hindi VigyanPrashnManch ", conducted by Hindi VigyanParishad, BARC. AECS Indore stood first in the junior category and AECS -4, Mumbai stood first in the Senior category at the All India Inter AECS Debate conducted by AEES.

Achievements of Students in Art, Music And Dance

The All India Inter AECS Art Exhibition was held at AECS-1 Tarapur. Spectacular paintings by students of AEC schools all over, on different topics were brought for the final display. The paintings were assessed by renowned artists. The All India Inter AECS/JC Cultural Meet in Music was organized at AECS, Narora. 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 music. One student from AECS-1, Hyderabad was selected to perform in Russia in the programme "Namaste India" by Ministry of External Affairs, Govt. of India.

All India Inter AECS/JC Sports Tournament

The All India Inter AECS Athletic Meet & Table Tennis tournament for Under 19 Boys & Girls were held at AECS Indore in 2015-16.

Summer Sports Coaching Camp

Atomic Energy Education Society in collaboration with the Department of Atomic Energy Sports and Cultural Council organized Summer Sports Coaching Camp for school children during the months of April and May, 2015 in various sports such as Football, Volleyball, Basketball, Lawn Tennis, Table Tennis etc.

Achievements in Sports

One student of AEJC, Mumbai has achieved a world record by becoming the first Asian to complete Jersey-Round Island swim of 66 kilometers, in 10 hrs and 11 minutes. One student of AECS-2, Mumbai received a Silver Medal in the International Taekwondo Competition. A girl student of AECS-4, Mumbai has participated in the FIDE World School Chess Championship representing India held at Pattaya, Thailand in 2015. She was ranked 7th in the Under-9 Girls category. She also participated in the Commonwealth National Chess Championship representing Maharashtra State in the Under-11 category.

Jawaharlal Nehru National Science, Mathematics and Environmental Exhibition (JNNSMEE)

3 projects from AEES were selected to be displayed at the Jawaharlal Nehru National Science, Mathematics and Environmental Exhibition, an annual event conducted by NCERT.

Right to Education

The Constitution of India gives the right to free and compulsory education to all children in the age group of six to fourteen years, as a Fundamental Right. The same was implemented in AEES, in the year 2015-16. 433 students from various centres were inducted in AEES in the year 2015-16, under RTE.

ASTER Programme

AEES aims at the broader development of the complete personality of its students through modern and technical educational infrastructure. In this regard, AEES runs a project called Application of Science and Technology for Educational Reforms (ASTER). AEES has established the Satellite Interactive Terminals at all

centres and a recording studio has been set up at Anushaktinagar, Mumbai. 22 programmes on various subjects and interviews were recorded this year.

Workshops, Seminars and Orientation Programmes

The concept of an orientation programme emphasises teachers as agents of socio-economic change and national development and underlines the need to make them skill–oriented teachers. Orientation Programmes were organized for the TGTs & PGTs of AEC Schools /Junior College teaching staff, with a view to empower the teachers to plan and execute the various classroom activities

Rolling Trophies

AEES institutes a healthy competition amongst all AEC schools to bring out the best of every child as well as teacher and administrator to achieve brilliance in overall development. The Dr.HomiBhabha Rolling Trophy for the best overall performance amongst Schools/ Junior colleges of AEES, Dr.Vikram Sarabhai Rolling Trophy for the best academic performance among Schools/Junior Colleges, Dr. Raja Ramanna Rolling Trophy for the best performance in Co-scholastic activities among Schools / Junior Colleges and Dr.HomiSethna Rolling Trophy for the Best Sports achievements among all schools/Junior Colleges were awarded to different AECS Schools/Junior Colleges, for the year 2014-15.

It is important that the children of the country understand the necessity of cleanliness. All AEC schools and Junior colleges took part in the Swachh Bharat Abhiyaan with great enthusiasm.

It is a matter of pride for AEES that Shri Madan Rao, Principal, AECS-1, Tarapur and Smt. Usha Chaturvedi, Headmistress, AECS-5, Mumbai were bestowed upon with the National Award for Teachers for the year 2015, conferred by Ministry of Human Resource Development.

Many members of the teaching and non-teaching staff of AEES have provided selfless service to the cause of education in our schools. 37 awards were given to teaching and non-teaching members of AEES for the year 2014, as a token of recognition of their valuable contributions.

RTI COMPLIANCE

The Right to Information Act of Government of India which came into force on 12th October 2005 has been implemented at DAE and all its constituent units.

RTI applications received pertaining to the Selection Process for the OCES/DGFS programmes of the BARC Training Schools were addressed. During the year 2016, 66 RTI applications were received and replied.

At IGCAR, the provisions contained in RTI Act, 2005 were fully complied with suomoto disclosure under Section 4 of RTI Act 2005 and updated information was uploaded in the website. During the year 2016, 118 applications were received and 7 applications were transferred to other PIOs. Information provided to all the 118 applicants within the prescribed time limit.

A total of 161 RTI applications were received at AMD, out of which 151 were replied, 4 transferred and 6 rejected. 24 appeals for first appellate authority were received and replied. 11 CIC hearing on second appeal were attended.

During the Financial Year 2016-17, till December 2016 total 580 RTI applications and 136 Appeals were received under the RTI Act, 2005 and were disposed of by NPCIL. Recently, Department of Personnel and Training (DoPT) has facilitated NPCIL to receive and respond RTI applications and Appeals online through RTI online portal. The online RTI applications and Appeals so received are being disposed online through portal.

During the period, IREL received 138 RTI queries

out of which 132 RTI queries were replied to. RRCAT received 107 RTI applications and out of which 97 applications were disposed of. At SINP, the total no. of applications received were 21 out of which 18 applications were answered, one application was transferred and two applications are pending.

AWARDS & PRIZES

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

TAPS-1&2 bagged various awards such as National Safety Council of India (NSCI) Safety Award (Bronze Medal) from Hon'ble Minister of State (Independent Charge), Labour & Employment, Govt. of India, Shri. Bandaru Dattatreya on 06.04.2016 at Vigyan Bhavan, New Delhi for the assessment period of three years 2012-14; National Safety Council (Maharashtra Chapter) award of a plaque for “Factories Working over One Million Man-Hours” under scheme-I-Lowest Accident Frequency Rate for the year 2015-16 and AERB Industrial Safety winner Award for the year 2015 in the category of productions units (NPCIL & Heavy Water plants group) at Gandhinagar on 23.11.2016.

TAPS-3&4 bagged NSC Safety awards-2015 “Shreshtha Suraksha Puraskar” (Silver trophy and Certificate) for the assessment period 2012-14 in Group-C (Power Generation - Thermal / Hydal / Nuclear power plants); “National Safety Award” from Ministry of Labour, Government of India, as First Runner-up for the performance year of 2014 ; “Safety Award” for the performance year 2015 for achieving - Lowest Average Accident Frequency Rate and Longest Accident Free Period from NSCI Maharashtra Chapter and a group of employees (4 persons) of TAPS-3&4 received the prestigious Vishwakarma Rashtriya Puraskar for the year 2014.

RAPS-5&6 won NSCI Safety Award for the year 2015 (Suraksha Puraskar - Bronze Trophy).

NAPS-1&2 won “Environment Protection Award” of AERB for the year-2015 in 'Operating units/ Operating mines group'.

KAPS-1&2 won “Gujarat State Safety Award” for outstanding achievements in safety management as runner-up in category-V, Group-A for the year 2014; “SILVER AWARD” from GREENTECH FOUNDATION for outstanding achievements in safety management for the year-2015; “National Safety Award” for outstanding performance in Industrial Safety as runner-up for the year of 2014 in achieving Accident Free Yearly Minister

NSCI award for KGS-3&4

SILVER AWARD” 2015 from Green Tech Foundation for KAPS

of State for Labor& Employment, Government of India and “AERB Fire Safety Award” for outstanding performance in Industrial Safety for the year-2015 in Category -I.

KGS-1&2 bagged “Suraksha Puraskar”- 2016 (Bronze trophy) from National Safety Council, Mumbai

and “Suraksha Puraskar” (Bronze trophy) - 2015 from National Safety Council, Mumbai.

KGS-3&4 bagged “Sarva shreshta Suraksha Puraskar”-2016 (Gold trophy) from National Safety Council, Mumbai and “Shreshtha Suraksha Purskar” – 2015 (Silver) from National Safety Council, Mumbai.

KK-1&2 received the prestigious AERB safety award for the year 2015. NPCIL employees from KK-1&2 have won various awards during the competitions held by National Safety Council, Tamilnadu chapter and 33rd DAE Safety & Occupational health professionals meet.

In Public Awareness, the "Halls of Nuclear Power" won the first prize under Best Public Awareness Programme and "Connecting Lives" won the third prize under Best Communication Campaign in the Public Relations Society of India (PRSI), National Awards 2016, held at Kolkata.

The AMD officers were conferred with Life Time Achievement Award – 2015, Manthripragada Sita Devi – Ramarao Medal -2015 & Dr. G.R. Udas – Dr. K.K. Dwivedy Medal –2015 by Indian Society of Applied Geochemists (ISAG), DAE Hindi Sevi Samman 2014-15, Homi Bhabha Science & Technology Award- 2015, and Group Achievement Award – 2015 from DAE.

During the year 2016-17, UCIL has received a few accolades for its outstanding activities in different domains. This includes 8th CIDC Vishwakarma Award 2016 by Construction Industry Development Council under the category 'Achievement Award for Artisans & Supervisors' to two Lady Forklift operators and under the category 'Achievement Award for Social Development & Impact'. PSE Excellence Award 2016 by Indian Chamber of Commerce.

ECIL has been awarded the prestigious 41st ELCINA EFY (Electronics Industries Association of India-Electronics for You) Award for excellence in Electronics in RESEARCH & DEVELOPMENT for the year 2015-16 in recognition of its unparalleled contribution to R&D as well as assimilation of new technologies in Electronics and allied Fields in SEPT 2016. Other awards won by ECIL included Gold Award from Quality Circle Forum of India for innovations in the Quality Systems; CII Industrial Innovation Award for the Year 2016; 'IEI Industry Excellence Award 2016' from Institute of Engineers India; National Convention on Quality Concepts (NCQC), PAR EXCELLENCE AWARD Category and ECIL has also been conferred with the 'Best Industry Award' for the year 2016 as a recognition to its creativity, excellence, technology leadership, and exceptional contribution for the BrahMos program.

The HWP, Kota has received DAE's Group achievement award for installation and commissioning of Sodium Sulphate Crystallizer. The Hazira plant has won National Safety Award-2014 based on Accident free year and National Safety Award-2014, for achieving the Lowest Average Frequency Rate during 2014-15 was awarded to Heavy Water Plant (Hazira) for outstanding performance in Safety as a Winner and runner-up respectively. The HWP Thal process engineer were Felicitated “Safety Ambassador for July/August 2016”. HWP Thal received award for “Meritorious Performance in Industrial Safety 2015” from NSC on 17/09/2016 at Mumbai.

The scientists from TIFR have won prestigious national awards during this period. Dr. Satyanarayana Bheesette, has been awarded the “MGA Achievement Award” of IEEE. Prof. Shiraz Minwalla, has been awarded the “The World Academy of Sciences (TWAS) Prize”. Dr. Vivek Polshettiwar, has been awarded the CRSI Bronze Medal – 2017 by the Chemical Research Society of India (CRSI), IISc – Bangalore and has been recognized as one of the “Emerging Investigators 2016 for Novel design strategies for new functional materials” by Journal of Materials Chemistry 'A', of Royal Society of Chemistry, UK. Dr. Ankona Datta, has been recognized as one of the 17 emerging investigators whose work has appeared in the American Chemical Society Select Virtual issue on Bioinorganic Chemistry. Prof. Amlendu Krishna, has been awarded the “Shanti

Swarup Bhatnagar (SSB) Prize" for the year 2016 in Mathematical Sciences, and Prof. Arnab Bhattacharya received the INSA 2017 Indira Gandhi Prize for Popularization of Science.

CHAPTER 11

The Department of Atomic Energy has a mandate to develop peaceful uses of nuclear energy in areas like power generation and basic research in frontier areas of science and technology. In view of the nature of activities carried out by the Scientific and Technical persons in various Research Centres, Public Sector Undertakings, Industrial Units and Aided Institutions of the Department, this Department is not in a position to implement the provisions of reservation of posts fully as required under the "Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act, 1995". Therefore, this Department has already sought exemption for the Units like Heavy Water Boards and Nuclear Power Corporation of India Ltd. From the provisions of the said Act. No specific scheme under plan projects for the benefit of persons with disabilities has been introduced in the Department. In-spite of the constraints, all the Units/PSUs/Aided Institutions have attempted to identify posts, where persons with disabilities could be employed without impairing the activities or causing inconvenience.

The sanctioned strength and number of persons with disabilities in various posts in Group A, B, C & D against 3% vacancies to be reserved for them under Section 33 of the said Act is indicated in the pages that follow.

IMPLEMENTATION OF PERSONS WITH DISABILITIES (EQUAL OPPORTUNITIES, PROTECTION OF RIGHTS & FULL PARTICIPATION) ACT, 1995

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS ON 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 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	8377	1	1	42	1	2	4	182	1	0	10	NIL	NIL	NIL	14	0	0	0
Group B	9526	6	7	73	2	6	4	210	0	1	13	NIL	NIL	NIL	142	0	0	2
Group C	10803	17	37	121	2	7	18	379	3	6	35	0	0	1	88	0	0	0
TOTAL	**28706**	**24**	**45**	**236**	**5**	**15**	**26**	**771**	**4**	**7**	**58**	**0**	**0**	**1**	**244**	**0**	**0**	**2**

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 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 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	1332	2	2	6	3	4	4	11	2	1	2	NIL	NIL	NIL	2	0	0	0
Group B	2727	4	2	20	1	2	3	4	0	0	1	NIL	NIL	NIL	8	0	0	0
Group C	2486	5	14	40	5	2	1	5	2	2	1	0	0	0	4	0	0	0
TOTAL	**6545**	**11**	**18**	**66**	**9**	**8**	**8**	**20**	**4**	**3**	**4**	**0**	**0**	**0**	**14**	**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 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 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	6984	10	4	50	2	42	32	126	2	2	3	NIL	NIL	NIL	0	0	0	0
Group B	5690	10	9	59	1	14	5	75	0	3	9	NIL	NIL	NIL	0	0	0	0
Group C	4948	15	6	49	23	27	21	34	6	12	4	0	0	0	0	43	0	0
TOTAL	**17622**	**35**	**19**	**158**	**26**	**83**	**58**	**235**	**8**	**17**	**16**	**0**	**0**	**0**	**0**	**43**	**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 CHARTER

CHAPTER 12

I) OUR VISION

The vision of the Department of Atomic Energy is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

II) 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) WHOM TO CONTACT

I. Public Grievance and complaints
Shri S. Mervin Alexander, Joint Secretary(A&A) &
Public Grievance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. marg,
Mumbai – 400 001.
Tel. No. 022-22022816
Email I.D. jsaa@dae.gov.in

II. Vigilance Complaints
Shri Sanjeev Sood, Joint Secretary (I&M) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-23638640
Email I.D. jsim@dae.gov.in

III. Public Relations
Shri Ravi Shankar,
Head, Public Awareness Division,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22823144
Email I.D. amrita.rs@dae.gov.in

Government of India
Department of Atomic Energy
Anushakti Bhavan, C.S.M. Marg,
Mumbai - 400 001

NOTICE

WE, THE PUBLIC SERVANTS OF INDIA DO HEREBY SOLEMNLY PLEDGE THAT WE SHALL CONTINUOUSLY STRIVE TO BRING ABOUT INTEGRITY AND TRANSPARENCY IN ALL SPHERES OF OUR ACTIVITIES. WE ALSO PLEDGE THAT WE SHALL WORK UNSTINTINGLY FOR ERADICATION OF CORRUPTION IN ALL SPEHERES OF LIFE. WE SHALL REMAIN VIGILANT AND WORK TOWARDS THE GROWTH AND REPUTATION OF OUR ORGANISATION. THROUGH OUR COLLECTIVE EFFORTS, WE SHALL BRING PRIDE TO OUR ORGANISATIONS AND PROVIDE VALUE BASED SERVICE TO OUR COUNTRYMEN. WE SHALL DO OUR DUTY CONSCIENTIOUSLY AND ACT WITHOUT FEAR OR FAVOUR.

THIS OFFICE IS THUS COMMITTEED TO MAINTAINING THE HIGHEST LEVEL OF ETHICS IN ITS WORKING TOWARDS ACHIEVING THE ABOVE OBJECTIVE, ALL ARE REQUESTED:

§ NOT TO PAY BRIBE

§ IF ANYBODY IN THIS DEPARTMENT OR ITS OFFICES ASKS FOR BRIBE : OR

§ IF YOU HAVE ANY INFORMATION ON CORRUPTION: OR IF YOU ARE A VICTIM OF CORRUPTION IN ANY OF OUR OFFICES.

§ You MAY COMPLAIN TO:-

Shri Sanjeev Sood, Joint Secretary (I&M) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-23638640
Email I.D. jsim@dae.gov.in

YOU CAN ALSO COMPLAIN TO THE :-
CENTRAL VIGILANCE COMMISSION,
SATARKTA BHAWAN, BLOCK 'A',
GPS COMPLEX, INA,
NEW DELHI – 110 023.

ANNEX-I

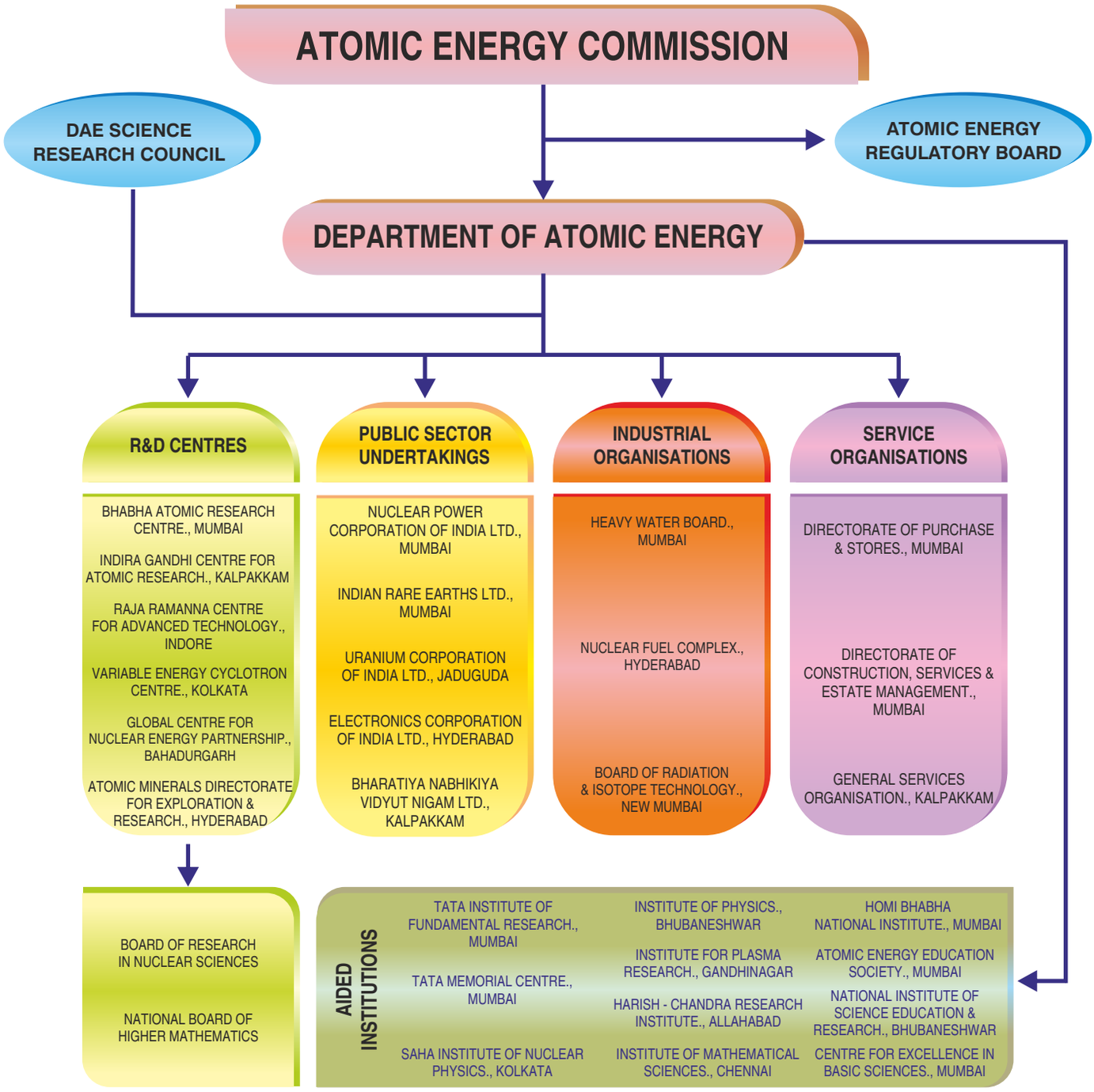
THE ORGANISATION

The Department of Atomic Energy (DAE), that came into being on August 3, 1954, has been engaged in the development of nuclear power technology, applications of radiation technologies in the fields of agriculture, medicine, industry, and basic research.

An integrated group of organizations, the Department comprises six Research Centres, three Industrial Organisations, five Public Sector Undertakings and three Service Organisations. It has under its aegis two Boards for promoting and funding extra-mural research in nuclear and allied fields, and mathematics, and a national institute (deemed university).

It also supports Ten institutes of international repute engaged in research in basic sciences, astronomy, astrophysics, cancer research and education, etc., and a society that provides educational facilities to the children of DAE employees.

ANNEX-I


ATOMIC ENERGY COMMISSION
DAE SCIENCE RESEARCH COUNCIL
ATOMIC ENERGY REGULATORY BOARD
DEPARTMENT OF ATOMIC ENERGY
R&D CENTRES
BHABHA ATOMIC RESEARCH CENTRE., MUMBAI
INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH., KALPAKKAM
RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY., INDORE
VARIABLE ENERGY CYCLOTRON CENTRE., KOLKATA
GLOBAL CENTRE FOR NUCLEAR ENERGY PARTNERSHIP., BAHADURGARH
ATOMIC MINERALS DIRECTORATE FOR EXPLORATION & RESEARCH., HYDERABAD
PUBLIC SECTOR UNDERTAKINGS
NUCLEAR POWER CORPORATION OF INDIA LTD., MUMBAI
INDIAN RARE EARTHS LTD., MUMBAI
URANIUM CORPORATION OF INDIA LTD., JADUGUDA
ELECTRONICS CORPORATION OF INDIA LTD., HYDERABAD
BHARATIYA NABHIKIYA VIDYUT NIGAM LTD., KALPAKKAM
INDUSTRIAL ORGANISATIONS
HEAVY WATER BOARD., MUMBAI
NUCLEAR FUEL COMPLEX., HYDERABAD
BOARD OF RADIATION & ISOTOPE TECHNOLOGY., NEW MUMBAI
SERVICE ORGANISATIONS
DIRECTORATE OF PURCHASE & STORES., MUMBAI
DIRECTORATE OF CONSTRUCTION, SERVICES & ESTATE MANAGEMENT., MUMBAI
GENERAL SERVICES ORGANISATION., KALPAKKAM
BOARD OF RESEARCH IN NUCLEAR SCIENCES
NATIONAL BOARD OF HIGHER MATHEMATICS
AIDED INSTITUTIONS
TATA INSTITUTE OF FUNDAMENTAL RESEARCH., MUMBAI
TATA MEMORIAL CENTRE., MUMBAI
SAHA INSTITUTE OF NUCLEAR PHYSICS., KOLKATA
INSTITUTE OF PHYSICS., BHUBANESHWAR
INSTITUTE FOR PLASMA RESEARCH., GANDHINAGAR
HARISH - CHANDRA RESEARCH INSTITUTE., ALLAHABAD
INSTITUTE OF MATHEMATICAL SCIENCES., CHENNAI
HOMI BHABHA NATIONAL INSTITUTE., MUMBAI
ATOMIC ENERGY EDUCATION SOCIETY., MUMBAI
NATIONAL INSTITUTE OF SCIENCE EDUCATION & RESEARCH., BHUBANESHWAR
CENTRE FOR EXCELLENCE IN BASIC SCIENCES., MUMBAI

Major Programmes and Sub-Programmes

MP 1		MP 2		MP 3		MP 4		MP 5		MP 6		MP 7	
1.01	PHWR	2.01	Fast Reactors	3.01	Advanced Heavy Water Reactor	4.01	Research Reactors	5.01	Mathematics & Computational Sciences	6.01	Human Resource Development	7.01	Infrastructure
1.02	LWR	2.02	Materials	3.02	Thorium Fuel Cycle	4.02	Isotope Processing	5.02	Physics	6.02	Sponsored Research	7.02	Housing
1.03	Front End Fuel Cycle	2.03	FBR-Front End Fuel Cycle	3.03	Other Thorium Reactor Systems	4.03	Agriculture	5.03	Chemistry	6.03	Prospective Research Fund		
1.04	Back End Fuel Cycle	2.04	FBR-Back End Fuel Cycle	3.04	Accelerator Driven Sub-critical Systems	4.04	Food Processing	5.04	Biology	6.04	Homi Bhabha Centre for Science Education		
1.05	Health, Safety & Environment	2.05	Repair and Inspection Technologies	3.05	Materials	4.05	Health	5.05	Cancer	6.05	Information Technology Application Development		
1.06	Waste Management	2.06	FBR-Health, Safety & Environment	3.06	Hydrogen Energy	4.06	Water	5.06	Synchrotrons & their Utilisation				
				3.07	Fusion Reactor	4.07	Industrial Applications	5.07	Cyclotrons & their Utilisation				
						4.08	Accelerators	5.08	Fusion & Other Plasma Technologies				
						4.09	Lasers	5.09	Material Science				
						4.10	Special Materials	5.10	Interdisciplinary Areas				
						4.11	Advanced Technologies	5.11	International Research Collaborations				
						4.12	Special Programmes						

MAJOR PROGRAMMES

MP-1 : Nuclear Power Programme-Stage-1
MP-2 : Nuclear Power Programme-Stage-2
MP-3 : Nuclear Power Programme-Stage-3 and beyond
MP-4 : Advanced Technologies and Radiation Technologies and their Applications
4A : Advanced Technologies and their Applications (Includes sub-programmes 4.01, 4.08 to 4.12)
4B : Radiation Technologies and their Applications (Includes sub programme 4.02 to 4.07)
MP-5 : Basic Research
MP-6 : Research Education Linkages
MP-7 : Infrastructure & Housing

ANNEX-I

ATOMIC ENERGY ESTABLISHMENTS IN INDIA

ANNEX-II

REPLIES TO AUDIT OBSERVATIONS

Report no. Chapter I of Compliance report of Vol I: Compliance Audit – Union government, Scientific Ministries / Departments

Para No.1.1: Payment of City / Site Conveyance Allowance to officials provided with Transport facility

Nuclear Power Corporation of India Limited extended undue benefits of City/site Conveyance Allowance to those officers/staff who were already provided with independent car/transport facility. This resulted in consequential extra of 105.47 crore during September 2008 to March 2015

Action Taken:

ATN Under submission

Report no. 12 of 2016

Para No. 2.1: Following up Audit on Procurement Audit (Performance Audit)

Based on 32 recommendations made in Audit Report of the Comptroller and auditor General iof India No. 13 of 2010-11 (Performance Audit), Department of Atomic Energy (DAE) Submitted a detailed action plan with measurable timeframes to implement the audit recommendations. A Follow up audit was carried out to examine the extent of compliance by DAE to the proposed action plan.

The follow up audit showed that full implementation was achieved in only six out of 32 recommendations made. While partial implementation was seen in action proposed for seven recommendations, the progress was insignificant against 16 recommendations. No progress was made against actions stated for three recommendations. Deficiencies in planning for procurements, adherence to time schedules and contract management persisted. Implementation of computerisation of materials management functions remained insignificant.

Thus, on the whole, action taken by DAE against its own stated plan was largely inadequate.

Action Taken:

Action has been initiated for implementation of e-tendering system. If is planned to implement this in the beginning at MRPU and then in sequence at IRPU, HEUP, DPS followed by all other units of DPS. A contract has already been awarded for this purpose and sample files are under process by e-tendering solution. Regular processing solution of non-sensitive indents by using e-tendering solution will commence from June, 2010 at MRUP. The services of e-procurement solution will be extended in phased manner to other units with a gap of three months. Actions have also been initiated to implement the workflow automation system at IGCAR and BARC in which Stores Management Information System will also cover the Stores and Purchase activities. An order has already been awarded for this work

at IGCAR and is expected to be made available to users in a period of six months. Similarly, a tender has been floated for implementing this system at BARC. The workflow automation system will be implemented at other units of DAE in a progressive manner.

Centralisation of computerisation across DAE Units needs an elaborate study by a team of experts considering the aspects of sensitivity and security of data. This aspect will be discussed at DAE level to evolve strategy for moving ahead in this direction.

The new web based e-tender portal having features is being used by majority of the regional purchase units. If would also be extended to smaller units.

Para No. 2.2: Non-installation of Steam Turbine Generator

Due to inefficient contract management by Heavy Water Board and Directorate of Purchase and Stores, Mumbai, a Steam Turbine Generator could not be installed even after lapse of more than 10 years. This resulted I blocking of 2.06 core in its procurement besides loss of opportunity to generate electricity estimated at 40 corer.

Action Taken:

Heavy Water Board actually came out with a novel way of utilizing the steam used in the process of heavy water production by introducing a Steam Turbine Generator in the production process. This modification involved innovative design, manufacture of Steam Turbine suited to the location, erection and commissioning in an already functioning Heavy Water production plant. This intricate and innovative arrangement was expected to save 2000 kW of electricity at the generator terminal and net gain of electricity of 1373 kW. The purchase order was placed with M/s. Kessels Engg. Works Pvt. Ltd., New Delhi for design, drawings, installation & commissioning on 9.2.2005. The delivery period has to be extended many times due to the intricate nature of the job and the firm could not execute the order fully but could only supply the most of the equipments by July 2011. Realizing that the contractor is losing money in completing the work order, he demanded additional money which could be negotiated and finalised only in June 2013. But, the additional cost involved of ` 126 lakh could not be finalized and it was decided to go in for a risk purchase and the balance work was taken up by HWB departmentally. Therefore, the risk purchase cost was saved by the Department and the total payment to M/s. Kessels was restricted due to the Departmental efforts to `284.51 lakh.

ANNEX-III

REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2017)				Number of appointments made during the calendar year 2016									
					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	8377	596	145	844	209	5	1	16	291	20	10	4	0	0
Group B	9526	1741	819	2215	230	40	27	108	324	50	13	14	0	0
Group C	10803	2247	986	3276	434	62	23	195	335	78	24	0	0	0
TOTAL	**28706**	**4584**	**1950**	**6335**	**873**	**107**	**51**	**319**	**950**	**148**	**47**	**18**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2017)				Number of appointments made during the calendar year 2016									
					By Direct Recruitment				By Promotion			By Deputation		
	Total Emp	SC	ST	OBC	Total	SC	ST	OBC	Total	SC	ST	Total	SC	ST
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Group A	1332	64	7	99	64	0	0	6	87	3	0	1	0	0
Group B	2727	418	105	452	64	8	7	11	73	5	4	0	0	0
Group C	2486	759	157	419	120	20	3	28	35	13	4	0	0	0
TOTAL	**6545**	**1241**	**269**	**970**	**248**	**28**	**10**	**45**	**195**	**21**	**8**	**1**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2017 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2016 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2017)				Number of appointments made during the calendar year 2016									
					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	6984	782	223	1065	147	21	6	53	810	95	47	0	0	0
Group B	5690	931	456	1509	89	15	5	41	1007	196	103	0	0	0
Group C	4948	945	680	1263	52	12	0	27	816	173	90	0	0	0
TOTAL	**17622**	**2658**	**1359**	**3837**	**288**	**48**	**11**	**121**	**2633**	**464**	**240**	**0**	**0**	**0**

ABBREVIATIONS

AAIS	Augmentation of Amenities and Infrastructure
ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADFTS	Automated Direct Fuel Transfer System
ADS	Accelerator Driven System
ADU	Aammonium Di-Uranate
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AES	Atomic Emission Spectroscopy
AFFF	Advanced Fuel Fabrication Facility
AFMTF	AHWR Fuelling Machine Test Facility
AFR	Away From Reactor
AGN	Active Galactic Nuclei
AHWR	Advanced Heavy Water Reactor
ALARA	As Low as Reasonably Achievable
ALIMCO	Artificial Limbs Manufacturing Corporation of India
AMD	Atomic Minerals Directorate for Exploration & Research
AMOS	Atomic, Molecular and Optical Science
AMP	Ammonium Molybdo Phosphate
ANL	Argonne National Lab
APD	Antiphase Domains
APPJ	Atmospheric Pressure Plasma Jet
APPLE	Advanced Planar Polarized Light Emitter
ARPES	Angle Resolved Photoelectron Spectroscopy
ASDF	Actinide Separation Demonstration Facility
ASE	Atomstroyexport
ASFSF	Additional Spent Fuel Storage Facility
ASTEC	Accident Source Term Evaluation Code
ATI	Administrative Training Institute
ATLAS	Advanced Thermal hydraulic Test Loop for Accident Simulation
ATTF	AHWR Thermal Hydraulic Test Facility
AUSCPP	Advanced Ultra-Supercritical Power Plant
BARC	Bhabha Atomic Research Centre
BDBA	Beyond Design Basis Accident
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BHW	Bi-thermal Hydrogen Water
BNHS	Bombay Natural History Society
BOTLR	Battery Operated TL Reader
BPI	Beam Position Indicators
BPM	Beam Profile Monitor
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BWI	Bonds Work Index
BWO	Backward Wave Oscillator
CARM	Compact Arial Radiation Monitor
CAROT	Cobalt AR Remote Operating Tool
CBS	Centre for Excellence in Basic Sciences
CBT	Core Balance current Transformers
CCD	Charge Coupled Device
CCPS	Capacitor Charging Power Supply
CCW	Condenser Cooling Water
CDR	Critical Design Review
CEP	Condensate Extraction Pumps
CERN	European Organisation for Nuclear Research
CESAM	Code for European Severe Accident Management
CFD	Computational Fluid Dynamics
CFT	Captive Flight Trials
CFVS	Containment Filtered Venting System
CIM	Camera Integrated Modules
CIWH	Condensation Induced Water Hammer
CLOE	Corrosion Loop Experiments
CMLC	Concrete Mortar Lined and Coated
CNT	Carbon Nanotubes
CoARs	Cobalt Absorber Rods
COG	Candu Owner's Group
CORAL	Compact Reprocessing facility for Advanced fuels of Lead cells
CPB	Cemented Paste Backfill
CPSE	Central Public Sector Enterprise
CQC	Chemical Quality Control
CRDM	Control Rod Drive Mechanisms
CRZ	Coastal Regulation Zone
CSDU	Crude Sodium Diuranate
CSP	Core Sub assembly Plant
CSR	Corporate Social Responsibility
CSRDM	Control & Safety Rod Drive Mechanism
CSS	Containment Spray System
CTA	Cherenkov Telescope Array
CTA	Carrier Tube Assembly
CTS	Cobalt Teletherapy Sources
CVC	Central Vigilance Commission
CVD	Carbon Vapour Deposition
CVD	Chemical Vapour Deposition
CVO	Chief Vigilance Officer
CWMF	Centralised Waste Management Facility
CZTI	Cadmium Zinc Telluride Imager
DAE	Department of Atomic Energy
DBA	Design Basis Accident
DBP	Di Butyl Phosphate
DBR	Design Basis Reports
DCC	Direct Contact Condensation
DCM	Double Crystal Monochromator
DCSEM	Directorate of Construction Services & Estate Management
DDCS	Digital Distributed Control System
DGFS	DAE Graduate Fellowship Scheme
DOG	Dissolver off Gas
DoPT	Department of Personnel and Training
DOS	Dioctyl Sebacate
DPE	Department of Public Enterprises
DPS	Directorate of Purchase & Stores
DPSS	Diode Pumped Solid State
DPR	Detailed Project Report
DPT	Differential Pressure Transmitter
DRDO	Defence Research Development Organisation
DSRDM	Diverse Safety Rod Drive Mechanism
DSSC	Dye Sensitized Solar Cell
EBW	Electron Beam Welding
ECCS	Emergency Core Cooling System
ECIL	Electronic Corporation of India Limited
EDC	Electron Density Contrast
EDF	Électricité de France
EDM	Electric Dipole Moment
EDS	Energy Dispersive X-ray Spectroscopy

ABBREVIATIONS

EELD	Extended Electrode Leak Detector
EFPY	Effective Full Power Years
EETF	Experimentation and Equipment Test Facility
EIA	Environmental Impact Assessment
ELCB	Earth Leakage Circuit Breakers
EMCCR	En-masse Coolant Channels Replacement
EMFR	En-masse Feeders Replacement
EMS	Environmental Management System
EMTR	Emergency ModeTransfer
EOS	Equation of State
EOT	Electric Overhead Travelling
EPC	Engineering, Procurement and Construction
ERM	Environmental Radiation Monitor
ESCIA	End Shield Calandria Integral Assembly
ESP	Environment Stewardship Programme
EVTP	Ex-vessel Transfer Port
EXAFS	Extended X-Ray Absorption Fine Structure
FAF	Fast Axial Flow
FAIR	Facility for Antiproton and Ion Research
FBG	Fiber Bragg Grating
FBTR	Fast Breeder Test Reactor
FBR	Fast Breeder Reactor
FCIPT	Facilitation Centre for Industrial Plasma Technology
FEM	Finite Element Method
FESEM	Field Emission Scanning Electron Microscopy
FFW	Fire Fighting Water
FMA	Flux Mapping Algorithm
FMS	Flux Mapping System
FMTF	Fuelling Machine Test Facility
FOAK	First of a Kind
FOFB	Fast Orbit Feedback
FPC	First Pour of Concrete
FPDW	First Priority Design Works
FPE	First Priority Equipment
FRENA	Facilities for Research in Experimental Nuclear Astrophysics
FReT	First Research and Technical
FRFCF	Fast Reactor Fuel Cycle Facility
FTIR	Fourier Transform Infrared
FWHM	Full Width at Half Maximum
GCNEP	Global Centre for Nuclear Energy Partnership
GDWP	Gravity Driven Water Pool
GFA	General Framework Agreement
GFL	Greenstar Fertilizers Ltd
GFP	Green Fluorescence Protein
GHAVP	Gorakhpur Anu Vidyut Pariyojana
GHRSS	GMRT High Resolution Southern Sky Survey
GIXRD	Grazing Incidence X-Ray Diffraction
GMP	Good Manufacturing Practices
GMRT	Giant Metrewave Radio Telescope
GNW	Graphene Nanowalls
GRAS	Generally Recognized As Safe
GUI	Graphics User Interface
HAP	Hydroxy Apatite
HBCSE	Homi Bhabha Centre for Science Education
HBNI	Homi Bhabha Nationa Institute
HBRA	High Background Radiation Areas
HCR	Handling Control Room
HDR	High Dose Rate
HFLM	Hollow Fibre Liquid Membrane
HHG	High Harmonic Generation
HLGR	High Level Ground Reservoir
HOM	Higher Order Modes
HPCL	Hindustan Petroleum Corporation Limited
HPM	High Power Microwave
HPS	He Purge gas System
HREM	High Resolution Electron Microscope
HRI	Harish-Chandra Research Institute
HRTF	Hydrogen Recombiner Test Facility
HWB	Heavy Water Board
HTS	Hydro Technical Structures
HYMERES	HYdrogen Mitigation Experiments for REactor Safety
IAEA	International Atomic Energy Agency
ICAL	Iron Calorimeter
ICAR	Indian Council of Agricultural Research
ICW	Inner Containment Wall
IDBP	IInsertion Device Beam Position Indicator
IERMON	Indian Environmental Radiation Monitoring Network
IFTM	Inclined Fuel Transfer Machine
IGCAR	Indira Gandhi Centre for Atomic Research
IIFC	Indian Institute Fermilab Collaboration
ILLW	Intermediate Level Liquid Waste
IMRT	Intensity Modulated Radiation Therapy
IMS	Ion Mobility Spectrometry
IMSc	Institute of Mathematical Science
INAA	Instrumental Neutron Activation Analysis
INE	India Nuclear Energy
INO	India-based Neutrino Observatory
INPO	Institute of Nuclear Power Operations
INRP	Integrated Nuclear Recycle Plant
IOP	Institute of Physics
IPR	Intellectual Property Rights
IPR	Institute for Plasma Research
IPWR	Indian Pressurised Water Reactor
IREL	Indian Rare Earths Limited
IRMA	Immunoradiometric Assay
IRSIS	Infrared Spectroscopic Imaging Survey
ISE	Ion Selective Electrode
ISI	In-service Inspection
ISM	Induction Skull Melting
ISNS	Indian Spallation Neutron Source
ITER	International Thermonuclear Experimental Reactor
ITFT	Integrated Thermal Hydraulic Test Facility
IVTP	In-vessel Transfer Port
JHR	Jules Horowitz Reactor
JNPP	Jaitapur Nuclear Power Project
KAMINI	KAlpakkam MINI Reactor
KAPP	Kakrapar Atomic Power Project
KAPS	Kakrapar Atomic Power Station
KARP	KAlpakkam Reprocessing Plant
KGS	Kaiga Atomic Power Station
KKNPP	Kudankulam Nuclear Power Plant
LAD	Liquid and Amorphous Diffractometer
LCW	Low Conductivity Water
LDP	Level Density Parameter
LERF	Large Early Release Frequency

ABBREVIATIONS

LIA	Linear Induction Accelerator
LLLW	Low Level radioactive Liquid Waste
LMBFS	Longitudinal Multi-Bunch Feedback System
LOCA	Loss of Coolant Accident
LPPLA	Liquid Phase Pulsed Laser Aablation
LST	Large Size Telescope
LTB	Lithium Tetra Borate
LTD	Linear Transformer Driver
LVDT	Linear Variable Differential Transformer
LWR	Light Water Reactor
LZO	Lithium metazirconate
MACE	Major Atmospheric Cerenkov Experiment Telescope
MAPS	Madras Atomic Power Station
MCF	Medical Cyclotron Facility
MoEFCC	Ministry of Environment, Forest and Climate Change
MOI	Moment of Inertia
MOT	Magneto Optical Trap
MoU	Memorandum of Understanding
MPECVD	Microwave Plasma Enhanced Chemical Vapour Deposition
MSBRDF	Molten Salt Breeder Reactor Developmental Facility
MSG	Management Services Group
MSIV	Main Steam Isolation Valve
MSLB	Main Steam Line Break
MSP	Millisecond Pulsar
MWCNT	Multi-Walled Carbon Nanotubes
MWPF	Metallurgical Waste Processing Facility
NAA	Neutron Activation Analysis
NAPS	Narora Atomic Power Station
NBHM	National Board of Higher Mathematics
NCD	Nano-Crystalline Diamond
NCQC	National Convention on Quality Concepts
NDP	Neighborhood Development Programme
NDT	Non Destructive Testing
NFC	Nuclear Fuel Complex
NGADU	Nuclear Grade Ammonium di-Uranate
NHL	Non-Hodgkin's Lymphoma
NIC	National Informatics Centre
NISER	National Institute of Science Education & Research
NLD	Nuclear Level Density
NMC	Neutron Multiplicity Counter
NODRS	National Occupational Dose Registry System
NORMS	Naturally Occurring Radioactive Materials
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NRB	Nuclear Recycle Board
NRCL	National Research Centre on Litchi
NSCI	National Safety Council of India
NTPC	National Thermal Power Corporation
NTTF	NPCIL Thermal Hydraulic Test Facility
OAR	Organs at Risk
OCW	Outer Containment Wall
OECD	Organization for Economic Co-operation and Development
OHSMS	Occupational Health and Safety Management System
PAC	Perturbed Angular Correlation
PACSR	Post Accident Containment System Response
PBT	Profit BeforeTax
PCBM	Phenyl-C61-Butyric acid Methyl ester
PCE	Photon-to-current Conversion Efficiency
PCIS	Passive Containment Isolation System
PCP	Primary Coolant Pump
PCPTF	Primary Coolant Pump Test Facility
PCRD	Passive Catalytic Recombiner Devices
PDB	Protein Data Bank
PDCA	Pyridine Dicarboxylic Acid
PDDC	Pulsed Disc and Doughnut Column
PDHRS	Passive Decay Heat Removal System
PEEM	Photo Emission Electron Microscopy
PES	Photo-Electron Spectroscopy
PET	Positron Emitting Tomography
PFBR	Prototype Fast Breeder Reactor
PGA	Peak Ground Acceleration
PHM	Prognostic and Health Management
PHWR	Pressurised Heavy Water Reactors
PIG	Pipeline Inspection Gauges
PIGE	Particle Induced Gamma-ray Emission
PLD	Pulsed Laser Deposition
PLF	Plant Load Factor
PMS	Portal Monitoring System
PMT	Photo Multiplier Tube
POC	Payload Operation Centre
POC	Project Office Complex
PPA	Polarization Position Angle
PREFRE	Power Reactor Fuel Reprocessing
PRSI	Public Relations Society of India
PRTRF	Power Reactor Thorium Reprocessing Facility
PSA	Probabilistic Safety Assessment
PSI	Pre-service Inspection
PSP	Primary Sodium Pump
PSPC	Pulsed Sieve Plate Column
PTFE	Poly Tetra Fluro Ethylene
PTS	Passive Thermal Sensors
PTV	Planning Target Volume
QCD	Quantum Chromo Dynamics
RAL	Radioanalytical Laboratory
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RCC	Reinforced Cement Concrete
RECL	Rare Earths Chloride
REE	Rare Earths
RFID	Radio Frequency Identification
RFQ	Radio Frequency Quadrupole
RGA	Residual Gas Analyser
RGMS	Radiation and Gas Monitoring System
RIA	Radioimmunoassay
RIB	Radioactive Ion Beam
ROCOM	Rossendorf Coolant Mixing Model
RPC	Resistive Plate Chamber
RPC	Radiopharmaceutical Committee
RPP	Radiation Processing Plant
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RTIL	Room Temperature Ionic Liquid
RUP	Reprocessed Uranium Oxide Plant
SAC	Space Application Centre

ABBREVIATIONS

SANS	Small Angle Neutron Scattering
SAMG	Severe Accident Management Guidelines
SBF	Simulated Body Fluid
SBF	Stuffed Baked Food
SBT	Ship Borne antenna Terminal
SCR	Selective Catalytic Reduction
SCRF	Super Conducting Radio Frequency
SCWR	Super Critical Water cooled Reactor
SDC	Shut Down Cooler
SDCP	Shutdown Cooling Pump
SDS	Shut Down System
SDU	Sodium Di Uranate
SED	Spectral Energy Distribution
SFSF	Spent Fuel Storage Facility
SIGMAS	Symptom based Intervention Guidelines Management System
SINP	Saha Institute of Nuclear Physics
SiPM	Silicon Photo Multiplier
SMA	Seismic Margin Assessment
SMVC	System for Management of Vigilance Complaints
SNDHM	Startup Neutron Detector Handling Mechanism
SOFT	Safety of Flight Tests
SPNCL	Supercritical Pressure Natural Circulation Loop
SPND	Self Powered Neutron Detector
SPP	Solvent Production Plant
SR	Synchrotron Radiation
SRC	Safety Review Committee
SSE	Safe Shutdown Earthquake
SSRP	Solid State Reaction Process
SSTP	Stainless Steel Tube Plant
SUT	Start-Up Transformer
SWDM	Solid radioactive Waste Disposal Module
SWM	Scanning Wire Monitor
SWMF	Solid Waste Management Facility
SWRO	Sea Water Reverse Osmosis
SXP	Solvent Extraction Plant
SYMPLE	SYstem for Microwave PLasma Experiments
TACTIC	TeV Atmospheric Cerenkov Telescope with Imaging Camera
TaN	Tantalum mononitride
TAPS	Tarapur Atomic Power Station
TBM	Test Blanket Module
TBP	Tributyl Phosphate
TDC	Technology Development Council
TDC	Time-to-Digital Converter
TDCR	Triple to Double Coincidence Ratio
TDFL	Thulium Doped CW Fiber Laser
TDP	Technology Demonstration Plant
TEHP	Tri-Ethyl Hexyl Phosphate
TEPC	Tissue Equivalent Proportional Counter
TES	Tritium Extraction System
TFC	Thin-Film Composite
TFS	Tritium Filled Self-luminous
TiAP	Tri-Isoamyl Phosphate
TIFR	Tata Institute of Fundamental Research
TKE	Total Kinetic Energy
TLD	Thermo Luminescence Dosimeters
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TNMB	Tamil Nadu Maritime Board
TNPCB	Tamil Nadu Pollution Control Board
TOR	Terms of Reference
TREE	Total Rare Earths
TREI	Toyotsu Rare Earths India Pvt. Ltd.
TRS	Treatment Planning Software
TSHB	Tensile Split Hopkinson Bar
TSO	Trainee Scientific Officer
TTC	Telemetry and Tele-Command
TXRF	Total reflection X-Ray Fluorescence
UCIL	Uranium Corporation of India Limited
USUSS	Under Sodium Ultrasonic Scanner
VASP	Vienna Ab-initio Simulation Package
VCMS	Vigilance Clearance Management System
VECC	Variable Energy Cyclotron Centre
VENUS	VECC array for NUclear Spectroscopy
VHRR	Very High Resolution Radiometer
VMAT	Volumetric Modulated Arc Therapy
VNA	Vector Network Analyzer
VOF	Volume of Fluid
VRF	Volume Reduction Factor
VSSP	Versatile Solvent Synthesis Pilot Plant
VTS	Vertical Test Stand
VWSF	Vitrified Waste Storage Facility
WACT	Waste Assay Computed Tomography
WANO	World Association of Nuclear Operators
WBM	Water Bound Macdam
WER	WANO Event Reports
WII	Wildlife Institute of India
WIP	Waste Immobilization Plant
WNA	World Nuclear Association
XANES	X-ray Absorption Near Edge Spectroscopy
XBIS	X-ray Baggage Scanning System
XPS	X-ray Photoelectron Spectroscope
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
XMCD	X-ray Magnetic Circular Dichroism
YDFL	Ytterbium Doped Fiber Laser

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