सत्यमेव जयते

GOVERNMENT OF INDIA

DEPARTMENT OF ATOMIC ENERGY



राष्ट्र की सेवा में परमाणु

पऊवि
DAE

ATOMS IN THE SERVICE OF THE NATION

ANNUAL REPORT
2020-21



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GOVERNMENT OF INDIA

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Cover page front & back : Kakrapar Unit 3 & 4 Main Plant Construction area

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EXECUTIVE SUMMARY

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

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

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

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

During the year 2020-21, the programmes of the Department achieved impressive growth in all the segments and domains. These are described below:

NUCLEAR POWER PROGRAMME: STAGE 1

PRESSURISED HEAVY WATER REACTORS

Nuclear Power Corporation of India Limited (NPCIL), formed in 1987, is a Public Sector Enterprise under the administrative control of Department of Atomic Energy (DAE). NPCIL is a dividend paying company with highest credit rating of AAA by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. Safety is given overriding priority in all facets of nuclear power reactors. Despite the challenging times due to Covid-19 pandemic and lockdowns, NPCIL managed to continue safe and normal operation of its power stations. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. Narora Atomic Power Station (NAPS) Unit-2 completed 852 days of continuous, safe and reliable operation on December 24, 2020 after which the unit has been taken under planned Biennial Shutdown (BSD). So far, safe, reliable and continuous operation for more than two years has been achieved 4 times and for more than a year 34 times, by various reactors operated by NPCIL. First pair of indigenously designed 700 MW Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (Kakrapar Atomic Power Project-3&4) followed by second pair at Rawatbhata in Rajasthan (Rajasthan Atomic Power Project -7&8) and second pair of Light Water Reactors (LWRs) at Kudankulam i.e. Kudankulam Nuclear Power Project (KKNPP)-3&4 (2x1000 MW) are under various stages of construction. The first indigenously designed 700 MW Pressurized Heavy Water Reactor (PHWR) at Kakrapar, Gujarat, has successfully achieved two major commissioning milestones namely “First Criticality” (controlled self-sustaining nuclear fission chain reaction for the first time) on July 22, 2020 and Synchronization of the unit with the Grid on January 10, 2021 in spite of challenges due to COVID-19 pandamic and lockdowns. Consent for First Pour of Concrete (FPC) has been granted by Atomic Energy Regulatory Board (AERB) on November 18, 2020 for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP)-1&2 and subsequently first pile construction commenced on November 21, 2020 in Nuclear Building area. Long manufacturing cycle equipment have been



KAPP-3 First Criticality being hailed by Shri K.N. Vyas, Chairman, AEC & Secretary, DAE and Shri S.K. Sharma, CMD, NPCIL

ordered and are under various stages of manufacturing. In KKNPP-5&6, excavation was completed and award of work for Main Plant Civil Works is in process. Application has been submitted to AERB for consent on First Pour of Concrete (FPC). Various preparatory/pre-project activities are in progress for 10 PHWRs (10x700 MW) in fleet mode towards commencement of construction of these projects. MoEFCC clearance is available for GHAVP-3&4 Chutka site and Kaiga-5&6. Siting consent is received and excavation consent is under review from AERB for Kaiga-5&6. Procurement activities for various long manufacturing cycle equipment are in progress.

In addition, various activities including Techno commercial discussions are in progress for setting up of large size LWRs at Jaitapur in Maharashtra, Kovvada in Andhra Pradesh, etc. with international cooperation as an additionality. NPCIL, in all its endeavours, is committed towards up-gradation and continuous improvements in Quality Management Systems which includes; Quality Assurance (QA), Quality Surveillance, Pre-Service Inspection/In-Service Inspection and Software Quality Assurance (SQA) activities.

Power Generation

NPCIL managed to continue safe and normal operation of its power stations during challenging times due to COVID-19 pandemic and lockdown.

During the Calendar Year (CY) 2020, NPCIL registered commercial power generation of 44613 Million Units (Mus). In the previous CY 2019, the power generation was 45163 MUs.

The actual generation up to December 31, 2020 is 33948 MUs and expected total generation for the FY 2020-21 is about 43000 MUs. Actual generation during the previous FY 2019-20 was 46472 Mus.

The overall annual Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2020 for all the reactors in operation were 87% and 84% respectively. These figures for last FY 2019-20 were 87% and 82% respectively.

During the Financial Year 2020-21, RAPS-5 achieved continuous, safe and reliable operation of more than a year and registered continuous, safe and reliable operation of 472 days on July 29, 2020 after which the unit was shut down manually for carrying out maintenance activities. The four reactors KGS-1(962 days), NAPS-2 (852 days), RAPS-3(777 days) and RAPS-5(765 days) have operated continuously for more than two years. The continuous, safe and reliable operation of 962 days registered by KGS-1 is the second longest continuous operation in world among all reactor technologies.

Nuclear power reactors in operation registered 539 reactor years of safe operation by the end of CY 2020.

Operating Units taken in Project mode

Madras Atomic Power Station (MAPS) Unit-1 (220 MW), Rajasthan Atomic Power Station (RAPS) Unit-2 (200 MW) and Tarapur Atomic Power Station (TAPS) Unit-1&2 (2x160MW) are under long shutdown and have been taken in project mode. MAPS Unit-1 has been taken in project mode since April 1, 2018 for end shield related works. RAPS Unit-2 (200 MW) has been taken in project mode since August 15, 2020 for boiler hairpins replacement. TAPS Unit-1 & Unit-2 (2x160MW) have been taken in project mode since April 1, 2020 and August 1, 2020 respectively, for extensive inspection and repair of reactor recirculation line piping welds.

Projects under construction

All Construction & commissioning activities were continuing till Mar 24, 2020 and thereafter due to Covid-19 lockdown, only essential activities including preservation were continuing in all projects under construction i.e. at KAPP Units-3&4 in Gujarat, RAPP Units-7&8 in Rajasthan and KKNPP Units-3&4 in Tamil Nadu. Construction activities have gradually started resuming in these project sites from May 4, 2020 onwards. All efforts are being made by NPCIL to commence and speed up the project works, in line with the MoHA guidelines and permissions of the local authorities. However, considering that there are challenges in transport of materials, return of migrant skilled labour to project sites and other larger issues like stressed cash flows of contractors and suppliers, restoration of the project implementation process to its full pace may take some time.



Kakrapar Unit 3 & 4 Main Plant Construction area

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

Unit-3 achieved first criticality (Establishing controlled self-sustaining nuclear chain reaction for the first time) on July 22, 2020, which is first unit in the series of 700 MWe Indigenous Indian Pressurized Heavy Water Reactor (IPHWR). The Unit is synchronized to grid for the first time on January 10, 2021. The physical progress of the unit is about 99.9% as on December 31, 2020.

In Unit-4, civil structural works are completed. Erection of the equipment & components is in progress. Feeders erection is in progress. The physical progress of the unit is about 91% as on December 31, 2020.

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

In Unit-7, erection of equipment and piping is in progress. Concreting of shell of Natural Draft Cooling Tower (NDCT)-7B is completed. Commissioning of Plant water pump house, Start Up Transformer, De-mineralized (DM) Water plant, Compressors, etc. is achieved. The physical progress of the unit is about 91% as on December 31, 2020.

In Unit-8, installation of Calandria vault top hatch beam, placement of Inner Containment Dome supporting structure of Reactor Building, placement of Generator Stator on foundation in Turbine Building, etc. are completed. Coolant Channel Installation is in progress. The physical progress of the unit is about 77% as on December 31, 2020.

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

Civil construction works are in progress. The project is making headway steadily both in civil construction and components erection. Construction of Internal Structures, Inner Containment and Outer Containment of Reactor Building, Hydro-Technical structures etc. is in progress.

Manufacturing and progressive delivery of various equipment and components are in progress. Manufacture of Long Manufacturing Cycle Equipment like refuelling machine, separating bellows of Unit-3 and turbine, polar crane of Unit- 4 etc. is in progress and so far about 85% of manufacturing milestones are completed. Major equipment and materials are being progressively delivered from Russian Federation and Third Countries to KKNPP Site.

The physical progress of Unit-3 and Unit-4 was about 48% and 44% respectively as on December 31, 2020.

Sanctioned Projects

Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) Unit-1&2 (2x700 MW PHWRs)

First Foundation Pile Construction commenced on November 21, 2020 in Nuclear Building (NB) area after receiving First Pour of Concrete (FPC) consent from regulatory body on November 18, 2020. Excavation Completed in Turbine building area. Excavation works for IDCT area is in progress. Manufacturing is in progress for major long manufacturing cycle equipment/components like Primary coolant Pumps, Steam Generators, Calandria, End-shields, Reactor Headers, Refuelling machines heads, D_2O Heat Exchangers etc. for which Purchase Orders (POs) were already placed.

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

Following the excavation consent from AERB in November 2018, pit excavation of main plant buildings and other structures to the tune of 9.4 lakh cubic meters have been accomplished. Subsequent activities like confirmatory geo-technical investigations at founding level, ground improvement by consolidation grouting

and concrete levelling course have been completed. Application for First Pour of Concreting (FPC) consent has been submitted to AERB and is under review. Tenders for the main plant civil construction has been opened and award of work is in progress. Besides, working drawings of major buildings foundation and structure up to ground level has been issued by the designers of Russian Federation. Long Manufacturing Cycle Equipment (LMC), First Priority Equipment (FPE) and Balance of Plant-1 (BOP-1) manufacturing are in progress at Russian Federation. Logistic contract for shipment of equipment and supplies has been invited.

Ten 700 MW PHWRs in Fleet Mode

Land: Land is available for GHAVP-3&4 and Kaiga-5&6. Land acquisition is in progress at Chutka site in Madhya Pradesh and at Mahi Banswara site in Rajasthan.

Rehabilitation & Resettlement (R&R): R&R colony for the Project Affected Persons (PAPs) is under construction as per approved architectural plan in respect of Chutka site. In respect of Mahi Banswara site, distribution of R&R award is in process. Tender has been floated for construction of R&R Colony for Project Affected People.

Ministry of Environment, Forest and Climate Change (MoEFCC) Clearance: MoEFCC clearance is available for GHAVP-3 to 4, Chutka site and Kaiga-5&6. Wild Life Clearance is available for Kaiga-5&6. Application for Environmental Clearance (EC) is under consideration of MoEFCC for Mahi Banswara site.

Site Activities: Reports of Geo-technical investigation works are under review for GHAVP-3&4. Placement of work order for Excavation and Ground Improvement is under process. All the scope of work of Geo-technical and Geo-physical investigation is completed for Kaiga-5&6 and tender has been floated for main plant excavation work and application for Excavation consent is under review by AERB. At Mahi Baswara site, Geo-technical investigation works are in progress. At Chutka site, Geo-technical investigation works could not be taken up due to non-cooperation by villagers, which is being continuously brought to the notice of concerned authorities of MP State Government.

Siting consent from AERB: Siting consent from AERB is available for GHAVP-3&4. Siting consent from AERB is received for Kaiga-5&6.

Procurement activities: Bulk purchase Orders are placed for various quantities of Forgings for Steam Generators, Lattice Tubes and Plates for End Shields, Pressurisers forgings, Bleed Condensers forgings, tubes for 40 Steam Generators and Reactor Headers. Tendering process for Steam Generators, pressurisers, Bleed Condensers, Primary Coolant Pump (PCP) motor units, etc. is in progress.

New Project / Sites

Pressurized Heavy Water Reactors (PHWRs)

Bhimpur, Madhya Pradesh: Commitment for water is to be confirmed by State Government.

Light Water Reactor (LWR) Projects

Jaitapur, Maharashtra: Land has been acquired. All statutory clearances are available. Techno-commercial discussions with Électricité de France (EDF), France are in progress.

Kovvada, Andhra Pradesh: Land acquisition process is in progress. Techno-Commercial discussions with Westinghouse Electric Company (WEC) are in progress.

Mithi Virdi, Gujarat: Land is to be acquired as per the new Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013.

Haripur, West Bengal: Land acquisition is contingent to initiative by State Government.

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 reactors. The Nuclear Fuel Complex at Hyderabad manufactures fuel assemblies for pressurised heavy water reactors, boiling water reactors and fast breeder reactor.

Heavy Water Production

As an industrial facility of DAE, Heavy Water Board (HWB) remains the flagship unit for enabling India's self-reliance in not only production of heavy water, which was its prime mandate, but also specialty materials which are required by other DAE Units for processing the inputs and products of nuclear fuel cycle. Going beyond the nuclear realm, HWB has also promoted application of deuterium and deuterated products in the field of technology and health care.

HWB has successfully navigated through multiple technology cycles over the last few decades, pivoting and adapting each time to build new capabilities, enabling DAE units to realize the benefits of these new technologies. The proactive approach towards new challenges and adaptability to change within available resources has been core to HWB's saga of excellence.

Various basic synthesis processes developed by research units of DAE are developed and demonstrated by HWB by designing, developing the technology from lab scale to pilot plant scale and further scaling up to industrial production units. Thus on one hand HWB possesses the expertise in handling tonnage quantities of hazardous chemicals, extreme process conditions and RTC operation, on the other hand, it has developed expertise in setting up and fine tuning operating parameters in small pilot or demo scale plants which handle variety of special and hazardous chemicals and require high end laboratory analytical techniques.

Activities planned during the year at the Heavy Water Plants were successfully completed in phased manner to sail through the challenging situation in the beginning of the year due to COVID-19 pandemic. The Major Turn Around schedules were stretched out to take care of delay in lining up and execution of contracts due to shortage of manpower. Though there were interruptions in receipt of material at site during lock down period, the projects/ capital scheme activities continued with the limited resources. Subsequent to easing of lockdown rules, the HWPs regained back the momentum of activities.

Heavy Water Plants (HWPs) at Hazira and Thal were in operation during the lockdown period as the connected fertilizer units were operating as part of essential services and feed synthesis gas was available to these HWPs.

HWB has achieved the production targets planned for the operating period of the year, for heavy water as well as for other specialty materials such as Boron, organo-phosphorus solvents and synthesis of d-labeled compounds. Overall safety management was excellent at all Heavy Water Plants.

At HWP, Tuticorin, revamping jobs for restart up of the plant are in full swing.

To counter the high cost of the commercially available Calix Crown-6 (CC-6) used for recovery of Cs-137 from Medium Level Waste (MLW) for production of Cesium pencils, HWB took up the task of in-house production of CC-6. Yield as high as 80% could be achieved. The cost of in-house production is less than the commercially available product and quality of the product has been found suitable by Waste Immobilization Plant (WIP), BARC.

Diversification Activities

In line with the new mandate, HWB continued demonstrating Solvent Extraction technologies for nuclear hydrometallurgy; producing stable isotope products like 10B enriched boron carbide pellets for control & safety mechanisms in Fast Breeder Reactors; production of nuclear grade Sodium for FBRs (Fast Breeder Reactors) and production of 18O enriched water for societal applications. New initiatives taken in some of the key areas in these activities during the period are as follows:

Solvent Technology

Nuclear grade solvents required for extraction of various materials through solvent extraction process are produced and supplied by HWB to DAE units like, NFC, BARC, IREL, KARP, IGCAR etc. The existing solvent production facilities at Baroda and Talcher continued to meet the demand placed by various DAE units for organo-phosphorus solvents. HWP, Tuticorin, has been building experience in synthesis of novel organo-phosphorus solvents and an industrial scale Solvent Production Plant is in advanced stage of construction for synthesis of solvents.

At Technology Demonstration Plant (TDP), Mumbai, activities are initiated towards extraction of rare material from Indian phosphate rocks. Laboratory Hammer and Ball mill were commissioned at TDP, Mumbai and grinding of rock phosphate samples brought from prospecting site in Madhya Pradesh is under progress. Analysis of ground samples will be taken up subsequently.



Technology Demonstration Plant (TDP), RCF, Mumbai

Subsequent to successful demonstration of the solvent extraction technology in industrial proto-type scale for various nuclear hydrometallurgical operations at TDP, a Solvent Extraction Plant of industrial scale for the production of rare materials is now being set up at HWP, Tuticorin. For the Integrated Solvent Production Plant, erection work has commenced for the equipment and machineries received at site through the EPC contract. At Solvent Extraction Plant, land development, boundary wall, peripheral road and fencing work for securing newly acquired land was completed. Geo technical investigation works at site was carried out.

Boron Enrichment

Enriched Boron Carbide pellets find application in control & safety systems for FBR program and enriched BF_3 gas, in neutron detection systems. HWB continued production of various 10B enriched Boron products. At HWP, Manuguru Elemental Boron Plant and Boron Carbide Pelletization Plants are in operation for production of enriched Boron Carbide powder/ pellets of various isotopic purities. The ^{10}B IP 50% and 90% Boron Carbide pellets were produced based on the request from IGCAR. Samples of these pellets were tested for physical and chemical properties at IGCAR for confirming suitability for use in FBTR. Subsequent to clearance from IGCAR, production of desired quantity of ^{10}B IP 50% Boron Carbide pellets was taken up and completed.



Boron Carbide Pellets

At HWP, Talcher, ^{10}B enrichment by exchange distillation route generates BF_3 ether complex, which can be converted to enriched boric acid and in the next step to enriched BF_3 gas. This finds application in ^{10}B enriched BF_3 based neutron detectors which is one of the best thermal neutron flux measurement devices for nuclear reactors.

Application for obtaining consent for commissioning and operation of BF_3 Gas Generation and Bottling Unit has been sent to AERB. The by-product of ^{10}B enrichment in this unit is ^{11}B enriched BF_3-

ether complex which is used in production of ^{11}B enriched BF_3 gas. It is to be noted that ^{11}B enriched BF_3 gas finds use as doping agent in Integrated Circuit manufacturing industry.

Sodium Metal

BHAVINI is setting up 500 MWe FBR at Kalpakkam. FBR requires 2200 MT of nuclear grade Sodium Metal as coolant. There are no indigenous manufacturers in India for nuclear grade Sodium metal and its demand is entirely met by import.

In order to achieve self-reliance in second stage nuclear power program, HWB has drawn up elaborate roadmap to cater this requirement of Sodium for FBRs. HWB carried out test operation of various configurations of 2kA electrolytic cells to generate operational data. 24 kA prototype cell is in advanced stage of construction. Concurrently, setting up the industrial scale production plant of 600 MTPA capacity at HWP, Baroda has commenced.

From July, 2013 to July, 2019, five nos. of 2kA capacity closed Sodium production test cells of different configurations have been fabricated and operated successfully at HWP, Baroda. Various parameters including type of anode, diaphragm, eutectic composition, anode-cathode distance, current density etc. have been finalized. Operation of these test cells has produced Sodium metal containing more than 99.9% of Sodium with major impurities like oxides of Sodium and Calcium, Carbon, Iron, Magnesium etc. Technology for removal of the impurities to produce nuclear grade Sodium metal is not available on transfer from any industry or research organization or in literature or patents and was completely developed by HWB. A Bench Scale Sodium Metal Purification Unit (BSPU) was set up at HWP, Baroda. Subsequent to purification of sodium metal in this unit, 3000 kg of nuclear grade Sodium metal was supplied to IGCAR on 26.09.2020. This was a significant achievement of HWB towards making the Stage 2 of INPP (Indian Nuclear Power Programme) self-reliant.



Sodium Purification Unit at Heavy Water Plant, Baroda

Mineral Exploration and Mining

Atomic Minerals Directorate for Exploration and Research (AMD) has accelerated the pace of exploration activities by integrated, multi-disciplinary methodology and judicious utilisation of man power with a focussed approach for augmentation of uranium, thorium, rare metals and rare earth resources.

This resulted in the augmentation of additional uranium oxide (U_3O_8) reserve of over 20,362 tonnes in the areas of Andhra Pradesh, Jharkhand, Rajasthan and Karnataka.

Significant uranium anomalies were located in Himachal Pradesh, Andhra Pradesh, Arunachal Pradesh, Chhattisgarh and Odisha. Surveys along West Bengal and Jharkhand has indicated promising helium values in spring water and soil gas samples. About 1,86,380m reconnoitory, exploratory and evaluation drilling was carried out to establish additional uranium reserve in the known deposits and sub-surface continuity of uranium and mineralization in the new promising areas. Significant uranium mineralized intercepts / bands have been identified in boreholes drilled at Uttar Pradesh, Himachal Pradesh, Karnataka, Andhra Pradesh, Jharkhand, Rajasthan, Chhattisgarh and Madhya Pradesh. New Potential/significant blocks taken up for subsurface exploration were at Himachal Pradesh, Madhya Pradesh, Karnataka and Rajasthan.

Geochemical surveys (4,563 sq km) have been carried out in different parts of the country for delineating

targets for detailed investigations. Ground geophysical surveys (Regional: 605 sq km and Detailed: 342 sq km) have delineated high chargeability- low magnetic – low resistivity zones towards north of Rajasthan; Great Boundary Fault (GBF), the contact between Vindhyan sediments and Jahazpur Group / Berach Granite in Rajasthan; low resistivity and high chargeability zone in the east of Kanchankayi; and unconformity contact between Bijli Rhyolite and Bortalao Sandstone and litho-contact between Bortalo Sandstone and Sitagota Basalt in Maharashtra. Airborne survey and remote sensing surveys over 36,392 line km have been carried out in parts of North Delhi Fold Belt, Rajasthan & Haryana and Chhotanagpur Granite Gneiss Complex, parts of Jharkhand, Uttar Pradesh, Madhya Pradesh and Chhattisgarh.

Rare Metal and Rare Earth (RMRE) investigations surveys were carried out in parts of Chhattisgarh, Madhya Pradesh, Odisha, Rajasthan, Gujarat and Karnataka.

Beach Sand and Offshore Investigations (BSOI) resulted in establishing potential heavy mineral zones mainly along the east coast of India. Significant zones of Total Heavy Mineral (THM) concentration have been located in Odisha, Kerala and Andhra Pradesh. Sonic drilling, along Brahmagiri coast, Odisha established the persistence of sand column up to 40m with up to 34% THM content.

UCIL received 'Excellent' MoU rating for FY 2018-19, for the second time in a row. For the first time, UCIL successfully implemented 10 (ten) year tenure settlement of 'Revision of Wages and Allowances' in respect of workmen with effect from 4th February 2020. In April, 2020, UCIL commissioned the facility for production of 'Heat Treated Uranium Peroxide (HTUP)' in place of 'Magnesium Di-Uranate (MDU) at Turamdih Mill. UCIL has applied for mining lease for Rohil Project in Rajasthan. Long term mine development and operation contracts have been awarded for Tummalapalle underground and Banduhurang opencast mines.

At IREL, production of minerals increased by 1.6% compared to corresponding period last year, inspite of the pandemic situation.

Operations of chemical plants was affected due to disruption in supply chain and closure of downstream industries. Production of Nuclear Grade Ammonium di-Uranate (NGADU) and Mixed Rare Earths Chloride (MRECL) stood at 13.4 tons and 2964 tons respectively.

Dysprosium production facility at RED, Aluva was dedicated to the Nation by Shri K. N. Vyas, Chairman, AEC & Secretary, DAE by virtual mode in commemoration of IREL's Platinum Jubilee celebrations in the presence of Shri. D. Singh, Chairman and Managing Director, IREL (India) Limited.

Statutory clearances for the Rare Earth Permanent Magnet Plant at Vizag have been received from Ministry of Environment & Forest (MoEF&CC), BARC Safety Committee and Andhra Pradesh Pollution Control Board. Site activities have commenced.

Capacity expansion of mineral separation plant of OSCOM unit in Odisha has been initiated on EPC basis. The project will boost the total mineral producing capacity of the Company to 1.0 million tons.

Commenced Site activities for civil construction of the Rare Earth & Titanium Theme Park at Bhopal. Activities pertaining to upscaling of laboratory technology developed by BARC to pilot scale has also been taken up.

Mining & mineral processing activities continued during the year with the discovery of Uranium mineralization in Naktu, Son valley, UP and in Chitrial, Telengana. Ores from these sites contain significant fractions of rare earths (RE) besides Uranium. The carbonatites of Ambadongar are rich hard rock resource of REs and metals such as Mg, Nb and V. Metallurgical studies on different ore samples revealed that REs occur in the form of monazites and fluoro-carbonates with a possibility of 50-55% overall recovery.

The technology for production of high purity yttrium oxide (99.99%) from Xenotime, a complex phosphate mineral rich in yttrium, was developed and the technical details were shared with IREL for bulk production of high purity Y_2O_3

Magnetic scrap containing NdFeB is recycled by a multi-step hydrometallurgical process leading to precipitation of RE (Nd, Pr&, Dy) double sulphates with more than 85% recovery of REs with purity of about 98%. Sorbent materials such as bio-hybrid of nano-silica with a very high capacity to adsorb mercury contaminated liquid wastes have been designed using Fe_3O_4 nano-particles. A molten salt electrolysis using LiCl-KCl/NaCl-KCl was developed for production of 99% pure La metal in 1kg batch from indigenous LaO supplied by IREL.

A novel environment-friendly process was developed for treating columbium tantalite ore dissolver solution to separate Nb and Ta. The process of dissolution of zirconium hydroxide frit in concentrated nitric acid was developed in a 70L SS dissolver, which was scaled-up to 700 L for continuous operation.

More than 95% uranium was recovered using intensified solvent extraction from lean streams (200 ppm uranium) using 30% tri-n-butyl phosphate in dodecane as solvent.

Technology for extraction of boron from boron carbide scrap by electro-extraction was demonstrated by extracting 200 g high purity boron (98%) and Ordnance Factory Khamaria, Jabalpur support is being supported for improving the purity of boron.

Fuel Fabrication

Nuclear Fuel Complex (NFC), an ISO 9001, ISO 14001 & OHSAS 18001 organisation under DAE, remained engaged in the production of natural Uranium fuel bundles for Pressurized Heavy Water Reactors (PHWRs), enriched Uranium fuel assemblies for Boiling Water Reactors (BWRs), Reactor Core Structurals (calandria tubes, coolant tubes, square channels etc.), Reactivity Control Mechanisms and special materials like Tantalum, Niobium etc. In addition, for Fast Breeder Reactors, NFC produced all the core sub-assemblies and other critical components like fuel cladding tubes, hexagonal wrapper tubes etc. made out of special stainless steels/D9 materials. NFC also catered to the demands of high-quality stainless-steel tubes/pipes and titanium half alloy products for critical and strategic applications in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

About 31-ton nuclear grade Uranium in the form of 450-850 kg metal ingots was produced during the year for fabrication of research reactor fuel. UED developed a process to produce uranyl nitrate solution from SLM, by selectively leaching CaO, with uranium concentration 10-12 gpl. Around 300 kg of SLM was processed to recover 4.33 kg uranium at a recovery rate more than 99.5%.

Favourable thermo-physical and metallurgical properties make U-16wt.%Mo a novel fuel for future reactors. Extensive microstructural and thermophysical characterization was carried out on this material for deployment as a fuel in fast reactor or pressurized water reactor (PWR).

As a part of the quality control, 330 nuclear material samples from PHWR, FBTR and APSARA-U, including plutonium-based materials were analysed. An Indigenous setup using quartz-based combustion was developed for identification of traces of carbon in Uf_4.

BACK END FUEL CYCLE

Fuel Reprocessing and Waste Management

An Artificial Neural Network model was used to predict vortex shapes under different operating conditions of a vortex mixer to construct computational domains so that single-phase CFD (Computational Fluid Dynamics) simulations could be carried out with a significantly reduced computational time.

A process for purification of DTBDB18C6 was developed to obtain 90% pure material starting from crude DTBDB18C6. Ammonium nitrate is one of the most common wastes generated in both front and back end nuclear fuel cycles. An ultrasonic time-of-flight measurement system is developed for online estimation of ammonium nitrate concentration in process vessels. The system is ready for installation at thermal denitration plant for treatment of waste.

Am containing trace amounts of Eu was purified (more than 99% Am recovered) using TODGA based extraction chromatography at Nuclear Recycle Board, Tarapur.

Ru was recovered to the extent of 90% from alkaline media using commercial strong base anion exchange resin by NaOCl washing followed by elution with 8M HNO_3.

An agglomeration onset detection system was developed to monitor pressure fluctuation data in a fluidized bed reactor. The data is processed using an attractor comparison algorithm to detect the onset of agglomeration 30–40 min earlier than existing methods.

R&D OF POWER SECTOR

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

Eight column sections were fabricated for the second heavy water distillation tower and tested at KAPP-3&4. Sound proofing in the plant improved the safety against noise pollution. Test protocols to estimate radioactive dose rates for various in-core structural components and a system for measurement of vibration and pressure pulsation in primary heat transport system were developed for 700 MWe PHWRs. Capability of the existing In-Service Inspection device was enhanced by introducing Ultrasonic Time of Flight measurement tool for accurate detection of defects.

Reliability of nuclear fuels has a large bearing on economics of nuclear power and radiation safety. Performance of fuel bundles discharged from reactors is assessed periodically by Post Irradiation Examination (PIE) and causes of failure, if any, analysed. Similarly, PIE of pressure tubes from PHWRs is also periodically carried out to assess the in-reactor performance of the Zr–2.5Nb tubes. PIE of full length pressure tubes and pressure tube stubs from various PHWRs have been carried out. Performance of various PHWR out of core components was assessed and root cause of failure (if any) and performance characteristics was established and reported to NPCIL and AERB.

Indigenous reactor pressure vessel steel forgings of composition 20MnMoNi55 were manufactured and characterized for the ductile to brittle transition. As a part of the Indian Light Water Reactor (LWR) programme, high sensitivity radiation detectors and reactivity meters were developed. Integrated Test Facility of Radiation and Gas Monitoring System (RGMS) for LWR was established for training, operation, maintenance and verification of Systems.

Fuel cladding is the first barrier against the release of radioactivity into environment. Ballooning and burst behavior of Zircaloy-4 cladding were investigated for creating a database of fuel safety criteria to frame new safety guidelines for Indian PHWR fuel cladding in a loss-of-coolant accident (LOCA) scenario.

A number of surveillance specimens from Kudankulam VVER were tested to evaluate changes in material properties due to neutron irradiation & thermal exposure and to assess the structural integrity of the reactor.

HEALTH SAFETY & ENVIRONMENT

A coincidence system consisting of Plastic Scintillator and NaI(Tl) for beta and gamma detection was developed indigenously with performance comparable to the existing 4πβ-γ coincidence system. This will be used as a primary standard for radioactivity measurements. 106Ru eye plaques developed by BARC for treatment of eye cancer were standardized at Radiation Standards Section, BARC.

Environmental Survey Laboratories (ESLs) equipped with state-of-the-art instruments are established at each DAE facility for periodic monitoring of environmental matrices. Samples of various environmental matrices such as soil, sediment, air particulate matter, water, milk, food items, sea food, grass, etc., upto 30 km from a facility are analysed. The results clearly indicate that the dose to the members of public at fence post (1.6 km) is only a small fraction of regulatory limit of 1000 micro Sv/year. ESLs at Nuclear Power Plants (NPP) participate in regular public awareness programmes and also act as Emergency Response Centres. A Geographical Information System based database has also been developed covering areas around 50 to 100 km of NPP sites using open source data to assist response action planning during emergency conditions.

Occupational radiation protection and environmental safety surveillance in and around front end facilities was provided at the Uranium Corporation

of India Ltd in Jharkhand and Andhra Pradesh, Indian Rare Earths Ltd. (Kerala, Tamil Nadu, & Odisha) and Nuclear Fuel Complex (Hyderabad). During the year, 8699 occupational workers were monitored for external and internal radiation exposure. In-plant radiological survey and radiation dose evaluations were carried out to ensure compliance with regulatory norms. The occupational radiation doses to workers in underground uranium mines and Thorium handling facilities are well within regulatory limits.

A wound phantom using tissue equivalent material was developed to calibrate HPGe detectors for 17.6, 26.3 and 59.5 keV energies of 241Am photons for different depths varying from 0 to 20mm. This enables estimation of Pu content in the wound using 241Am content in the wound as tracer, in the event of an injury in Pu handling facility.

Solar powered, GSM based Environmental Radiation Monitors (ERMs) are working for more than 15 years under Indian Environmental Radiation Monitoring Network (IERMON). To mitigate GSM related communication issues and to achieve near real time data reception, ERM with Satellite Communication (ERM-SAT) was developed. The system communicates through dedicated carrier on Data Relay Transponder (DRT) on-board INSAT-3D as primary mode of data transmission. The data transmitted from ERM-SAT systems are secured using in-house developed encryption algorithm. 40 units of ERM-SAT have been fabricated and installed in the first batch.

Environmental Gamma Radiation Monitoring in and around DAE facilities is carried out using Thermo Luminescent Dosimeters (TLDs) by RPAD, BARC. A 2D barcode based neutron badge tracking and dose database management software- ANU-KOSH were developed and introduced in neutron personnel monitoring programme. A machine vision based automated image analyser system was developed with the capability to read upto 100 neutron dosimeters in 30 min. Cosmic ray dose rate and neutron spectrum are studied using the Bonner sphere spectrometer deployed at High Altitude Research Laboratory (HARL), Gulmarg, J&K. A novel method for estimating thoron concentration using a vacuum based wall mounting accumulator designed for in-situ measurement of thoron exhalation rate.

NPCIL has recorded about 539 reactor years of safe operation of reactors by the end December 2020. 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. NPCIL is committed in the implementation of ALARA (As Low As Reasonably Achievable) principles in all radioactive works carried out at NPPs to ensure that occupational exposures and releases of radioactive effluents from NPPs are maintained well within the limits stipulated by AERB. Radiological Safety Performance Indicators (RSPI) have been developed for the assessment of Plant performance based on radiological parameters. NPCIL continue to maintain low radiation exposure in the public domain due to operation of nuclear power stations. At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001:2015 and Occupational Health and Safety Management System (OHSMS) as per IS-18001:2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

NUCLEAR POWER PROGRAMME: STAGE 2

FAST BREEDER REACTORS

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

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

Based on the fast breeder reactor technology developed by IGCAR, a 500 MWe Prototype Fast Breeder Reactor (PFBR) is coming up at Kalpakkam. The project is being executed by the Bharatiya

Nabhikiya Vidyut Nigam Limited (BHAVINI), a public sector undertaking of DAE.

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

Fast Breeder Test Reactor

Fast Breeder Test Reactor (FBTR), the flagship of IGCAR is continuing its objectives as a test bed for irradiation of fuel & structural materials in fast neutron flux and a training hub for fast reactor operators. It has completed 35 years of operation so far. In the current year, 29th irradiation campaign was completed during which FBTR was operated at 32 MWt with the Turbo Generator (TG) synchronised to the grid delivering an output of 8 MWe.

Towards obtaining regulatory clearance for raising the power of FBTR to its rated capacity of 40 MWt; reconfiguration of core, reactor physics & shielding studies, safety analysis and plant dynamic studies have been carried out. The grid plate of the reactor, a non-replaceable component, is the life-limiting component because of its degradation by reduction of ductility, due to neutron fluence. Introduction of tungsten carbide shielding material is expected to increase the life of FBTR by an additional 3 full-power years. Global SID (Sodium Ionisation Detector) in secondary sodium system and sodium purification system for flooding circuit have been successfully commissioned. Biennial inspection of reactor vessel, leak test of containment building and purification of 64m3 of sodium to nuclear grade sodium purity has also been accomplished. Irradiation of metallic fuel, special insulation material for fusion reactor & structural materials and testing/ calibration of indigenously developed high-temperature detectors has also been completed. The sodium flooding system, an engineered reactor safety system, has been successfully modified by providing remotely operated valves outside reactor containment building.

Prototype Fast Breeder Reactor

The Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is a 500 MWe (1250 MWt) liquid sodium cooled, pool type reactor using mixed oxide of uranium and plutonium as fuel. After completion of construction, manufacture & erection of all the systems/ components of PFBR, commissioning of the individual system and the integrated commissioning are in progress.

During the past eight months, the work progress got slowed down due to the impact of COVID-19 lockdown. BHAVINI had continued the essential jobs, although the flow of contractual manpower had been interrupted during the initial months of April - May 2020 & only limited manpower was deployed during the suceeding months. The major activities that have been completed during the reporting period includes Indegenous development & manufacture of spacer balls for bearing of Large Rotatable Plug (LRP) used for positioning of in-vessel fuel handling machine; Commissioning works of Fuel Handling equipment and Modification of double walled sodium pipe lines of Decay Heat Exchanger for design improvement.

IGCAR continued to provide necessary support for the 500 MWe Prototype Fast Breeder Reactor (PFBR) which is in the advanced stage of commissioning. A very large number of scientific and technical personnel from the various Groups have been providing all necessary technical support on full-time basis and working in very close coordination with BHAVINI personnel towards the commissioning of PFBR. Out-of-pile qualification trials of the remote in-service vehicle DISHA for inspection of dissimilar weld between main vessel & roof slab at high temperature has also been carried out in a dedicated test facility.

FBR Fuels

The CERMET fuel is a composite of fissile ceramic particles dispersed in a metallic matrix. A new concept for fast reactor fuel design, CERMET is designed to have the optimal properties of a ceramic, such as high temperature resistance and those of a metal - high thermal conductivity and mechanical properties. CERMET nuclear fuels have significant potential to enhance fuel performance because of low internal fuel temperatures and low stored energy.

Digitization of NDT techniques have been

implemented in the quality control of FBTR fuel. Strenuous manual inspection has been replaced with an automated machine vision based software aided technique without compromising any QA parameters. Magnetic pulse welding system was automated for welding PFBR fuel pin T91 tube and end-plug.

Fast Reactor Fuel Reprocessing

The Compact Facility for Reprocessing of Advanced Fuels (CORAL) has been operating as per approved procedures and scheduled number of reprocessing campaigns of FBTR spent fuel with 155 GWD/t burn-up have been completed with very significant reduction in man-rem expenditure. Towards hot-commissioning of the Demonstration Fast reactor fuel Reprocessing Plant (DFRP), special purpose remote handling equipments have been designed, fabricated and tested. Process instrumentation and radiation monitoring systems, security systems and electrical systems at DFRP have been successfully installed. Radiometry of the hot cells; an essential AERB requirement for shielding integrity assessment is also in progress.

Civil construction of nuclear plant buildings for the integrated and self-contained Fast Reactor Fuel Cycle Facility (FRFCF) continues to make steady progress. Civil construction of solid waste building, plant water pump house, a 60 m tall RCC stack and a 30 m tall chimney have been completed, in spite of the setbacks owing to the COVID-19 pandemic. Mega pours involving placement of temperature-controlled concrete of 7,200 and 8,000 cubic-meters have also been undertaken for expeditious completion of civil construction. Various process equipment, electrical equipment, SS pipes and other components required for commissioning of plants are being received at site in a phased manner.

FBR Related Technologies

R&D activities towards the design and development of future FBRs, including testing of a large-diameter (4.5 m) bearing at ambient/ elevated temperatures, shake table testing of a model multi-storied building with and without seismic base isolators, sodium testing of large diameter Inconel bellows for sodium piping, qualification of radar level probe for sodium level measurement, qualification of sodium aerosol detection system in nitrogen environment, and development of servo-manipulator for hot cell applications were undertaken. Development of an eco-friendly geo-polymer-based concrete, a candidate material for the sacrificial layer over structural concrete in steam generator buildings of FBRs, is in progress.

Future FBRs

As part of continuing endeavor towards development of metallic fuels, irradiation of the sodium-bonded binary metallic fuel test pins with various compositions which had been initiated earlier continued. In addition, irradiation in FBTR of ternary metallic fuel pins has also been initiated. The fuel composition is arrived at based on requirements of future metallic-fuel FBRs. The irradiated pins have attained burn ups of 15-27 GWd/t, without any failure.

Chemically purified Strontium-89 (a bone cancer palliative), produced by irradiating Yttria pellets in FBTR, has qualified the various radio-pharmaceutical and biological quality control protocols as suggested by Radio Metallurgy Division, BARC. Further discussions towards marketing of the product through Board of Radiation & Isotope Technology (BRIT) are in progress.

Health, Safety & Environment

In the area of radiological safety, effective and efficient radiological protection and surveillance has been provided for the various active facilities at IGCAR. A retrospective dosimetry laboratory based on physical dosimetry techniques including electron paramagnetic resonance, thermal luminescence and optical stimulated luminescence has been successfully established. Methodologies are being established for dose estimation using electronic components, chip cards, finger nails and tooth enamels. Regional gamma calibration facility has provided calibration services even during the pandemic. More than 250 radiation monitoring instruments from within DAE and other organisations including hospitals have been calibrated. Gamma irradiation services had been provided using the BRIT gamma irradiators available at HSEG, IGCAR. Over 2000 samples including extractants, polymers,

special glasses, TLD materials, cables, amnion graft samples, sugarcane buds, papaya, sesame seeds, nano composites, live fishes-for studying adaptive response and bacterial colonies received from within DAE and various units of Tamil Nadu Agricultural University (TNAU), Vellore institute of Technology, Cancer Institute Adyar, King Institute Chennai, M.S. Ramaiah University etc. were irradiated.

The nuclear counting laboratory has successfully participated in the proficiency test conducted by International Atomic Energy Agency (IAEA) for the determination of anthropogenic and natural radio nuclides in water and soil samples and contaminated filter papers. An easy and simple passive sampling technique for measuring site specific carbon-14 activity has been developed and standardised. The measurements have been bench marked with the standard active sampling methods within error limits of 2%. Experiments for quantification of sodium aerosol transport through concrete blocks were conducted with various parameters to evaluate environmental source term in the case of accidents in Sodium cooled Fast Reactors (SFRs). A theoretical model has been developed based on the experimental results. The Online Nuclear Emergency Response System (ONERS) at Kalpakkam has been upgraded by developing and incorporating a Time-Varying source term module for realistic and online dispersion and radiological consequence assessment during nuclear emergencies. The new module was tested during the off-site emergency exercise at Kalpakkam.

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

Thermal-hydraulic iterations were carried out for power distribution by external coupling of FEMFOL and ARTHA for AHWR initial, transition and equilibrium core. The xenon dynamics study of intermediate core of AHWR was carried out with FEMFOLXe after introducing reactivity perturbation. It was observed that AHWR operates in stable region. A numerical model for point kinetic equations with thermal hydraulics feedback has also been developed for simulations to actually mimic the behaviour of reactor during small perturbations.

Channel power measurement technique for AHWR was demonstrated in AHWR Thermal hydraulic Test Facility (ATTF) at Tarapur. The civil construction of Containment System Integral Simulation Test (CONSIST) facility, at Tarapur is completed for AHWR containment safety related studies.

KAlpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) continued to operate successfully at a maximum power level of 30 kWt. It is serving its unique role as a facility for neutron activation studies, neutron radiography of irradiated fuels, active and inactive components, and testing indigenously developed neutron detectors. The safety control plate drive mechanism has been replaced with an improved design considering easy maintainability. The computer-based alarm annunciation and process control system has also been replaced by a new state-of-the-art system to take care of obsolescence.

Research Reactors

Dhruva reactor operated at 65% availability factor during the year and produced radioisotopes for various applications including 500 irradiated cans delivered to various users. Apsara-U was operated for

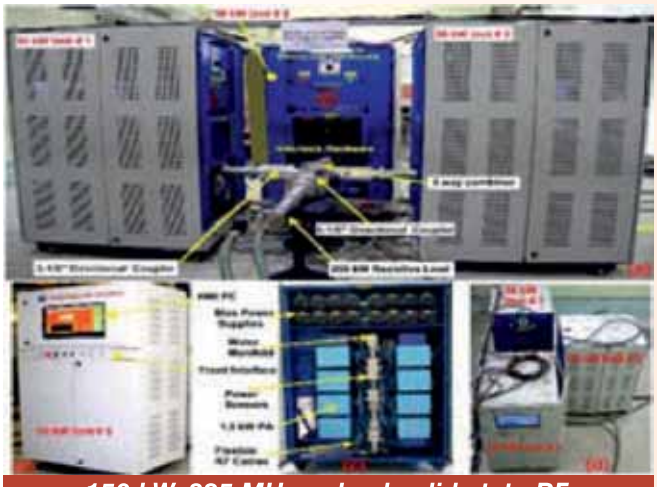
development of theranostic radioisotopes and 20 irradiated cans were delivered. Feasibility of producing Neutron Transmutation Doped Silicon and fission moly are being explored. Critical Facility for Advanced Heavy Water Reactor was operated on 52 occasions for testing nuclear detectors and neutron activation analysis.

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 150 kW, 325 MHz pulsed (2-5 ms) solid-state RF amplifier was designed and developed for RFQ, having three amplifier units of 50 kW each combined using 3-way high power RF combiner. Necessary tests like DC test, pulse characterization and high-power RF test of 150 kW solid state RF amplifier was carried out with variable pulse width from 1 ms to 5 ms, at 50 Hz of pulse repletion rate. Its pulse amplitude droop measured at 1 ms is 0.46 dB.



150 kW, 325 MHz pulsed solid-state RF amplifier for RFQ



Assembly of dressed cavity in HTS cryostat

Commissioning trials of the Horizontal Test Stand (HTS) facility for testing of dressed superconducting RF (SCRF) cavities at 2 K were carried out. The dressed cavity was integrated with the HTS cryostat and cooled in the HTS facility with liquid helium to achieve a temperature up to 1.94 K. Liquid helium was successfully transferred in both saturated liquid and supercritical mode. RF testing of the dressed cavity was conducted with unity coupler at 2 K temperature. Slow and fast tuners for the cavity were tested at 4 K and 2 K temperature.

An important milestone was achieved with successful dressing of 650 MHz, β=0.92 five-cell (SCRF) cavity in the indigenously developed controlled environment welding glove-box. The completed dressed cavity has been qualified for vacuum leak test, pressure test and RF qualification. The post dressing field-flatness is 92% (required> 90%) and change in frequency -86 kHz, within tuning range of 200 kHz.



Cavity coming out after jacketing

Tuner is a device that keeps the SCRF cavity within operating frequency bandwidth i.e tune the cavity. Lever tuner has been developed at RRCAT and it is

assembled with HB650 cavity for its qualification at 2 K temperature in horizontal test stand (HTS). The slow and fast tuners have been tested for its range 215 KHz and 3.46 kHz (100 V). The successful testing with stepper motor and piezo actuator at 2 K has paved the way for operational control of the SCRF cavity by tuner during high power testing in HTS.

The control system for HTS handles signals from various sub-system like cryostat, vacuum, radiation, cryogenics etc. The system was used successfully to test the cryogenics operation of the cryostat. As per the need to include additional signals related to 5-cell SCRF cavity and RF power coupler in the system, development of control system software & hardware was carried out for necessary augmentation.

In the post-accelerator chain of the RIB facility, two RF Re-bunchers are have been fabricated, cleaned and components have been assembled, aligned and vacuum tested at VECC. Thereafter measurement of axial field along the length of the Re-bunchers using bead-pull method was completed.

A new 2.45 GHz ECR ion source has been indigenously fabricated, installed and tested. The two ring magnets have been designed in-house and fabricated in a local. The ring magnets are assembled on water cooled; stainless steel plasma chamber connected to a beam extraction chamber. High voltage isolation between microwave generator and plasma chamber is provided by a DC break that has also been fabricated in-house. A locally fabricated waveguide coupled to an E-H tuner ensures the impedance matching between the microwave generator and plasma chamber. Typically measured beam current for Argon 1+ ions is 1.2 mA at extraction voltage of 8 kV and microwave power of 45 Watt.

A dual channel Digital RF Power Meter is designed and developed for the measurement of forward and reflected power simultaneously. The meter along with a Dual Directional Coupler (DDC) with a coupling factor around 60, is capable of measuring RF power up to 25 kW over a frequency range of 30 MHz-120MHz. The combination is tested at 37.8MHz in the RF line with amplifier at the RIB facility in VECC up to 5kW of RF power and it is found satisfactory.

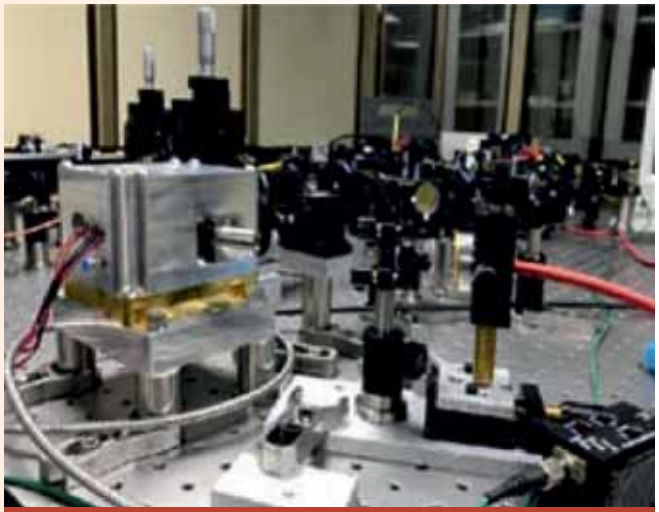
A 4/6 MeV dual energy Linac capable of imaging low atomic density materials, such as plastics and explosives, with a good contrast, was developed by BARC for cargo scanning application. The Linac was commissioned and qualified for reliable operation at 100 Hz at 3% stability.

Laser Technology Development and Applications

The following lasers and laser based systems have been developed during the period of annual report for industrial, nuclear applications and applied R&D:

An engineered version of ultra-narrow line-width diode pumped Non Planar Ring Oscillator (NPRO) has been designed, fabricated and characterized for use as a light source for 10 m arm length prototype laser interferometer being built at RRCAT for technology development and expertise building related to gravitational wave detection. The developed engineered version of the NPRO laser has a linewidth of 51 Hz integrated over a time period of 1 sec measured using the heterodyne beat frequency method, when operating at 5.5 W output power at 1064 nm wavelength.

Four numbers of high reflectivity and high laser induced damage threshold mirrors of size 125 mm x 125 mm have been developed and characterized. Reflectivity achieved is 99.8 % 0.1% at wavelength 1053 nm and laser damage threshold was found to be 1.3 J/cm2 @ 1 ns. These mirrors have been developed for



The monolithic NPRO laser system on the test table (aluminum box on the left)



The high reflectivity high damage threshold mirrors

high energy physics prototype Nd: Glass amplifier system.

100 W all-fiber Tm-doped CW fiber laser oscillator at eye-safe wavelength of 1940 nm with single transverse mode output and an optical-to-optical conversion efficiency of 35% was developed. This laser has potential application in lithotripsy, surgery and plastic welding.



100 W Tm-doped all-fiber CW fiber laser at eye-safe wavelength of 1940 nm

Development of an engineered version of 500 W all-fiber single transverse mode Yb-doped CW fiber laser at 1080 nm has been carried out with an optical to optical conversion efficiency of 70 % and M2 value of 1.26. Laser output was found to be stable within 1.5% over 1 hour of continuous operation and will now be utilized for material processing applications.

The infra-red free electron laser (IR-FEL) at RRCAT has lased at a wavelength of 28 micrometers with a maximum continuous wave average out-coupled



In-house developed 500 W single mode Yb-doped CW fiber laser



The IR-FEL setup installed inside a 60 m long and 5 m wide radiation shielded area

power of 7 mW at 2 Hz pulse repetition rate. This corresponds to a peak saturated power output 4.6 MW in 10 picosecond pulses. The IR-FEL is the first free electron laser in the country to lase and achieve saturation.

The other Laser technologies developed at RRCAT for various applications includes Laser additive manufacturing of mesh type spacers for fuel cluster simulators of 540 MWe PHWR fuel bundle using powder bed fusion; Laser cladding of SiC layers on Zircloy tubes using directed energy deposition; Providing customized FBGs to industry and research institutes for trials/qualification purposes in intended applications and Development of a 500 W average power fiber coupled pulsed Nd:YAG laser for welding of radioactive waste management canisters at BARC.

At BARC, Laser Isotope Separation of 176Yb with high selectivity was realized in Advanced Tunable Laser Application facility. Composite beams of pulsed dye lasers are used to photo-ionize 176Yb and the ions

are extracted by applying an electric field and collected onto a collector plate. Production of 3mg / hour with enrichment better than 96% from its natural abundance of 12.8% was achieved.

Electronics & Instrumentation

A safe and secure Programmable Logic Controller (PLC) was developed to mitigate the issues related to cyber security, technological denials and obsolescence. A distributed control system integrated test facility consisting of 32 Node and 9 Node NUCON-1000 PLCs interfaced with SCADA servers was setup at ECIL, Hyderabad. Validation exercise established the suitability of Secure PLC for I & C applications of INRP project and the test results were documented. ANU NISHTA for Cyber Security of C&I Systems developed by Reactor Control Division was enhanced to facilitate execution of only White listed applications on windows. Software modules for White listing of Windows applications, device drivers and integration with ANU NISHTA hardware module have been developed.

Prototype four-train Reactor Protection System (RPS) based on Diverse Modular Safety Platform (DMSP) was set up. Application program for the four trains RPS was implemented using the SPERTS framework and integrated with CPU firmware. IO simulator and Operator Information System (OIS) were implemented. Integrated four trains of RPS along with IO simulator and OIS is tested as per system validation plan.

Digital Mobile Radio (DMR) for wireless communication at security posts in BARC and Anushaktinagar were commissioned. Communication towers, repeater station, network management centre and 20 base stations of DMR Network for CISF and Anushaktinagar security have been installed. Integrated systems such as handsets, static sets and vehicle mounted sets are handed over for BARC perimeter protection. Personnel Thermal Screening System based on uncooled thermal camera was installed at BARC and DAE headquarters to screen employees' body temperature in compliance with COVID-19 guidelines. Lab prototype of face recognition based surveillance system was developed to recognize persons from videos captured in semi-indoor environment. Tests indicated 87 % TPIR on 1627 video sequences. Electric Fence Energizer was developed to generate 120 μs sharp pulses of 8-9 kV, at 0.66 or 0.33 Hz repetition rate and energizes upto 250 m of fence. This system is intended to deter unauthorized attempts of intrusion by giving a very sharp but non-fatal electric shock.

BARC developed a low noise Multi Channel Analyser for high resolution Gamma ray spectroscopy using HPGe detector. PRID is a hand-held instrument, suitable for detecting radioactive materials in nuclear & security establishments and ports, was developed to measure characteristic gamma spectra in the energy range 60keV to 3 MeV. An inbuilt isotope library enables it to identify the isotopic composition of the material.

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

Radiation induced mutagenesis along with recombination breeding was used to develop new crop

varieties. Two crop varieties namely, Trombay Linseed TL99 and Mustard TMB204 have been released and notified for commercial cultivation by Ministry of Agriculture & Farmers Welfare, Government of India. The Linseed variety TL99 is released for Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam and Nagaland. The mustard variety TBM204 with a yield of 1336 kg/ha is released in West Bengal. For popularization and supply of quality seeds to farmers, breeder seed multiplication was taken up in Trombay rice and pulses varieties. A total of 332 quintals of Trombay groundnut breeder seed varieties were distributed to 22 agencies such as National & State Seed Corporations. In biotechnological approach for crop improvement, a rapid, reproducible and sustainable micropropagation technology was developed for pineapple and turmeric. This offers a continuous source of numerous uniform sized and disease-free plantlets in a relatively short time and space and is useful for in vitro mutagenesis for generating variability. In banana, transgenic lines harbouring PVND7-Sm1 showing resistance to fusarium wilt race1 was developed.



Field view of Turmeric tissue culture derived plants

Food Technology

GRAS (Generally Recognized As Safe) preservatives used for treating mangoes to extend shelf life was approved by the US Dept. of Agriculture. A new treatment process was developed to extend the shelf life of Kinnow mandarin up to 45 days at 8±2ºC storage and relative humidity >85%. The control fruits lost 17% weight, while the treated and packaged fruits lost only 2.7%. The spice-herbal infusion BhAVI-23 comprising of 23 selected spices and herbs displayed prominent anti-viral activity as evident from inhibition of the HIV1-RT as well as through reduction in the infectivity of P1 bacteriophage as well as in-vitro anti-diabetic potential against haemoglobin glycation. About 46 compounds were detected in the dehydrated Jamun stick developed



Dehydrated Java plum (Jamun) strips with ensured safety,preserved aroma, and Extended storage life

to address perishability and limited seasonal availability of the fresh fruit.

Nuclear Medicine and Healthcare

Production & supply of medical radioisotopes and ready-to-use radiopharmaceuticals to Nuclear Medicine (NM) centres all over India continued. Except during the stringent nationwide lockdown due to COVID-19 (end of March 2020 to April 2020), radiopharmaceuticals were produced and supplied to cater to patient requirements. During the period of COVID induced lockdown, Radiopharmaceutical Program, BRIT was declared as Essential Services.

Production and supply of $^{99}Mo/^{99m}Tc$ generators was continued. Totally, 225 Ci of 99Mo activity was processed to supply 519 no. of $^{99}Mo/^{99m}Tc$ generators to hospitals across the country.

More than 40,000 cold kits (towards preparation of ^{99m}Tc, ^{188}Re and ^{177}Lu radiopharmaceuticals) were supplied to NM centres, diagnostic laboratories and research institutes throughout India.

A total of 1080 of Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits for the diagnosis of thyroid and diabetes related disorders were supplied to pathology laboratories, NM centres and research laboratories throughout India.

More than 500 Ci of I-131 products (diagnostic & therapeutic) were supplied in 4800 consignments towards treatment of thyroid related disorders.

BRIT re-launched the production and supply of I-131 therapeutic capsules (25 mCi and 50 mCi). For the first time, 100 mCi capsules were produced and supplied to the NM Centres this year.

Regular production and supply of ready to use ^{177}Lu radiopharmaceuticals viz. ^{177}Lu-DOTATATE (LUM-3) and ^{177}Lu-PSMA (LUM-5) was carried out. Around 350 consignments (60 Ci) of LUM-3 and 125 consignments (24 Ci) of LUM-5 were supplied for neuroendocrine tumour therapy and prostate cancer therapy respectively.

Other therapeutic products produced and supplied include ^{153}Sm-EDTMP, ^{177}Lu-EDTMP and ^{32}P-Sm phosphate colloid in 75 consignments totalling 6 Ci of radioactivity.

^{106}Ru notch plaque sources (developed by Waste Management Group, BARC) (n=6) were marketed and supplied to eye cancer hospitals all over India.

Around 600 batches of radiopharmaceutical samples (which includes TCK kits, ready-to-use radiopharmaceuticals injections and oral solution and capsules) and 48 batches of ^{99}Mo-^{99m}Tc COLTECH Generators were routinely analysed and certified by QC during this period.

Regular Quality Assurance was performed before the batch release of all the radiopharmaceuticals which were supplied during the reported period. Batch release certificates were issued for a total of 285 batches of TCK cold kits, ready-to-use radiopharmaceuticals injections, oral radiopharmaceuticals. This also includes radiopharmaceuticals based on Lu-177, Ga-68 and ^{99}Mo-^{99m}Tc COLTECH Generators.

Online QMS was introduced and is being followed as a pilot study since August 2019. This would be a step towards eco-friendliness by the reduction in paper work, while data retrieval instantaneously, thereby simplifying the procedure.

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, and [F-18]-FET, which are produced in smaller scales. So far ~64.5 Ci of [F-18] FDG in 164 consignments have been supplied to various hospitals in Mumbai for PET imaging. More than 15000 patients are benefitted with PET investigations in the reported year 2020-21.

Production of other medically useful isotopes (a) ^{64}Cu in the indigenously developed solid target irradiation system via irradiation of 95% enriched ^{64}Ni, and (b) ^{68}Ga via irradiation in the liquid target system via irradiation of highly enriched ^{68}Zn was carried out during 2020-21.

Production of Fluorine-18 isotope for the preparation of Fluorodeoxyglucose (FDG) was carried out successfully using Medical Cyclotron, CYCLONE-30, at Radiopharmaceutical Facility of Regional Centre (Kolkata) of BRIT located at Variable Energy Cyclotron Centre (VECC).

RC, Kolkata, BRIT, has also introduced another important F-18 product, namely, Sodium Fluoride [18F]-NaF, in the market. This product is a valuable imaging modality of the skeleton.

BRIT continued the supply of Custom synthesis and supply of 14C-labelled compounds such as preparation of Sodium acetate 1,2- C-14 & Standardization of synthetic route for the preparation of acrylic acid – 1-C-14, was completed, Custom synthesis of C-14 labelled Methylamine hydrochloride was synthesized & supplied to IIT Mumbai.

During the Year 2020-21, more than 16400 Tritium Filled Sources (TFS) sources of various sizes, shapes and tritium content were supplied to defence establishments.

Production and supply of C-14 Urea Capsules was continued for 'Urea Breath Test', useful in the diagnosis of the infections caused by microorganisms named, Helicobacter pylori, a spiral bacterium, and may be responsible for gastritis, gastric ulcer, and peptic ulcer disease.

Based on MoU between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers. All the solvents supplied had >99.8% Deuterium abundance.

A proposal is submitted for setting up of tritium gas facility at CIRUS reactor building, BARC, Trombay, and the associated work has been initiated. Design and fabrication of metal vacuum line is completed. Once this facility is ready for operation, the tritium gas handling operation related to Tritium filled light sources and tritium labelled compounds production activity will be shifted to CIRUS building.

The 30 MeV DAE Medical Cyclotron Facility became operational at Chakgaria, Kolkata on September 18, 2018 and 18F (Fuorine-18 isotope) was successfully produced with experimental production of Fluro-Deoxy-Glucose (FDG) radiopharmaceutical. VECC facilitated BRIT to start regular commercial production of FDG in June, 2020 and deliver to hospitals/ Nuclear Medicine Centers in and around Kolkata. Further, Gallium-67-citrate and Gallium-68 radioisotopes were successfully produced by BRIT from solid target of Zinc-68, on trial basis, in Medical Cyclotron Facility at Chakgaria, Kolkata.



30 MeV Medical Cyclotron at Chakgaria campus of VECC Kolkata

Radiopharmaceutical Committee of DAE (DAE-RPC) clearance was obtained for the manufacture and supply of three new radiochemicals / radiopharmaceuticals / freeze-dried kits such as No-carrier-added $^{64}CuCl_2$ as a PET radiotracer for cancer imaging; Freeze-dried HYNIC-RGD kit for the formulation of ^{99m}Tc-HYNIC-RGD dimer for SPECT imaging of cancer and ^{90}Y alumino silicate microspheres for radionuclide therapy of liver cancer. Proposals for two new radiopharmaceuticals such as freeze-dried DOTA-TATE kits for formulation of ^{177}Lu-DOTA-TATE and 'Ready-to-use' formulation of patient doses of ^{177}Lu-Trastuzumab for radio-immunotherapy of metastatic breast cancer have been submitted to DAE-RPC for obtaining approval.

Intrinsically radiolabelled $^{177}Lu_2O_3$-HSA hybrid nano-composite was synthesized with favourable pharmacokinetics and tumor regression in animals. ^{177}Lu-labeled nitroimidazole decorated gold nanoparticles (DOTA-Au-NIM) prepared for targeting tumor hypoxia showed excellent results in-vitro. An electrochemical separation technique was developed for the separation of $^{132/135}$La theranostic pair from proton irradiated natural $BaCO_3$ target.

Studies were carried out to evaluate the potential of Ubiquicidin derived peptides as infection imaging agents to elucidate mechanism of interaction with bacterial membranes. ^{177}Lu labelled antibodies and their fragments (Pertuzumab, Trastuzumab & Nimutozumab) were developed for targeting cancers and understand the mechanism of action with epigenetic drugs. Human serum albumin (HSA) nano-colloid, required for the preparation of lyophilized HSA nano-colloid kits was synthesized and delivered to BRIT for supplying as freeze-dried kits to the nuclear medicine centers.

The success of any radiotherapy for cancer treatment depends on the use of comprehensive quality assurance (QA) program. An image based dosimetry QA system for advanced radiotherapy was developed with several user interactive features to modify the input for quantitative and qualitative analysis, Physics QA module for the evaluation of radiation field size, radiation beam uniformity, radiation beam symmetry and radiation beam penumbra. The QA system is useful for clinical medical physicists in evaluating advanced treatment plans for accurate and consistent treatment delivery.

PSMA-617, a peptide based Lu labelled ligand is used in radiotherapy of prostate cancer. However, this ligand is not readily available in India. Using novel synthesis strategies such as triphosgene chemistry and coupling chemistry, BARC has synthesized upto 5 mg of the material and has been labelled with Lu-177 at BRIT. RPC approval is obtained to use it as therapeutic agent

in the treatment of prostate cancer. Two batches of 2 mg each of the NOTA-bisphosphonic acid ligand with >97% purity with application in bone metastasis have also been synthesized.

Positron Emission Tomography (PET) helps in early detection of cancer and new radiopharmaceuticals are being developed for imaging of different cancers and for radiotherapy. Clinical trials on animals are carried out at Radiation Medicine Centre (RMC) by injecting them with ^{18}F Fluoroethyl- 2-Nitroimidazole and Fluoroethylated Thymidine.

Alternative Applications of Heavy Water

In order to extend DAE's contribution towards societal benefits, HWB is shouldering responsibility for production and supply of ^{18}O enriched water of 95.5% enrichment required for PET scanning and 10% enrichment which is useful in metabolic studies. $H_2{}^{18}O$ is the precursor for generation of radiopharmaceutical ^{18}F-FDG in cyclotron which provides the images of PET scanning by radioactive decay with emission of positron. PET is a diagnostic technique used in oncology, neurology and cardiology. Nuclear grade Heavy water is used as raw material in the first indigenously developed ^{18}O production plant at HWP, Manuguru. The unit remained under steady operation during the year. First drop of ^{18}O enriched liquid of usable concentration of 97 % (w/w) was withdrawn on 21.07.2020 and 500 ml extracted for purification.



Positron Emission Tomography Setup

Cancer Diagnostics & Treatment Services

Under the cloud of fear of the unknown and ignoring the life-threatening risks during pandemic, the pan India staff of hospitals under Tata Memorial Centre (TMC) were at the forefront to treat the cancer patients. No cancer hospital or cancer centre was closed even for a single day during these trying times. This was despite the fact that many medical & non-medical staff were under quarantine due to COVID infection.

Cancer patients with COVID infection were also treated. Separate wards were created to isolate cancer patients with COVID infection from the non-COVID cancer patients. Adequate protective measures were in place and the staff in these wards were fully geared up in Personal Protective Equipment (PPE) kits. During the lock-down period in the year 2020, the patient load was markedly reduced.

At the Tata Memorial Hospital (TMH), in view of the lockdown, teleconsultation facilities were initiated and more than 900 patients availed of this facility. Over 6000 patients registered online. On the occasion of the National Sadbhavna Day (20th August), TMH launched emotional support helpline service for cancer patients in Mumbai & Pune. It was named Can-Helper, a toll-free number, founded in association with Cipla Palliative Care & Training Centre and Municipal Corporation of Greater Mumbai and the Pune Municipal Corporation.

At the Advanced Centre for Treatment, Research & Education in Cancer (ACTREC), the programs of the Cancer Research Institute's (CRI) Principal Investigator led laboratories continued during 2020.

Director TMC, Dr. RA Badwe inaugurated the Patient Registration Counter and the St. Jude India Childcare Centre at MPMMCC in 2020. The first Linear Accelerator, the second in Varanasi was commissioned in MPMMCC. The Brachytherapy services were made available at MPMMCC from July 2020. The Uttar Pradesh Chief Minister, Shri Yogi Adityanath praised the radiotherapy services offered by MPMMCC. Dental prosthetic services were introduced from the year 2020.

The Homi Bhabha Cancer Hospital (HBCH) in Sangrur saw a 3% rise in number of new patient registrations. The Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) in Mullanpur is due to be commissioned soon.

The Honorable Chief Minister of Assam, Shri Sarbananda Sonowal lauded the role of BBCI during this COVID pandemic. A fellowship in Pediatric Oncology was started from January 2020.

A Memorandum of Understanding (MoU) has been signed between Tata Memorial Centre (TMC) and the Vietnam National Cancer Hospital (VNCH) in Hanoi.

Industrial Applications of Radioisotopes & Radiation

Nine ^{60}Co-teletherapy sources with total activity of about 97.8 kCi in the range of 132 and 184 RMM were supplied to various cancer hospitals in India during the reported year 2020-21. Co-60 Irradiator sources were exported to Research & Development Centre for Radiation Technology (Vinagamma), Vietnam (350 kCi); Ansell Lanka, Sri Lanka (244 kCi) and Reviss Services (UK) Ltd., United Kingdom (499.99 kCi) during the reported period. Sixty-two W-91 Irradiator sources of industrial grade & 187 BC-188 Irradiator sources with 3508 kCi activity were supplied to 14 radiation processing plants within the country during the year 2020-21 from April 2020-Decembr 2020. Supply of Irradiator sources with total strength of 2200 kCi for eight radiation processing plants is planned upto March 31, 2021.

A total of 45 consignments (with total activity of 1492 Ci) of ^{192}Ir & ^{60}Co Radiography sources were supplied to NDT user's during the year 2020-21. Another 200 Ir-192 sources with activity 8000 Ci and 3 Co-60 radiography sources with 150 Ci is expected to be suplied up to March 2021. Nine nos. of Co-60 Custom Made Reference (CMR) sources in 318 consignments with total activity of 1.57 Ci were supplied to various users upto December 2020. Another 8 CMR sources with 600 mCi is planned upto March 2021.

Six absorber rods from RAPS (Rawatbhata Power Plant, Kota) was successfully transported to RAPPCOF. It is planned to transport 12 Adjusters from NAPS upto March 31, 2021. Fifteen numbers of neutron sources were removed from the devices at RSMS, BARC, for safe management and removal of sources stored at IFRT, Vashi Complex is planned.

BRIT has indigenously designed a Remotely Operated Tungsten shielded Exposure Device (ROTEX-I), an industrial radiography device using Ir-192 radio-isotope. The device uses tungsten as shielding material to make it compact & light weight. The fabrication of the first operational prototype of the device is completed. The device is checked for its operational functionality & shielding integrity and found to be satisfactory.

BRIT has designed a Molybdenum-99 radio-isotope transportation package. It has been designed for a maximum capacity of 44.4 TBq (1200 Ci) of Mo-99 radio-isotope. Tungsten has been used as shielding material in the package to make it comparatively light and compact. For the first time in India, the tungsten block of such big size (diameter of 210mm & 300mm long) weighing 160 kg has been developed in single piece lauding the Make in India initiative. The fabrication has been completed for the first prototype of the transportation package.

Mobile Food Irradiator (MFI), a Category-II, batch type irradiator designed to irradiate low dose food products such as fresh fruits, vegetables, cereals, pulses and medium dose food products like fish & frozen meat etc. has been conceptualized by BRIT. The irradiator will be mounted on a 40 feet trailer bed and can be moved to different places as per the irradiation schedule. The irradiator is designed for 100 kCi of Co-60 radioactive source. The Mobile Food Irradiator (MFI) has been conceived as an irradiator that can be extended to smaller districts at remote locations of India, so that it can benefit the farmers or distributor at the lower level of supply chain & storage.

A new comparatively efficient & light weight cranking unit for the safe remote operation of the indigenous industrial radiography device has been developed by BRIT. The new cranking unit is around 4 kg lighter than the existing one. It has also been ensured that the unit can be operated in any orientation with near zero slippage. The fabrication of the cranking unit prototype has been completed.

Total 577 sealed consignments of various radioactive sources were supplied through BRIT. About 112 ^{125}I brachytherapy seeds and fifteen ^{32}P skin patches were supplied to hospitals for treatment of eye, prostate and skin cancers.

Radiotracer investigations were carried out in two different glass production plants of M/s Borosil Renewable Limited, Bharuch, Gujarat. ^{140}La was used as a radiotracer to measure various flow parameters. Based on the results of the investigations, design of both the plants were evaluated and modified. In addition, the results were used to validate the computational fluid dynamics models. The radiotracer investigations helped the industry to optimize the process/operating parameters leading to significant revenue savings. Radioactive Particle Tracking (RPT) experiments were conducted for single-phase and liquid-liquid two-phase flows in a lab-scale air pulsed sieve plate column to measure local velocities, and turbulence variables. Data generated in the RPT experiments are useful for understanding local hydrodynamics and for validation of numerical models.

Many industrial components, structures and assemblies are examined by Gamma radiometry using sealed Cobalt-60 sources for thickness validation and defect localisation, particularly for components used in nuclear industry. Gamma radiometry, used for evaluating shielding integrity of a Product, Positioning and Handling Cask and Lead shielded casks were carried out at Kota.

Radiation Processing

Gamma Radiation Processing Plant at ISOMED, BRIT is being revamped and is under renovation during 2020-21. Radiation Processing Plant extended their services to irradiate about 3612 MT of spices, pet feed, ayurvedic & healthcare products during the reported time period. Radiation Processing Plant Facility at Vashi was re-certified for ISO 22000:2018. Surveillance Audits for ISO 9001:2015 Quality Management System was also carried out by certifying agency and found in full compliance with standard's requirements.

Dosimetry services during the commissioning of four Radiation Processing Plants (private vendors) for sterilization of medical products and for Class vi and Class iii food products, were completed during the reported period. Recommissioning dosimetry was carried out for two radiation processing plants. Dose rate certification was provided to three Cs-based blood irradiators and supplied to Apollo Hospital, Ahmedabad, National Institute of Immunology, Delhi and Rajiv Gandhi Cancer Institute, Delhi. Production & supply of 1.5 Lakhs Ceric-Cerous Sulphate Dosimeters was done for various gamma irradiators in the country for the measurement of absorbed dose.

BRIT signed three MoUs for setting up Gamma Radiation Processing Plants (GRPF) at various places within the country for disinfestations, shelf-life extension of food products and sterilization applications of healthcare products during the reported year 2020-21. These are namely M/s LION FOODS PVT. LTD. for setting up plant at Madhupur, Taluka: Talala, Distt: Gir Somnath, Gujrat, M/s Suzaina Foods for setting up plant at Chikhli, Navsari, Gujrat and M/s Sukshma Gamma Pvt. Ltd., Vijaywada for setting up plant at, Model Industrial Park, Mallavalli Distt. AP.

Radiation Technology based Equipment & Services

BRIT supplied 21 numbers of Radiography Cameras, ROLI-2 model (09 Nos.) and ROLI-3 model (12 Nos.), to various NDT users within India upto December 2020. Expected supply of radiography cameras upto March 2021 is 15 Nos. Inspection and services were provided for 366 numbers of BRIT and imported radiography cameras. Expected servicing for 264 radiography cameras (both imported and domestic) would be provided upto March 2021. Four Blood Irradiators-2000 units with Cs-137 source (5525 Ci) have been supplied to hospitals in India during April 2020 to December 2020 and supply of 02 units of BI-2000 is expected upto March 2021. Gamma Chamber 5000: Supply of two units of GC-5000 with Co-60 source is expected upto March 2021, while one unit of GC-5000 was decommissioned during the reported year 2020-21. Inspection & servicing was provided for eight units of GC-5000.

Water Purification, Water Desalination & Isotope Hydrology

A 1000 LPH community-scale Arsenic Removal Plant with water ATM facility was inaugurated at Ichapur Village, 24 North Parganas District, West Bengal (ground water here contains as high as 500 ppb Arsenic, way beyond the limit prescribed by WHO) on 6th July, 2020 as a part of DAE's project "Deploying Water Purification Technologies in 50 villages in India". Through 8 hours of daily operation, the plant has been providing Arsenic free water to about 400 families in 2 villages, at a daily consumption of 20 litres per family @ Rs. 5/-.

Forward Osmosis (FO) membranes based on poly (sulfone-co-amide) polymer were developed and rolled into 2512 spiral module. The membranes offered an average water flux of 20 l/hr/m2 (LMH) and with back diffusion of salt of 0.5 – 0.7 % from draw solution to the feed at standard FO condition. A process of degradation of dyesin contaminated waste water using microbubbles of ozone was developed. Apart from colour removal, removal of dissolved carbon to the extent of 75 % was attained within a short time of 5 min. Based on the successful lab trials, a bench-scale facility (2 L capacity at 30 LPH) was installed to continuously degrade dye contaminated waste water.

An isotope hydrological investigation in Tapoban-Badrinath geothermal area of Uttrakhand enabled to understand the source and origin of thermal water, and in estimatingthe residence time and reservoir temperature.

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

The main themes of research of the mathematics group at the Harish-Chandra Research Institute (HRI) were in the areas of Finite Group Theory, Algebraic Geometry, Differential Geometry, Harmonic Analysis, Lie Algebras and Number Theory.

Establishing the existence of phase transition of a model is one of the most fundamental problems in the rigorous, mathematical treatment of Statistical physics. In this work, a novel technique was developed in the particular context of phase transition for independent percolation model on general quasitransitive graphs (in particular, Cayley graphs) by TIFR.

The Institute of Mathematical Sciences (IMSc) continued the research activities in Algebra, Algebraic Number Theory, Differential Geometry, Koszul duality and the alternating Schur algebra, Modular forms, Higson-Roe sequence for transformation groupoids (Non-Commutative Geometry), Novikov's Theorem in Higher Dimensions, Representation Theory, Application of topology to complex networks etc.

Physics

At HRI, research in condensed matter systems and materials have focused on strongly correlated systems, topological materials and catalysts for energy applications. HRI have also made some progress on understanding the nature of topological phase transitions and how they can be classified in terms of known ideas from quantum critical phenomena. HRI have developed new insights into electronic structure of layered ternary transition metal tri-chalcogenide compounds. The High Energy research is primarily on beyond standard model physics searches at present and future accelerator experiments, neutrino physics, dark matter as well as Astrophysics experiments such as the Square Kilometre Array (SKA1). The contributions have come on new phenomenological studies of Beyond the Standard Model (BSM) of particle physics that involve extended scalar sectors, dark matter and supersymmetry. New ways of unravelling such scenarios at experiments using machine learning methods have been proposed. Contributions have been

made to a TDR on physics studies at a future lepton-hadron collider.

The equation of state of neutron stars has been studied with emphasis on the possible quark hadron phase transition in the core. In addition, theoretical study of Giant Dipole Resonance (GDR) width has been performed and compared with the data obtained at the VECC Cyclotron facility.

Effects of anomalous magnetic moment of quarks on the thermodynamic properties, dilepton emission and mesonic excitations of hot and dense magnetized quark matter have been investigated.

For a quantitative understanding the spread of COVID19 virus the evolution of droplets in space and time under varying external conditions of temperature, humidity and wind flow by using laws of statistical and fluid mechanics has been investigated.

The research and developmental activities carried out in the field of experimental nuclear physics included research on Wobbling in atomic nuclei, Jacobi shape transition in hot and rotating nuclei, Nuclear level density away from the β-stability line, Decay rate under compression, experiment to characterize the beams from K130 and K500 cyclotrons besides various developmental activities for physics research.

The 355 mirror panels of the MACE (Major Atmospheric Cherenkov Experiment) telescope reflector were aligned by BARC. Trial runs of the telescope with 120 panels were conducted for about 45 hours including Crab Nebula observations. The optimization of the operational parameters with 355 mirror panels and full 68 module imaging camera is in progress. Data analysis software was installed at the site for prompt analysis of results. A utility was developed to simulate the real source observation and estimate minimum time to detect various gamma-ray sources with MACE.

Exotic nuclear structures have been studied. The observation of significant cross sections for breakup of radioactive ^{7}Be nuclei clearly indicated that the ground-state of ^{7}Be can be considered as a cluster of ^{4}He and ^{3}He. Hexadecapole deformation of the light-mass nucleus ^{24}Mg has been determined for the first time using quasi-elastic scattering.

A Competing role of shell effects and entrance channel dynamics in fission fragment mass distributions of 191Au, a nucleus in the newly identified island of mass asymmetric fission in the sub-lead region was investigated. Effect of nuclear shell structure and deformation on quasi fission was studied by measuring fission fragment mass distributions of reactions ^{35,37}Cl $+^{206,208}$Pb in the Pelletron-Linac Facility. A comparative study of fission delay for the ^{16}O+^{208}Pb and ^{32}S+^{184}W reactions forming ^{224}Th at similar excitation energy has been carried out. Measurements of prompt fission neutrons and gamma ray spectra have been carried out in the fast neutron induced fission of ^{232}Th at an average neutron energy of 2.6 MeV at FOTIA, BARC.

Investigations using the INGA facility in TIFR were carried to understand the Nuclei with proton and neutron numbers between the magic numbers 20 and 28. The Indian Scintillator Matrix for Reactor Anti-Neutrinos – ISMRAN, is a large area plastic scintillator array for antineutrino measurements with potential application in reactor monitoring. A 9 x 10 matrix of 1m long scintillator bars wrapped with Gadolinium (Gd) foils having 1-ton weight has been assembled at BARC that will carry out measurements of anti- neutrinos emanating from the fission process at Dhruva Reactor.

Resolving the pore attributes of gas bearing shale formations is a key to precise estimation of the gas-storing capacity of a reservoir. Small-and wide angle scattering beamline (BL-18) at Indus-2 and reactor based ultra small-angle neutron scattering are used to quantify pore matrix roughening in Indian shale rocks.

The trace formulae discovered has been used to explain experimental results from alpha-radioactivity of even-even nuclei, pairing phase transition in tin isotopes, and temperature- and isospin-dependence of the level density parameter in mass region of 110.

Synchrotrons and their Applications

Both the synchrotron radiation sources, Indus-1 and Indus-2 were operated as national facility for the Synchrotron Radiation (SR) user community. Indus-1 was operated at the designed parameters with the beam availability of 2921 hours after restart in this period till December, 2020 for the SR users. Similarly, in Indus-2,

the beam availability was 1879 hours to the x-ray-SR users in the same period. With this performance, the projected beam availability from April, 2020 to March, 2021 is expected to be 4400 hrs for Indus-1 and 3300 hrs for Indus-2. The number of user experiments at Indus-1 and Indus-2 beamlines from April to December 2020 is 250 and by March 2021 this number is expected to cross 350.

For the upgradation of Indus-2 and other developments many activities have taken place at RRCAT these includes Development of prototype serial communication analyzer for Indus control system; Development of high-end high speed ADC card on VME64 Platform along with development environment; Design, development, fabrication and characterization of ferrimagnetic garnets for high power CW RF circulators for Indus-2; Installation, integration and deployment of 60 kW IOT based RF power system for Indus-2; Optimisation and testing of horizontal pinger magnet power supply with Pinger magnet and coated vacuum chamber; Indigenous development of NEG coated race track profile vacuum chamber for Indus-2 Undulator; Design and development of in-flange fast current transformer.

Cyclotrons & their utilisations

N4+ beam was accelerated and transported up to the extraction radius of 660 mm in the K500 Superconducting Cyclotron in the first harmonic mode. This beam trial for extraction from the cyclotron using two electrostatic deflectors and nine magnetic channels and optimization of the parameters of these elements are being done.

The room temperature cyclotron (RTC) has been operating round the clock and delivering light and heavy ion beams for various experimental research programs. The facility has been utilised by the experimentalists of VECC, SINP, ACD/BARC, RCD/BARC, HPU/VECC etc. The cyclotron is regularly fulfilling its target for beam availability and for the year 2020-21 the beam availability has been 1398 hours till December 21, 2020.

Fusion and Other Plasma Technologies

This year saw significant progress and achievements in several related areas and a plethora of activities at IPR, ITER and FCIPT. In the area of plasma-based technologies and applications at FCIPT, in line with the present demands of the CORONA pandemic and its applicability to societal benefits a portable hand held plasma sterilizer and a glow discharge-based plasma sterilizer was developed with significant success. Coupled to this were the development of nano anti-microbial coatings for its application to face masks and personal protective equipment's. The work on plasma activated water for milk industry led to microbial reductions to the tune of 71% which is a significant step in the disinfection of milk cans and fugal reductions on lemons. Plasma treatment has been successfully applied to reduce bacterial adhesions to catheter surfaces and will go a long way in the reducing catheter related and acquired infections in hospitals.

On the basic research front the studies related to emergences of inertial waves from coherent vortex source in strongly couple dusty plasmas is the highlight of the year. In the area of fusion and other plasma technologies remarkable progress was achieved in Aditya upgrade and SST-1 operations. About 85% of the peak current amounting to 212 kA and a maximum duration shot of 385 ms, 28% higher than the design value, have been achieved. In addition, repeatable 300 – 350 ms 200 kA discharges were obtained during various experimental campaigns. Plasma detachment and cold pulse propagation were observed with the injection of deuterium gas puff into ADITYA for the first time. Progress on SST-1 was marked with the energizing of one of the PF3 upper and lower coils pairs to 600 A/turn for a flat top duration of 7 sec. In addition, the recipe to achieve high pressure tests (25 bar) at elevated temperatures for components having 1 mm electrodeposited copper layers was successfully developed and will be of useful for similar components on the neutral beam systems and plasma facing components in tokamaks. A 200 kW/45 kV electron beam based high heat flux facility is operational in IPR. 27 keV 14 A H+ ion beam has been obtained for 3 sec on positive ion source based SST1-neutral beam test

stand. In the technology development front, the first indigenous cryopump with a pumping speed of 5000 l/s for air/nitrogen was delivered to ISRO Ahmedabad under an MoU.

At BARC, a triple torch air plasma gasifier of 1 ton / day capacity was developed for incineration of non-explosive and non-biodegradable solid wastes including chlorinated plastic without any harmful emissions.

Multi-filamentary Nb3Sn superconducting wires were developed using inter-tin process for National Fusion Programme. In this process, Nb and Sn filaments are embedded in a Cu matrix, and the composite goes through a series of metal working steps followed by reaction heat treatment during which Nb3Sn superconducting phase is formed.

Chemistry

Highly cross-linked polyglycidyl methacrylate (PGMA) gel capable of adsorbing Uranium from aqueous media was developed using UV polymerization. The gel brings down U in aqueous media to < 20 ppb from a feed of 1500-2000 ppb.

A novel multi-tube membrane reactor was designed with a provision for molten salt heating to enhance the HI conversion to hydrogen beyond 90%, with solar or nuclear energy as heat source. A prototype 6-tube membrane reactor was fabricated for production of 150 NLPH hydrogen up to 5 bar pressure.

Solid Polymer Electrolyte (SPE) membranes were developed with conductivity of 0.1 $S.cm^{-1}$. The membrane electrode assemblies with platinum based porous carbon electrodes are used for hydrogen and oxygen fuel cells and electrolysers. Bipolar membranes, capable of splitting water into H^+ and OH^- ions, were developed using SPEEK-PEG and anion exchange membranes. A 400 cm^2 bipolar electro-dialysis cell is developed, which can produce acid and base to concentration up to 1.7 M.

Low-cost polymer composite based ESR dosimeter containing poly (ethylene-co-vinyl acetate) and magnesium lactate for wide range dosimetry was developed. The response was reproducible over a wide dose range 80 Gy to 4000 Gy. Low weight of 50 mg and small size of 3.5 mm make it suitable for dosimetry of complex 3-D objects.

Theoretical studies were carried out to gain fundamental insight into early events in radiation damage in steel. Point defects generated during irradiation interact with various solute elements present naturally in steel, resulting in aggregation of different elements. Theoretical and computational studies were carried out to design materials or processes for CO_2 sequestration, inert gas adsorption, photovoltaic and photo-catalytic applications, ionic liquids for separation of Li ions from a mixture of alkali metals in aqueous solutions and design of suitable ligands for the separation of Zr and Hf.

The surface and depth profile of elements such as Ni, Fe, Cr, Zr, Sn and Nb in Zr-Nb(2.5%) using O^+ ion in secondary ion mass spectrometer revealed formation of secondary phase particles of $Zr(FeCr)_2$ and $Zr_2(FeNi)$ of size 1 – 20 m with inhomogeneous surface distribution for Ni, Fe and Cr. The elements Zr, Sn and Nb showed homogeneous surface distribution.

An electrochemical technique was developed to separate Pu (to the extent of 90%) from analytical waste containing U and large excess of Fe and Cr. An aqueous stable Uranyl(V) compound stabilized by di-picolinic acid was synthesized by anaerobic electrochemical process using platinum electrode at -0.9 V in aqueous medium.

BARC has undertaken a programme for production of Certified Reference Materials (CRM) for DAE and non-DAE institutes as well as for industrial & social sectors. Reference materials were prepared for evaluating the concentration of trace elements of Al, Ca, Cr, Cu, Mg, Mn, Zn and Ni in soil. Specialized analytical services were provided to various research institutes and industries across the country. These included analysis of water samples, a large number of high purity chemicals used in semiconductor industries, sulphuric acid used in submarine batteries and ferrocene used as burn rate modifiers of propellants. More than 3,000 samples with about 10,000 determinations, were analysed. A notable contribution was the analysis of helium in air samples received from thermal springs of

Bakreshwar (West Bengal) and Tantol (Jharkhand). BARC has incinerated thousands of litres of liquid organic chemicals & used machine oils and treated electronic waste.

Various synthetic organo-selenium compounds were investigated for antioxidant, radio-protection, anti-cancer and anti-viral properties.

Sorbents were developed to extract various metals such as Ga from Bayer's liquor and Cs from radioactive waste. The functionalized resin beads were supplied to HWB for testing in a pre-pilot scale column operation for Ga extraction. Fluorescence based sensors have been developed for b-Lactoglobulin, common milk allergen, amyloid fibrils, protamine, thrombin and perrhenate anion (a non-radioactive surrogate of hazardous pertechnetate anion).

Membrane - electrode assemblies were fabricated with Pt-based electro-catalysts to split water using aqueous electrolysis with Hybrid Sulfur process and produce hydrogen.

Mn coupled dissolved-ozone process was developed for decontamination of stainless steel surfaces. Mediated electrochemical oxidation for dissolution of chromium based oxides was developed and tested for TAPS decontamination. Alkylimidazolium ionic liquids with different alkyl side chain lengths were evaluated for prospective anti-biofouling formulations.

A process using functionalized CNT alginate micro beads was developed for removal of Hg^{2+} ions from waste water. A rapid spectrophotometric method was developed for the detection of total iron [Fe(II) + Fe(III)] at sub-ppb levels in the secondary coolant waters of PHWR. A glow discharge mass spectrometry method was developed to identify about 70 elemental impurities in Hf. Effluents from Be plant and water samples were treated by a method developed to adsorb Be using graphene oxide.

At TIFR, the researchers have developed the magnesiothermic defect engineering protocol to design a new catalyst system where metal nanoparticle active sites replaced with defects as catalytically active sites. This is the first metal-free-ligand-free catalyst for CO_2 conversion.

Biology

Several ingredients of Ayurvedic Kadha, repurposed drugs and chlorophyllin were found to bind and inhibit critical proteins of SARS-CoV-2 virus. The in silico work suggested that 16 FDA approved drugs and a few natural compounds could potentially inhibit key enzymes of the virus. The recombinant SARS-CoV-2 Mpro has been expressed and purified to homogeneity and crystallized for structural investigations. Chlorophyllin, a known radio-modifying agent, was found to inhibit multiplication of SARS-CoV-2 virus in vitro. In a Phase I clinical trial on healthy subjects, Chlorophyllin was seen to enhance lymphocyte counts and reduce the abundance of circulating hematopoietic stem cells in human blood. Drug Controller General of India approved for conducting Chlorophyllin for Phase II clinical trials on COVID19 patients.

Mitocurcumin, a derivative of curcumin is proposed to be an antibiotic against gram positive as well as gram negative bacteria. A multi-generation study on bacteria produced no evidence of resistance against mitocurcumin and the molecule was found to be active against multidrug-resistant strains like MRSA.

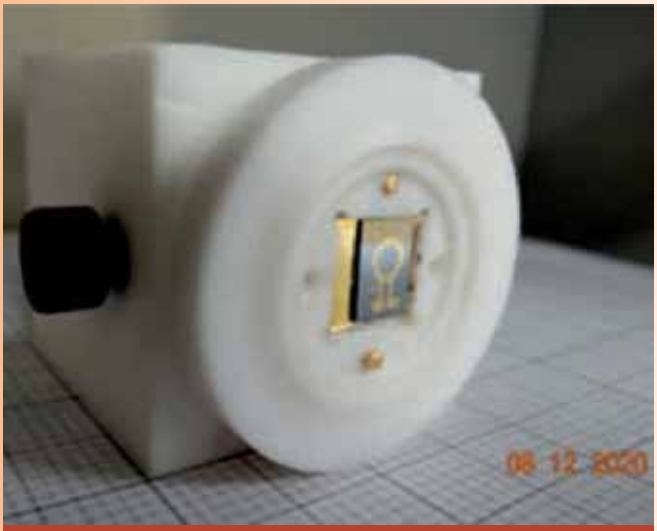
Health profiling of over 5580 newborns were carried out for various abnormalities in hospitals located in normal and high-level natural radiation areas (NLNRA&HLNRA) of Kerala coast.

The enzyme 3-chymotrypsin-like cysteine protease (3CLpro) controls coronavirus replication. Structural bioinformatics study showed potential of the fused flavonoids as anti-CLpro inhibitors in conformity with experimentally validated inhibitor N3. Moreover, in-silico ADMET study displays excellent drugability and extremely low level of toxicity of the synthesized molecules, which may pave the way for developing novel natural flavonoid based anti-COVID therapeutic spectra.

The components of Active Ingredient of Piper (AIP) betel leaves were identified for their anti-diabetic, anti-inflammatory, immune-modulatory, anti-ulcer, hepato-protective, anti-infectiveproperties. Allylpyrocatechol (APC), an active principle in piper betel leaves has excellent anti-hypertensive and cardio protective property.

Materials Science

The main activities carried out in the field of Materials Science at RRCAT were Development and deployment of customized R&D systems based on indigenously made GaAs PIN photodetectors; Development of GaAs based x-ray prototype detectors; Photovoltaic response and charge redistribution in GaAs/AlGaAs quantum wells structure; Optical characteristics of MOVPE grown GaAs micro-cavity structures; Optical spin orientation in indirect gap AlGaAs; Optimization of Molybdenum Thin Film Electrodes by RF Magnetron Sputtering for Piezoelectric Devices; Development of a compact UHV Magneto Optical Trap (MOT) by atomic beam injection; Assembly of MOT setup for atomic fountain; Adsorption and activation of carbon dioxide molecule on small Zirconium clusters and Development of fast UV photodetectors based on wide bandgap semiconductor $Mg_xZn_{1-x}O$.



An indigenously developed GaAs based X-ray prototype detector along with its spectral response



The Magneto Optical Trap (MOT) setup

A new series of age hardenable Ni-Cr-Mo alloys that are stronger than commercial Ni-alloys such as Inconel 686, Hastelloy C-276 were developed for various nuclear applications by BARC. A Patent has been filed on this development (app. no. 202021053024).

Carbon Nanotube (CNT) wool was produced by condensing CNT aerogel in floating catalyst chemical vapour deposition. Filters prepared using the CNT wool are effective in capturing bacteriophages. Polycarbosilane, a precursor for making SiC fiber, was synthesised at kilogram scale.

Design of Accident Tolerant Fuel (ATF) cladding to maintain fuel integrity for a considerably longer time during LOCA scenario is a long-term objective. High oxidation resistant Ti_3AlC_2 MAX-phase ceramic coating was developed for Zircaloy-4 flat substrate and fuel tubes using high purity powders and the feasibility of industrial scale production was demonstrated through cold spray deposition. Low Alloy Nano-bainitic steel of 1 GPa strength and ductility as high as 20% was produced in kilogram scale for important engineering applications such as in rail, defence and automotive sectors.

Stress Corrosion Cracking (SCC) of austenitic Stainless Steel (SS) is a safety issue, particularly in the case of nuclear reactor components made of this alloy. A Controlled Surface Rolling (CSR) technique was developed to minimize SCC.

Gun insulator for Scanning Electron Microscope, being developed by BARC, was fabricated by brazing alumina to various metals like SS, Kovar and Copper followed by TIG welding of two ceramic-metal sub-assemblies.

Composition of Lead silicate glasses for radiation shielding was optimised by adding suitable amount of B_2O_3, BaO and K_2O. Doping the glass by 0.1wt.% CeO_2 not only improved the transmission at lower wavelengths and but also makes it harder and radiation resistant.

An electron beam assisted environment friendly procedure is developed for preparing water-repellent fabrics without compromising the breathability and mechanical properties. The procedure involves

deposition of acrylate containing long-chain hydrocarbon on the microfibers followed by electron beam irradiation leading to covalent integration.

Cancer Research

Research activities at SINP on cancer focus via an integrated approach on the alterations in cellular architecture and metabolic reprogramming, in tandem with tumor-microenvironment interactions, which might determine the fate of cancer cells. The epigenetic reader ZMYND8 has been proposed as a candidate chemo-sensitizer for better therapeutic outcome in chemo-resistant breast carcinoma.

International Research Collaborations

RRCAT plays a major role in the development of power converters for Facility for Antiproton and Ion Research (FAIR), Germany, which is a major Indian in-kind contribution to the FAIR project. In addition to the delivery of 73 nos. of RRCAT-designed 300 A power converters to FAIR during the last year, additional 6 power converters of the same type and 48 nos. of four-quadrant, 100 A power converters designed and prototyped at RRCAT, were manufactured and tested at ECIL, Hyderabad and delivered to FAIR, Germany during this year, thus, taking the total number of delivered power converters to 127. The total 'deviation' allowed in the output current of these power converters for FAIR is ± 100 parts per million (ppm).

VECC has been participating in design & development of the muon chambers (MUCH) for the Compressed Baryonic Matter experiment at the upcoming FAIR facilities, at Darmstadt Germany. Over last one year VECC has made significant progress in R&D of both detector systems and associated services like HV, LV and Control software.

At IGCAR, Indo-UK collaborative project on Sodium Boiling and Aerosol Dynamics in Liquid Metal cooled Fast Breeder Reactor (LMFBR) has been initiated with prime objective of investigating sodium boiling phenomena towards analysis of postulated partially blocked fuel sub-assemblies in LMFBR.

The experimental high energy physics groups at IOP continued to participate in the collider-based experiments at various international laboratories, such as CMS and ALICE experiments at CERN-LHC, STAR experiment at RHIC, BNL (USA), and the proposed CBM experiment at FAIR, GSI (Germany).

ITER-Project

Indian contributions to ITER were marked with the completion of cryostat fabrication and the in-wall shield block fabrication activities. The last batch of the cryostat top lid segments was shipped to ITER in June 2020 while the one related to in wall shield blocks happened in Aug. 2020. Both these events were marked by video televised ceremonies addressed by several dignitaries in the present COVID restricted conditions and with the participation of ITER France, ITER India and the respective companies. Total 99% deliveries of components related to cooling water systems is another feather in the cap as far as completion of Indian commitments to ITER are concerned. It may be noted that in line with the 2016 ITER baseline the machine activities kick started at ITER France with the base section of the cryostat being installed in the tokamak pit as the first major component. The video televised ceremony to mark the occasion was addressed by all the heads of state of participating nations. For India the message from the honorable Prime Minister Shri Narendra Modi was read by Indian ambassador to France Shri Javed Ashraf.

RESEARCH EDUCATION LINKAGES

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

Indus -1 and Indus-2 are national facilities with 14 beamlines in Indus-2 and 6 beamlines in Indus-1. Users from different universities, national labs and institutes are regularly coming to these Indus beamlines for experiments. There has also been a significant increase in the number of users from the industry

specifically from the pharmaceutical sector, in the last few months. In view of the constraints due to COVID-19 pandemic, there have been 245 user experiments carried out in the period April 2020 to December 2020. There have been about 150 research publications in peer reviewed international journals in this period.

Dhruva continued to be the major facility for radioisotope production and served as a national facility for neutron beam research.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a Deemed to be University, is a grant-in-aid institute of the Department of Atomic Energy (DAE). It has successfully completed 15 years. During this period, it has established itself as one of the best research universities in the country, encouraging research in various facets of nuclear science and technology including mathematics. HBNI was placed in the 14th position in the Universities category, in the 2020 NIRF exercise. Based on high-quality publications during the calendar year 2019 in 82 Journals of high impact, the Nature Index 2020 has placed HBNI in the fourth position, among all institutions in India and in the top position among all institutions with regard to publications in the discipline of physical sciences.

During the period January to December 2020, HBNI awarded 81 MD degrees, 24 DM and 22 MCh degrees, contributing significantly to the number of specialists in medical oncology in the country. Till December 2020, HBNI has awarded 1730 PhD degrees in a variety of disciplines.

Training

Human Resource Development Division (HRDD) of BARC fulfills its mandate through BARC Training School (BARCTS), established in 1957 in Mumbai. It has 4 more Training Schools at - RRCAT, Indore (since 2000); NFC-HWB, Hyderabad (since 2001); IGCAR, Kalpakkam (since 2006); and AMD, Hyderabad (since 2010). They provide highly skilled human resources to DAE through two flagship programmes–OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). Linkage of BARCTS programmes with HBNI ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various units of DAE.

A total of 102 graduating Trainee Scientific Officers (TSOs) (74 engineering + 7 physics + 2 chemistry + 6 biosciences + 13 RSE), after successful completion of the training, were placed in various units of DAE. There were 6 Trainee Defence Officers, who passed out along with this batch and assigned to different Divisions/Units for pursuing MTech project.

The number of online applicants for OCES-2020 was 1,21,332 (1,40,622 last year). Only 71,341 candidates appeared the online examination (83,003 in the previous year). In order to enhance the reach, HRDD pursued its outreach programme by DAE officials visiting 68 institutes.

HRDD coordinates practical training (1 to 2 months) and academic projects (3 to 12 months) in BARC for students of BE / Btech / Mtech /ME/ MSc/MCA/JRF/SRF from all over the country. During January–December, 2020, there were 180 students from different institutes, who visited BARC for training/project work. The programme was fully stopped in the last week of March 2020 and it will be resumed on restoration of normalcy.

Due to on-going safety measures in place against the spread of Covid-19 pandemic, there was no graduation function for the outgoing 63rd batch, and induction schedule for 64th batch is inordinately delayed. With the completion of online exam process in 1st week of November, and selection interviews currently underway, HRDD is now hopeful of commencing the OCES-2020 course work by the 2nd week of January 2021, which would have otherwise commenced on August 1, 2020.

BARC Training School, AMD Campus, Hyderabad continued its activity wherein 12 TSOs of the

10th batch (OCES-2019) (10 Geology & 2 Geophysics) completed orientation training on 31-07-2020.

Twenty One young trained scientists and engineers (OCES-2019, 14th Batch) have successfully completed their orientation programme at BARC Training School at IGCAR and have been placed in various units of DAE. Also, 66 Category-I and 70 Category-II stipendiary trainees are presently undergoing class room training.

Human Resources Development activities at RRCAT revolve around imparting training to Ph.D. Scholars and M.Tech. Students from various Indian institutes. The stipendiary programme for CAT-I and CAT-II was conducted for the Scientific Assistants and Technicians. RRCAT has initiated "Trade Apprenticeship Scheme at RRCAT" abbreviated as TASAR to impart practical training to ITI trained boys and girls to expose them to modern technologies and improve their proficiency, skill and employability. About 85 candidates are being trained in current batches.

NPCIL has strong and dedicated workforce consisting of Engineers, Technicians and Supervisors, Non-Technical Executives, Staff and Auxiliary support staff who spearhead the activities of the organization. All the HR initiatives are directed towards fulfilling the NPCIL's mission and vision by attracting, motivating and retaining the right talent and intellect. While developing the strategic and incremental packages for employees, the individual goals and aspirations are encouraged by way of training culminating in achievement of goals of NPCIL.

Administrative Training Institute (ATI) with the motto of “Prashikshaneshu Dakshaprayate – Training Empowers” continued the professional development of officials from various cadres working in DAE, through a wide range of training programmes. There has been a steady growth in the number of courses being conducted and number of employees being covered. ATI has organized over 1022 programmes for over 30,100 participants till date. ATI converted the COVID-19 challenge into opportunity by exploring the possibilities of conducting online training and many programmes were conducted during the year. These programmes were immensely appreciated by the participants. Online training has facilitated ATI's mission of “reach the unreached” successfully. The participants from the distant areas were also benefitted. ATI could also avail the services of expert faculty/ professionals who were in different parts of the country. There was almost no expenditure towards TA/DA/Air fare of the faculty. This had brought down the cost incurred in training with no compromise on the quality of training.

SPONSORED RESEARCH

Promotion of Extra-mural Research in Nuclear Science

Board of Research in Nuclear Sciences (BRNS), being the extra mural funding agency of DAE, has been funding universities and research centres of the country for pursuing various research projects and for organising several scientific events of relevance to its programme. Over the years sponsoring such projects has nurtured many young members of the faculty in academic institutions and promoted research activities in topics of DAE interest in various academic and research institutes in the country.

During this year (FY 2020-21), 61 new research projects were sanctioned. All the projects entering in the final (usually 3rd) year or requiring extensions were reviewed by CDPs. In addition, 11 completed research projects were also reviewed.

In the pandemic year of COVID-19, BRNS initiated a new scheme for supporting fast track projects, for 18 months duration, targeted to diagnosis, therapy and prevention of the spread of the disease. In response to this initiative 75 project proposals were received which were evaluated by the Health Care Committee expeditiously and 9 projects were funded. They include 3 projects on diagnostics and testing, 5 projects on therapeutics and 1 project on personal protection material. The total funding for these projects has been ₹ 2.6 Crore.

BRNS Secretariat has taken an initiative for streamlining DAE-BRNS Fully Funded Symposia (DBFFS).

BRNS provides project funds for Memorandums of Understanding (MoUs) initiated by DAE institutions with the specific major objectives requiring participations of academic/research institutions outside DAE.

This year progress of 4 ongoing MoUs were reviewed by respective APEX Committees and Project Implementation Committees (PIC) of BRNS MoUs.

Promotion of Mathematics

The National Board of Higher Mathematics (NBHM) was set up by the Government of India under the Department of Atomic Energy (DAE), in the year 1983, to foster development of higher mathematics in the country, to formulate policies for development of mathematics, help in establishment and development of mathematical centres and give financial assistance to research projects and to doctoral and postdoctoral scholars.

Some of the activities of NBHM are Financial Support to Mathematical Institutions; Travel Grant/ Conference Support/ Research Project Grant; Mathematical Olympiad/ Madhava Mathematics Competition (MMC); Mathematical Training and Talent Search Programme (MTTS); Undergraduate/ Postgraduate/ PhD Scholarships, PD(F) Fellowship; Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes.

The Board has instituted several scholarships for outstanding students with a pronounced aptitude for research, studying for the Masters degree in the Mathematical Sciencs. Due to pandemic no scholarships are expected to be offered during the academic year 2020–21.

During the year, 47 candidates were selected for the PhD scholarships. NBHM awarded Post Doc Fellowships to 33 candidates out of a total of 89 applications during the year.

Institutional Support is provided by NBHM to Chennai Mathematical Institute, Chennai; Kerala School of Mathematics, Kozhikode; National Centre for Mathematics, Mumbai; Bhaskaracharya Pratishthana, Pune and Institute of Mathematics and Application, Bhubaneswar.

GRANTS-IN-AID

Grants to Aided Institutions

The aided institutions of the Department of Atomic Energy are an integral part of the Department in as much as there is a growing synergy between these institutions and the Research and Development Units of the Department. Several joint projects have been undertaken between the Units and Aided Institutions and there is frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. The Department has eleven aided institutions fully funded in terms of their recurring and non-recurring expenditure.

Olympiad Programme

India secured 1 Gold, 2 Silver, 4 Bronze and 3 Honourable Mentions in the XXXII Asian Pacific Mathematics Olympiad (APMO) 2020 and was ranked 8th among 38 countries of the Western Pacific and in Asia.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The various IT related activities that have taken place at RRCAT includes Design, development and deployment of scientific computing resources; Enhancement of RRCAT links concentrators to support predefined link selection for timeslot based routing; Commissioning of advanced security management station for vulnerability assessment of RRCATNet; Deployment of OFC Network Infrastructure Management System; Mock Drill Management System for Alarms of Critical IT Infrastructure; Design and development of a multi-channel event capturing and alarm generation system; Design, development and deployment of "e-सभा" Video Conferencing portal; Design, development and deployment of various Information Management Systems; Commissioning of multi-party voice conferencing facility and Access to e-Journal Gateway "J-Gate".

The activities related to information technology application development were recognized with IPR's

ANTYA getting the 11th position in the list of top supercomputers in India.

BARC developed and released Virtual Private Network (VPN) based secure Work From Home Facility. This infrastructure creates a VPN between the user's end point on Internet to BARC. CD also developed secure VC applications VMeet and DAEMeet for meetings–on BARC Intranet and on Anunet respectively. Computer Division also developed a robust, small form factor security appliance on VPN technology to securely access organizational resources using public network.

Secure webmail has been developed by IGCAR using open-source software to access mails from a web-browser, with OTP based two factor authentications. Further to thwart any brute-force login attacks, a CAPTCHA module was developed and integrated to the login page. IGCAR Vi-Meet desktop VC solution has been developed to facilitate conducting official video meetings securely over Internet.

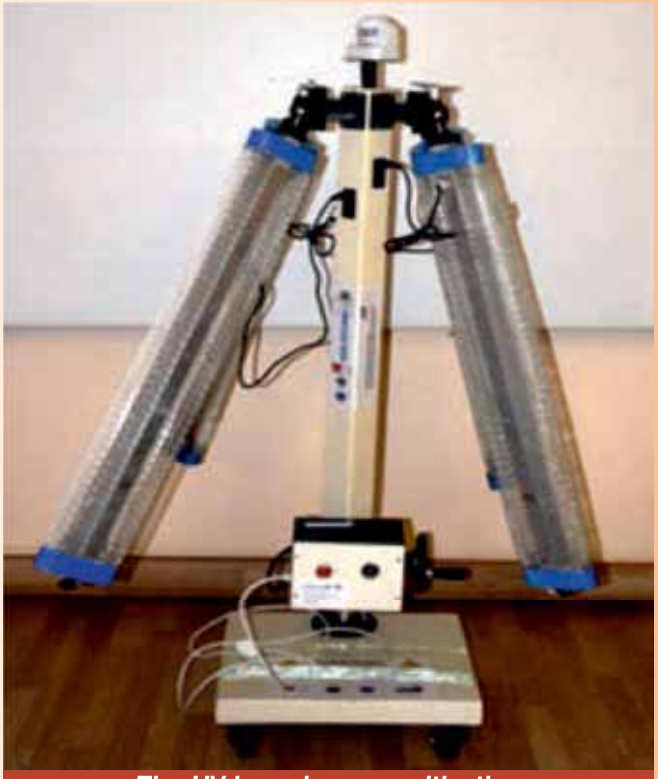
TECHNOLOGY TRANSFER

The technology of Ballistic Resistant bullet proof jacket Bhabha Kavach has been transferred to 5 companies. Public sector undertaking MIDHANI has received orders for more than 500 Bhabha Kavach bullet proof jackets. BARC handed over 55 Bhabha Kavach bullet proof jackets to CISF stationed in BARC Mumbai. The technology for on-site production of sodium hypochlorite (NaOCl), which is used as a disinfectant for COVID-19, was developed during the lockdown and has been transferred to the industry.

At BARC, forty-Six Transfer of Technology Agreements under different areas were entered into for transfer of 28 technologies.

Eighteen new technologies developed by various DAE units have been released and are available for transfer to interested entrepreneurs. Eight patent proposals were approved by TTSC for forwarding to DAE.

US patent was granted to “A novel versatile Phoswich Detector” which measures different kinds of radiation simultaneously. It was tested in Dhruva reactor beamlines and is being used in the mixed radioactive waste assay. This Technology was Transferred to ECIL.



The UV based area sanitization device (NeelBhasmi) to inactivate various micro-organisms including corona viruses

Technology Incubation Centre has been set up at DAE Convention Centre and it was inaugurated on 30th October 2020.

An advertisement of “Opacity Monitor for dust level of exhaust gas monitoring” technology was released on BARC web portal for incubation.

The spin-off technologies evolved out of the core Research and Development programmes of DAE were packaged and transferred to industries for commercial exploitation. The technologies developed by RRCAT includes Development of “NeelBhasmi” - an UV based area sanitization device to inactivate various micro-organisms including corona viruses and transfer of its technology to Indian industry; Upgradation and multi centre performance evaluation of the OncoDiagnoScope for screening of oral cavity neoplasia and SHIVAY (Sheetal Vahak Yantra): Liquid Nitrogen Based Transportable Refrigeration System.

SOCIETAL INITIATIVES

An instant method to estimate nitrite, nitrate, ammonia and total available nitrogen in soil was

developed and would be deployed for field applications though AKRUTI.

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 2020-21, three DAE-IPR cell meetings were held, which reviewed thirteen new patent proposals. By the end of the last quarter of the current FY 2020-21, all new patent proposals including three from the last financial year will be filed. This includes; eleven in India, three in USA & one in Europe. One application was filed under the Patent Co-operation Treaty (PCT). During this period, ten of the previously filed patents were granted to the Department. These includes; eight in India and two in USA.

PUBLIC SECTOR UNDERTAKINGS

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

NUCLEAR POWER CORPORATION OF INDIA LTD.

The provisional profit after tax (Total Comprehensive Income) up to December 2020 in current FY 2020-21 is ₹ 3601 crore and the estimated profit for FY 2020-21 is around ₹ 4065 crore. The net profit after tax (Total Comprehensive Income) for previous FY 2019-20 was ₹ 4339 crore. NPCIL Bonds are rated 'AAA' (Highest Safety) by CRISIL, CARE, ICRA and India Rating.

URANIUM CORPORATION OF INDIA LTD.

The total income and Profit before Tax of UCIL during the year 2019-20 were ₹ 2,419.60 crore and ₹ 596.83 crore as against ₹ 2,034.79 crore and ₹ 392.69 crore, respectively, during the previous year.

INDIAN RARE EARTHS LTD.

During the financial year 2019-20, IREL achieved highest ever sales turnover of ₹ 1038.74 crore, registering growth of 35% as compared to corresponding period of previous year. The company achieved highest ever Profit Before Tax (PBT) of ₹ 402.94 crore registering growth of 101% as compared to corresponding previous year.

During the period April to December 2020, the company has achieved Sales Turnover of ₹ 689.82 crore as against ₹ 773.21 crore achieved during the corresponding period of previous year. The Company achieved Profit Before Tax (PBT) of ₹ 253.30 crore during the period April to Dec, 2020 as against ₹ 312.68 crore during the corresponding previous year due to impact of COVID-19 pandemic.

Demand driving sector of IREL products viz Aviation, Automotive, Oil and Petroleum drilling Projects, e-mobility Robotics and Machinery severely impacted due to COVID-19. Chemical production was affected due to disruption in supply chain and closure of downstream industries.

ELECTRONICS CORPORATION OF INDIA LTD.

The Company recorded a turnover of ₹ 1639 Crore in the year 2019-20 as against ₹ 2716 Crore in the year 2018-19. Correspondingly, the Company achieved a PBT of ₹ 81.39 Crore with a PAT of ₹ 50.43 Crore against PBT of ₹ 367.03 Crore with a PAT of ₹ 242.50 Crore in FY 2018-19.

ECIL has set a target of ₹ 1640 Crore as turnover in its MOU with the Department of Atomic Energy for the year 2020-21 and has achieved a turnover of ₹ 710 Cr. till end Dec 2020.

OTHER ACTIVITIES

INTERNATIONAL RELATIONS

India, a founding member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA), continued to take active part in policy management and programmes of the IAEA. India was represented on a number of IAEA Committees, including those on safety, safeguards, nuclear radiation, nuclear engineering and application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings etc., and offered the services of its experts under the IAEA Technical Cooperation programme in a number of fields. India made contributions towards Innovative Nuclear Reactors and Fuel Cycles (INPRO), Technical Cooperation Fund (TCF) and Regular Budget of the IAEA.

Considering the primacy of the IAEA General Conference in India's international engagement in the field of civil nuclear energy, Chairman, AEC and Secretary, DAE led the Indian delegation and gave a pre-recorded video statement for delivering in the Conference.

On the sidelines of General Conference, Chairman, AEC had virtual bilateral meetings with delegations from AFCONE, Uzbekistan, France, Kazhakstan, Vietnam, U.K., Ghana and Russia.

During the period India - EURATOM Agreement was signed. New MoUs between GCNEP and AFCONE & GCNEP and M/s.Uzatom Agency, Uzbekistan were signed. Renewal of the MoU between GCNEP and USA was also done.

The Global Centre for Nuclear Energy Partnership (GCNEP) conducted International programs using virtual platform. GCNEP Phase-II construction activities are in advanced stage. Augmentation of Infrastructure facilities were carried out & setting up of SETBF (Sensor Evaluation Test Bed Facility) is in progress. Two new MoUs have been signed and two existing MoUs were renewed.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and is actively participating in their programs for enhancing the safety and reliability of nuclear power plants. NPCIL continued to provide information for IAEA PRIS (Power Reactor Information System) database.

BARC-SAFETY COUNCIL

BARC Safety Council (BSC) is responsible for safety review of all nuclear, radiological, industrial facilities of BARC. They include operating and upcoming facilities, such as research reactors, fuel fabrication, fuel reprocessing, waste management and post irradiation examination facilities; industrial irradiators; radiological laboratories; particle accelerators; and other radiological, industrial and research facilities. BSC undertakes safety regulation through BARC Safety Framework, consisting of about 90 safety committees. In the year 2020, more than hundred meetings of various committees of BSC were held.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), which is the standing Committee of senior officials of the Department of Atomic Energy (DAE), carries out the function of overseeing the Department's emergency preparedness for responding to any radiation emergency in the public domain and coordinating response actions with state or national level public officials / agencies. Testing of the formal emergency response systems on a regular basis was ensured during the year with an objective to check its efficacy. Also, CMG continued to function as the contact point of DAE to provide its expertise in the field of nuclear / radiological emergency management at various National and International fora. During the year 2020-21, India participated in three numbers of International Convention Exercises, known as “ConvEx”, conducted by IAEA, which are designed to test various aspects of the international emergency preparedness and response (EPR) framework. As the Competent Authority, Crisis Management Group (CMG) coordinated India's active and satisfactory participation in these exercises. To ensure that the emergency plans are in high state of readiness, major nuclear facilities like

nuclear power stations and heavy water plants periodically carry out variety of emergency exercises. CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Rawatbhata, Rajasthan as well as Kakrapar, Gujarat NPP sites. The exercises were found to be effective and satisfactory.

VIGILANCE

The overall responsibility for vigilance in any unit of the Department of Atomic Energy (DAE) rests with its Chief Vigilance Officer (CVO). To ensure effective functioning of the vigilance machinery a senior level officer in each of the Constituent Units and Aided Institutions of the Department has been designated as part time Vigilance Officer/ Chief Vigilance Officer. In the case of Public Sector Undertakings of the Department, full-time Chief Vigilance Officer discharges these responsibilities. The vigilance functions were continued at DAE. As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2020" was observed in DAE during October 27th to November 2nd, 2020 on the theme of "सतर्क भारत, समृद्ध भारत (Vigilant India, Prosperous India)". The week commenced by administering integrity pledge; it was displayed through DARPAN portal to the all employees of DAE Secretariat on 27.10.2020. Various competitions such as Slogan writing, Poster drawing competitions etc. were held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Prizes for the winners of the respective competitions were distributed by cash with due precautions as per COVID-19 guidelines. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance Directorate of NPCIL continued to spread awareness and to sensitize employees against malpractices and corruption to achieve organizational goals.

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.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC has subscribed to 661 online journals, 8 Standards and 12 Databases and added 488 books and 24 CDs to Library collection. Besides their availability in the BARC campus, they were also made available to the readers through the remote access facility HOoA. This facility was widely used by the scientists during the lockdown to access library resources.

IGCAR provided information resources to the scientific, academic and administrative fraternities of DAE campus at Kalpakkam, including IGCAR, BARC(Facilities), MAPS and HBNI. The Scientific Information Resource Division (SIRD) of IGCAR provided remote access to its e-resources, including the Royal Society of Chemistry, Proquest, Institute of Physics, Springer nature and Scifinder. SIRD has facilitated the Remote Access to IGCAR Subscribed E-resources (RAISE) facility through a mobile app.

PUBLIC AWARENESS

DAE along with RRCAT & HWB participated in "सार्थक Eduvision 2021", a three-day exhibition held during 15th-17th March 2021 at Bhopal, Madhya Pradesh organised by Bhartiya Shikshan Mandal. Relevant ministries of Central Government, representatives of various State Governments, Departments, Universities & Institutions showcased their activities, achievements, mission & vision in the exhibition. Eminent educationists, Students and faculties of various other colleges of Bhopal, Parents & citizens of Madhya Pradesh were the main visitors who visited DAE stall.



DAE Pavilion at "सार्थक Eduvision 2021", Bhopal, Madhya Pradesh during 15th-17th March 2021

An event was organized by Achievers Foundation, New Delhi for awareness on different Research and Development Programs of Government of India and their programs and schemes during 19th to 21st March 2021 at Rudrapur, Uttarakhand. The main theme was Atma Nirbhar Bharat (Self- reliant, India) to revive Indian economy and focus on promoting local products. AKRUTI (Advanced Knowledge and Rural Technology Implementation) Team Members from BARC participated in this exhibition. BARC scientists presented the AKRUTI Techno-preneurship program to all the visitors.

A one-day seminar on "Radiation and Environment" was organised under the aegis of the Indian Nuclear Society (INS), Hyderabad Chapter on 15th March, 2021 in the premises of Atomic Minerals Directorate for Exploration and Research (AMDER), AMD Complex, Begumpet, Hyderabad. The prime agenda of the seminar was creating and spreading societal awareness about the benefits of nuclear science and technology to mankind and removing the myths on its environmental impact. Theme specific lectures by eminent scientists and academicians, with vast domain knowledge were delivered in the seminar.

Due to the COVID-19 pandemic the 32nd DAE All India Essay Contest was organised online during the year. The notifications about the essay contest in English & Hindi inviting essays (in any Indian Language) on three different topics of Nuclear Science & Technology were uploaded on DAE website for participants. More than 700 participants sent their essays which were evaluated by the team of experts. Out of these, 30 winners (10 in each of the 3 topics) were given cash prizes of ₹ 10,000/- each. All the participants were given a certificate of participation signed by Secretary, DAE. This was the first time DAE conducted an online essay contest.

Due to recent pandemic, NPCIL adopted virtual mode of communication to reach out to the larger section of audience. Many webinars and online lectures were carried out on multiple aspects of nuclear power for wider reach. NPCIL has also used various social and digital media platforms including Facebook, YouTube, Twitter, Google etc., for sharing information related to nuclear power in innovative, interesting and lucid ways. During the period April to December, 2020 more than 20 innovative online contests were organized in which thousands of contestants participated.

SOCIAL WELFARE

Corporate Social Responsibility

NPCIL is committed to economic and social development of the local communities around all its Sites. CSR programme is implemented at the 14 Sites of NPCIL, where either the operating stations or the projects under construction are located. These Sites are located mostly in rural and underdeveloped areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme.

During the FY 2020-21, the Company allocated an amount of ₹ 95.52 Crore for implementation of CSR programme. It is a matter of satisfaction that for the last four consecutive years, NPCIL has spent more amount on CSR programme than that was mandated by Companies Act during that year.

The CSR projects have been taken up in line with Schedule VII of Companies Act, 2013 which falls in the areas of education, healthcare, infrastructure development, skill development, sustainable development.

Swachha Bharat Mission

As a part of Swachh Bharat Mission, Swachhta Pakhwada was observed in DAE headquarters from 16th February – 28th February 2021 on the occasion of World Science Day. Various competitive programmes such as Swachh Section Competition, Quiz Contest, Essay Contest, Poster Contest, Poetry Contest and Slogan Contest etc. were conducted by keeping the COVID guidelines in mind and by maintaining proper social distancing. The prizes were distributed to all the winners of the various contests and also felicitated the employees of the Department who were selected for their contribution in cleanliness.

DCSEM have engaged an agency namely Stree Mukti Sanghathana, expert in the field of domestic waste management and are in the field for last 25 years. It carried out door to door campaign and made the residents aware of the Importance of segregation of domestic waste; Various categories of domestic waste and how to handle them; How to recycle reduce the domestic waste and Ban on Single Use Plastic.



Shri K. N. Vyas, Chairman, AEC and Secretary, DAE participated in the cleanliness drive organised by DCSEM at Anushakitnagar, Mumbai

A "Certificate of Excellence" was awarded by Shri K.N. Vyas, Chairman, AEC and Secretary, DAE to RRCAT, Indore with Third Rank among all its constituent Units in recognition and appreciation of the Swachhata activities undertaken in the Centre as part of Swachhata Pakhwada.

At IGCAR, construction of toilet for contractor workers in FBTR has been completed.

At GSO, Swatchhta rallies, quiz and talks were conducted during the Swatchchta Pakhwada.

EMPLOYEES' WELFARE

The Contributory Health Service Scheme (CHSS) introduced in the Department in the year 1962 continued to provide specialised and personalised health care to its employees and the members of their family.

AWARDS & PRIZES

Several awards in areas of Safety and Performance and Official Language (OL) were bagged by various units of NPCIL and Headquarters. TAPS-1&2 has bagged CERTIFICATE OF APPERICIATION -2019 from NSC, India during the year 2020. TAPS-3&4 received Envirocare Green Award-2020 on June 25, 2020. It also won Maharashtra Safety Award Competition-2019 conducted by National Safety Council for achieving Lowest Average Accident Frequency Rate and Longest Accident Free Period. KGS-1&2 has received “Sarvashreshtha Suraksha Puraskar” (Golden trophy) NSCI Safety award - 2019 from National Safety Council, Mumbai. KGS-3&4 received “Shreshta Suraksha Puraskar” (Silver Trophy) from NSCI for the year 2019. IREL received the National Awards for Excellence in PSU, 10th PSE Excellence Awards 2019 for HR initiatives. The HWP Thal has won “Certificate of Merit” in National Safety Council Maharashtra Chapter for “Zero Accident Frequency Rate” in Maharashtra safety Award Competition for the year 2019.

CHAPTER

1



Kakrapar Unit 3 & 4 Main Plant Construction Area

NUCLEAR POWER PROGRAMME STAGE-1



Satellite Communication based Environmental Radiation Monitor (ERM-SAT)

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

Nuclear Power Corporation of India Limited (NPCIL), formed in 1987, is a Public Sector Enterprise under the administrative control of Department of Atomic Energy (DAE). NPCIL is a dividend paying company with highest credit rating of AAA by CRISIL and CARE. NPCIL is responsible for siting, design, construction, commissioning and operation of nuclear power reactors. Safety is given overriding priority in all facets of nuclear power reactors. Despite the challenging times due to Covid-19 pandemic and lockdowns, NPCIL managed to continue normal operation of its power stations. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. Narora Atomic Power Station (NAPS) Unit-2 completed 852 days of safe continuous operation on December 24, 2020 after which the unit has been taken under planned Biennial Shutdown (BSD). The continuous operation of 962 days registered by KGS-1 is second longest continuous operation in world among all reactor technologies. First pair of indigenously designed 700 MW Pressurized Heavy Water Reactors (PHWRs) at Kakrapar in Gujarat (KAPP-3&4) followed by second pair at Rawatbhata in Rajasthan (RAPP-7&8) are under various stages of construction. KAPP-3 unit achieved two major milestones namely "First Criticality" (controlled self-sustaining nuclear fission chain reaction for the first time) on July 22, 2020 and synchronization of the unit with the Grid on January 10, 2021. Second pair of Light Water Reactors (LWRs) at Kudankulam i.e. KKNPP-3&4 (2x1000 MW) are under various stages of construction. Consent for First Pour of Concrete (FPC) has been granted by AERB on November 18, 2020 for GHAVP-1&2 and subsequently first pile construction commenced on November 21, 2020 in Nuclear Building area. For Main Plant Civil Works of KKNPP-5&6, proposal for award of work is under approval stage. Application submitted to AERB for consent on FPC. Various preparatory/pre-project activities are in progress for 10 PHWRs (10x700 MW) in fleet mode towards commencement of construction of these projects.

Operating Performance

Despite the challenging times due to Covid-19 pandemic and lockdowns, NPCIL managed to continue normal operation of its power stations. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. Out of 22 operating reactors, fourteen reactors with total installed capacity of 4380 MW, are under IAEA safeguards.

Generation

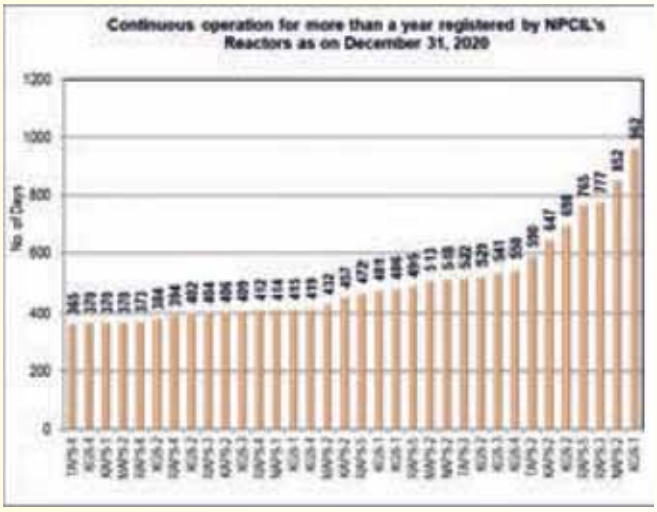
During the Calendar Year (CY) 2020, NPCIL registered commercial power generation of 44613 Million Units (Mus). In the previous CY 2019, the power generation was 45163 MUs.

NPCIL has registered power generation of 33948 MUs till December 31, 2020 in the current FY 2020-21. The expected power generation for the current FY 2020-21 is about 43000 MUs. The actual generation during the previous FY 2019-20 was 46472 Mus.

During the Financial Year 2020-21, the overall Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2020 for all the reactors in operation were 87% and 84% respectively. These figures for last FY 2019-20 were 87% and 82% respectively.

Continuous Operation for more than a year

During the Financial Year 2020-21, RAPS-5 achieved continuous operation of more than a year and registered continuous operation of 472 days on July 29, 2020 after which the unit was shut down manually for carrying out maintenance activities. NAPS-2, which registered continuous operation of more than a year in the last financial year, continued operation and registered 852 days of continuous operation on December 24, 2020, after which the unit was shut down manually for planned maintenance activities. So far, the continuous operation of more than a year has been achieved 34 times by various reactors operated by NPCIL. Out of these, four reactors KGS-1(962 days), NAPS-2 (852 days), RAPS-3(777 days) and RAPS-5(765 days) have operated continuously for more than two years. The continuous operation of 962 days registered by KGS-1 is second longest continuous operation in world among all reactor technologies.



Reactor Years of operation

Nuclear power reactors in operation registered 539 reactor years of safe operation by the end of CY 2020.

Operating Units taken in Project mode

MAPS Unit-1 (220 MW), RAPS Unit-2 (200 MW) and TAPS Unit-1&2 (2x160MW) are under long shutdown and have been taken in project mode. MAPS Unit-1 has been taken in project mode since April 1, 2018 for end shield related works. RAPS Unit-2 (200 MW) has been taken in project mode since August 15, 2020 for boiler hairpins replacement. TAPS Unit-1 & Unit-2 (2x160MW) have been taken in project mode since April 1, 2020 and August 1, 2020 respectively, for extensive inspection and repair of reactor recirculation line piping welds.

Projects under Construction

All Construction & commissioning activities were continuing till Mar 24, 2020 and thereafter due to Covid-19 lockdown, only essential activities including preservation were continuing in all projects under construction i.e. at KAPP Units-3&4 in Gujarat, RAPP Units-7&8 in Rajasthan and KKNPP Units-3&4 in Tamil Nadu. Construction activities have gradually started resuming in these project sites from May 4, 2020 onward. All efforts are being made by NPCIL to commence and speed up the project works, in line with the MoHA guidelines and permissions of the local authorities. However, considering that there are challenges in transport of materials, return of migrant skilled labour to project sites and other larger issues like stressed cash flows of contractors and suppliers, restoration of the project implementation process to its full pace may take some time.

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

These units are the first pair of indigenously designed 700 MW Pressurized Heavy Water Reactors.

In unit-3, various critical primary system testing and experiments were completed. The Unit achieved first criticality (Establishing controlled self-sustaining nuclear chain reaction for the first time) on July 22, 2020 at 09:36 hrs, which is first unit in the series of 700 MWe Indigenous Indian Pressurized Heavy Water Reactor (IPHWR). The Unit is synchronized to grid for the first time on January 10, 2021.



Kakrapar Unit 3 & 4 Main Plant Construction area

To achieve first criticality of Unit-3, many crucial activities were successfully completed in last one year, installation testing and qualification of Qualified drive mechanism units of Adjuster, control and Shut Down system (SDS-1), cleaning and drying of coolant channel, Calandria draining along with drying and Boxup, Pre Service Inspection of coolant channels, Initial Fuel Loading, Primary Heat Transport (PHT) circuit Helium leak test, PHT and moderator bulk D_2O addition, Integrated Leak Rate Test of Reactor building Containment, completion of containment filtered and ventilation system, 10 cycles of integrated fuel transfer operation were some of the Major critical activities that were completed to achieve the first criticality. Secondary side commissioning and testing of main Boiler Feed Pump, mass and alkaline flushing of secondary cycle system were successfully completed. Further, TG rotor

final alignment and TG running on barring gear was successfully achieved along with stator water system charging, generator excitation/AVR system commissioning, TG governing system commissioning and first time vacuum pulling in TG condenser.

In Unit-4, construction of Reactor Building Outer Containment dome and Natural Draft Cooling Tower (NDCT) 4A and 4B are completed. With this civil structural work is completed. In primary side, header boiler piping work was successfully completed and feeder erection work is in progress. Major PHT equipment such as bleed cooler, regenerative heat exchanger is erected.

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

These units are the second pair of indigenously designed 700 MW Pressurized Heavy Water Reactors. Civil, mechanical and electrical works are in progress.

In Unit-7, the milestone of 'Commissioning of Compressors' was achieved on September 24, 2020 and the milestone of 'Commissioning of De-mineralized (DM) Water Plant' was achieved on November 11, 2020. Service water pumps are commissioned successfully. Tube insertion in all three Condensers is completed. Installation of all Control panels is completed in Main Control Room. Installation of Reactivity Mechanism (Vertical & Horizontal) components is in progress. Physical completion and testing of PHT circuits are being progressively completed towards start of PHT Hydro Test. NDCT 7B shell concreting is completed. Construction of Sewage Treatment plant is completed. The physical progress of the unit is about 91% as on end December 2020.



Rajasthan Atomic Power Project (RAPP) - 7&8

In Unit-8, Sealing of Top Hatch Beam completed. Installation of Reactor Building Inner Containment (IC) Dome structure is completed. IC dome pre-stressing sheathing laying work and re-steel top mat work is completed and concreting started. Installation of Coolant Channel assembly is in progress. Service Auxiliary Building (SAB)-8A completed in all respect. SAB-8B all structural work completed. Placement of Generator Stator completed. Both EOT cranes in Turbine Building-8 erected and erection of roof trusses in progress. The physical progress of the unit is about 77% as on end December 2020.

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

Civil construction works are in progress. The project is making headway steadily both in civil construction and components erection.

In Unit-3, erection of dry shield and support truss are completed. Positioning of condenser hotwell and concreting of reactor cavity wall over +15 m high are completed. Completion of raft for generator transformer structures and concreting of raft of all 6 sections of caisson are completed. Erection and commissioning of fire alarm systems in Ware houses and concreting of TG deck slab in Turbine building are completed.

In Unit-4, +7.8 m slab in turbine building is completed. The physical progress of Unit-3 and Unit-4 was about 48% and 44% respectively as on December 31, 2020.



Overall view of KKNPP-3&4

Major equipment and materials like Trestle Crane, Unit Auxiliary Transformers, Transport Lock (material lock), Shock-Absorber of Spent Fuel Pool Cask Section, Cooling Pond Racks, Low-Voltage Control Devices, Tanks, Pumps, Valves, Pipelines, Filters etc. for both Units; Polar crane, valve with servomotor, Transport cask, Device for in-core Instrumentation Detectors Withdrawal, Standby Electric Feed Water Pumps, Ventilation Units etc. for Unit-3; and Main Circulation Pipeline, Generator Voltage Phase Screened Bus Duct, Thermal Insulation of Upper Unit, Control And Protection System (CPS) Drive, Air Duct etc. for Unit-4 delivered / dispatched from Russian Federation and Third Countries to KKNPP Site.

Manufacture and delivery of indigenous items / equipment, under various Packages in NPCIL scope of supply, is in progress. Plate type heat exchangers, 230 kV GIS Bays, 230kV & 400kV Capacitance Voltage Transformers, 120MT of Cable Metal Structures, 126.5MT of SS Plates for tanks, Embedded Guiding Structures (EGS) Connecting members etc. delivered at KKNPP Site.

Purchase Order (PO) placed for Supply of SS Pipelines for Mask air piping package. Development of Working Documentation (WD) is in progress.

Sanctioned Projects

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

Excavation & ground Improvement in Main plant area has been completed. Initial pile load tests along with Additional tests in Nuclear Building area and Control Building area has been completed which is required for validation of civil foundation design. Main Plant civil package has been awarded. First Foundation Pile Construction commenced on November 21, 2020 in Nuclear Building area after receiving First Pour Concrete (FPC) consent from AERB on November 18, 2020.



Foundation Pile Casting at GHAVP-1&2

Excavation completed and ground improvement work is in progress in Turbine Building area and Main Plant area (Other than Nuclear Building area). Excavation works for IDCT area are in progress.

Manufacturing is in progress for major long manufacturing cycle equipment/components like Primary coolant Pumps, Steam Generators, Calandria, End-shields, Reactor Headers, Refueling machines heads, Moderator and D_2O Heat Exchangers etc. for which Purchase Orders (POs) were already placed.

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

Pit excavation of main plant buildings and other structures have been accomplished. Subsequent activities like confirmatory geo-technical investigations at founding level, ground improvement by consolidation grouting and concrete leveling course have been completed. Application for FPC consent has been submitted to AERB and is under review. Proposal for award of work for Main Plant Civil Works is under approval stage. Besides, working drawings of major buildings foundation and structure up to ground level has been issued by the designers of Russian Federation. Long Manufacturing Cycle Equipment (LMC), First Priority Equipment (FPE) and Balance of Plant-1 (BOP-1) manufacturing are in progress at Russian Federation. Six intermediate manufacturing milestones of LMC Equipment, steam generator, condenser, turbine drive of feed water pump, deaerator and transport lock completed. Logistic contract for shipment of equipment and supplies has been invited.

AERB permission for construction of essential load pump house (UQC) obtained in May 2020.

Approval of ASE's sub-contractors for supply of equipment/ items to be manufactured in Russian Federation/ Third Countries is in progress. Submission, review & acceptance of design and working documentations under First Priority Design Works

Contract and Working Documentation Contract is in progress. Manufacturing of 12 sets of connecting members for Embedded Guiding Structures (EGS) of Sea water system completed and delivered to KKNPP Site. Tender for "Procurement of Large Diameter Stainless Steel Tanks" package opened and technical evaluation is in progress. Activities for issue of NIT (Notice Inviting Tender) for Condenser Cooling Water Pipeline are in progress.

Ten 700 MW PHWRs in Fleet Mode

Land: Land is available for GHAVP-3&4 and Kaiga-5&6. Land acquisition is in progress at Chutka site in Madhya Pradesh and at Mahi Banswara site in Rajasthan.

Rehabilitation & Resettlement (R&R): R&R colony for the Project Affected Persons (PAPs) is under construction as per approved architectural plan in respect of Chutka site. In respect of Mahi Banswara site, distribution of R&R award is in process. Tender has been floated for construction of R&R Colony for Project Affected People.

Ministry of Environment, Forest and Climate Change (MoEFCC) Clearance: MoEFCC clearance is available for GHAVP-1 to 4, Chutka site and Kaiga-5&6. Wild Life Clearance is available for Kaiga-5&6. Application for Environmental Clearance (EC) is under consideration of MoEFCC for Mahi Banswara site.

Site Activities: Reports of Geo-technical investigation works are under review for GHAVP-3&4. Placement of work order for Excavation and Ground Improvement is under process. All the scope of work of Geo-technical and Geo-physical investigation is completed for Kaiga-5&6 and tender is floated for main plant excavation work and application for Excavation consent is under review by AERB. At Mahi Baswara site, Geo-technical investigation works are in progress. At Chutka site, Geo-technical investigation works could not be taken up due to non-cooperation by villagers, which is being continuously brought to the notice of concerned authorities of MP State Government.

Siting consent from AERB: Siting consent from AERB is available for GHAVP-3&4. Siting consent from AERB is received for Kaiga-5&6.

Procurement activities: Bulk purchase Orders are placed for various quantities of Forgings for Steam Generators, Lattice Tubes and Plates for End Shields, Pressurisers forgings, Bleed Condensers forgings, tubes for 40 Steam Generators and Reactor Headers. Tendering process for Steam Generators, pressurisers, Bleed Condensers, Primary Coolant Pump (PCP) motor units, etc. is in progress.

New Projects / Sites

Future Light Water Reactor (LWR) Projects

The Government of India has also accorded In-principle approval for four sites namely Jaitapur in Maharashtra, Kovvada in Andhra Pradesh, Mithi Virdi in Gujarat and Haripur in West Bengal for setting up Nuclear Power Plants in the country with the mandate for taking up land acquisition at new Sites and Pre-project activities at all the Sites.

Jaitapur, Maharashtra: Land has been acquired. Statutory clearances are available. Techno-commercial discussions with Électricité de France (EDF), France are in progress.

Kovvada, Andhra Pradesh: Land acquisition process is in progress. Techno-Commercial discussions with Westinghouse Electric Company (WEC) are in progress.

Mithi Virdi, Gujarat: Land is to be acquired as per the new Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013.

Haripur, West Bengal: Land acquisition is contingent to initiative by State Government.

Future Pressurized Heavy Water Reactor (PHWR) Projects

The Government of India has also accorded In-principle approval for one site namely Bhimpur in Madhya Pradesh for setting up Nuclear Power Plant. At this site, commitment for water supply is to be confirmed by State Government.

Quality Assurance

NPCIL, in all its endeavours, is committed towards up-gradation and continuous improvements in Quality Management System which includes; Quality Assurance (QA), Quality Surveillance, Pre-service Inspection/ In-service Inspection and Software Quality Assurance (SQA) activities. Quality Assurance/ Surveillance (in India and overseas) activities have been carried out expeditiously for projects and stations. Pre-service Inspection/ In-service Inspection (PSI/ISI) activities of Projects/Stations has been carried out as per the Projects/Stations schedules. NPCIL continued to provide QA consultancy services to BARC and BHAVINI. SQA activities such as Independent Verification and Validation (IV&V) activities for 700 MWe projects are carried stage wise. Verifications & Validations at project site prior to KAPP-3 criticality & after up gradations of software systems at various stations are completed as per the program.

FRONT-END FUEL CYCLE

Heavy Water Production

As an industrial facility of DAE, Heavy Water Board (HWB) remains the flagship unit for enabling India's self-reliance in not only production of heavy water, which was its prime mandate, but also specialty materials which are required by other DAE Units for processing the inputs and products of nuclear fuel cycle. Going beyond the nuclear realm, HWB has also promoted application of deuterium and deuterated products in the field of technology and health care.

Activities planned during the year at the Heavy Water Plants were successfully completed in phased manner to sail through the challenging situation in the beginning of the year due to COVID-19 pandemic. The Major Turn Around schedules were stretched out to take care of delay in lining up and execution of contracts due to shortage of manpower. Though there were interruptions in receipt of material at site during lock down period, the projects/ capital scheme activities continued with the limited resources. Subsequent to easing of lockdown rules, the HWPs regained back the momentum of activities.

Heavy Water Plants (HWPs) at Hazira and Thal were in operation during the lockdown period as the connected fertilizer units were operating as part of essential services and feed synthesis gas was available to these HWPs.

HWB has achieved the production targets planned for the operating period of the year, for heavy water as well as for other specialty materials such as Boron, organo-phosphorus solvents and synthesis of D-labeled compounds.

At HWP, Tuticorin, revamping jobs for restart up of the plant are in full swing. For the Integrated Solvent Production Plant, erection work has commenced for the equipment and machineries received at site through the EPC contract. At Solvent Extraction Plant, land development, boundary wall, peripheral road and fencing work for securing newly acquired land was completed. Geo technical investigation works at site was carried out.

Heavy Water Plant, Manuguru

Major Turn Around (MTA-2020) for one stream of HWP, Manuguru was taken up in March 2020. Both streams had to be shut down in April 2020 due to COVID-19. Single stream operation continued from May to September 2020 due to paucity of manpower for carrying out shut down maintenance jobs in the other stream. Maintenance jobs pertaining to local contracts only could be initiated. The plant completed MTA-2020 activities with change in scope of work due to bottlenecks caused by COVID 19 pandemic. Common shut down activities also had to be carried out in phased manner. Operation of both streams resumed from November 2020. One of the major activities taken up during the year was revamping of five numbers of main cooling tower cells which was earlier damaged by severe gale.

Subsequent to clearance from IGCAR regarding physical and chemical quality of ^{10}B enriched pellet samples, Boron Carbide Pelletization Plant (BCPP), hot press was in operation for production of B_4C pellets of ^{10}B IP 50%. Mass production for B_4C pellets of ^{10}B IP 50% has been completed. Machining is in progress. For augmentation of production facility,

procurement of CNC machine for OD grinding and High Vacuum Induction Furnace (HVIF), Hot press, Cold Press, CNC for Face & Chamfering machines and air jet mill has been taken up. Production of Elemental Boron of IP $^{11}B \geqslant 95\%$ is completed (Two Electro Winning cells were in operation). Purification is in progress.

At ^{18}O water Plant, first drop of ^{18}O liquid was withdrawn at the usable concentration of 97 % (w/w) on 21.07.2020 and 500 ml extracted for purification. Subsequently the cascade was taken under shutdown for execution of planned modifications during Phase-II common shutdown of MTA-2020. During this shutdown, Class-III power supply facility was extended to various plant loads like 10TR chiller unit and 11TR chilled water package unit which is supplying chilled water to reflux condensers of exchange columns of ^{18}O unit.

In the Aerial Ropeway System for transport of coal from collieries to Captive Power Plant at HWP, Manuguru, there are total 250 numbers of Aerial ropeway buckets in service, In the original design, they were provided with Cast Steel wheels and they rolled on metallic track ropes. The life of track ropes was depending on the extent of wear and tear due to metal-to-metal contact of wheels with ropes. Adopting an innovative measure, HWP, Manuguru has replaced Cast Steel wheels with Poly Amide Cast Nylon Wheels (impregnated with finely dispersed powder of Molybdenum Sulphide for better lubrication). After using Cast Nylon Wheels, the operation is now very smooth and noiseless. Number of repairs on track ropes has drastically reduced, there by extending the life of track ropes, which are life line of ropeway system.

Installation and commissioning of Perimeter Intrusion Detection System (PIDS) encompassing a perimeter of 7.5 km is completed along with Security Control Room (SCR).

Heavy Water Plant, Kota

Shutdown of the plant was taken on account of COVID-19 pandemic as directed by Government. Plant re-startup activities commenced in mid June 2020. This period was utilized for carrying out planned maintenance activities. Plant implemented several improvisations and improvements during the maintenance period which included incorporation of numeric relays for the five numbers of HT motors of all the H2S gas boosters thereby replacing the old electromagnetic relays. This has enabled isolation of faulty equipment in minimum time thereby reducing damage. LASER alignment technique was adopted in place of conventional dial gauge for accurate alignment of motor with pump thereby enhancing overall performance of equipment. Soft starters for motors were installed to avoid motor failure due to high starting current.

Sodium Sulphate Crystallizer unit continued to operate to produce saleable quality of sodium sulphate crystals. Sale order for 100 MT of Sodium Sulphate Crystals was executed in July 2020.

Heavy Water Plant, Hazira

The plant was in regular operation including the period of lockdown due to COVID-19 pandemic, as the feed synthesis gas continued to be supplied by the connected fertilizer plant as part of essential services. There was a small interruption in operation on 24.09.2020 when both plants stopped because of low NG supply pressure from M/s GAIL due to fire incident at Hazira ONGC terminal.

In spite of manpower restrictions, the plant continued with the operation and maintenance activities like replacement of leaky tube bundles of Ammonia evaporator 14S3A with newly re-tubed tube bundle in July 2020. The catalyst tubes of Main and Mini Cracker of Plant B had completed one lakhs hour in May 2020. As per the requirement of latest Code of Practice for ISI of HWPs, one tube (Tube no. 65) was removed in June 2020 for detailed mechanical and metallurgical testing. Based on the test result the service life of Cracker tubes of Plant B has been extended to 1,20,000 hours.

Heavy Water Plant, Thal

As the feed synthesis gas continued to be supplied by the connected fertilizer plant as part of essential services, plant operation continued normally during the period of lockdown on account of COVID-19. In the beginning of June 2020, the coastal part of Maharashtra suffered extensive damage on account of

cyclone Nisarga. HWP, Thal being situated in this region, both plants were shut down and the planned jobs were suspended. All proactive measures were taken to handle the situation like checking important communications like phones, mobiles, siren and PA system, hooking all EOT cranes at extreme top point and kept energized, keeping charged all battery operated lights in control room, filling diesel in DG sets, keeping all storm water drain channel valves in open condition. No movement of persons and vehicles were allowed during cyclone. These measures resulted in negligible damage to plant machineries, equipment and structures.

Due to installation of Gas Turbine in Ammonia Plant of RCF, Deuterium concentration in the feed synthesis gas has come down. Ingress of oxygenated impurities like CO/CO_2 in feed synthesis gas necessitated higher consumption of potassium amide for purifying the gas and also resulted into lower processing rate and in turn lower production rate. Due to sustained efforts and pursuing with RCF, this long persisting problem has diminished and feed processing rate has been normalized.

Heavy Water Plant, Baroda

Tri-butyl Phosphate (TBP) plant and Potassium metal plant were in regular operation meeting the set production targets. About 35 MT of TBP was dispatched to NFC and 3 MT was dispatched to UED, BARC. MoU with NFC for supply of TBP was renewed for another ten years.

At HWP, Baroda, test operation of various configurations of 2kA electrolytic cells have been carried out to generate operational data and 24kA prototype cell is planned to be operated next. The assembly of 24kA prototype cell has been completed and power unit of rectifier system has been installed. Construction of industrial scale production plant of 600 MTPA Sodium metal is initiated at HWP, Baroda.

From July, 2013 to July, 2019, five nos. of 2kA capacity closed Sodium production test cells of different configurations have been fabricated and operated at HWP, Baroda. Various parameters including type of anode, diaphragm, eutectic composition, anode-cathode distance, current density etc. have been finalized. Operation of these test cells has produced around 6.9 MT of commercial grade Sodium metal. This Sodium contains more than 99.9% of Sodium metal with major impurities like oxides of Sodium and Calcium, Carbon, Iron, Magnesium etc. These impurities are required to be brought down to acceptable limit for producing nuclear grade Sodium metal. Technology for the same is not available on transfer from any industry or research organization. Sizes of equipment i.e. vessels, pipelines, spargers and process data are not available in literature or patents available on internet and were completely developed by HWB.



Rectifier for 24kA Prototype Sodium Cell at HWP, Baroda

To demonstrate and complete the entire cycle of production of commercial grade Sodium metal and purifying it further to nuclear grade for departmental use, a Bench scale Sodium metal Purification unit (BSPU) was set up at HWP, Baroda of capacity 400 ltr of Sodium metal per batch. In this regard, FRTG (IGCAR) was also consulted regarding safety related to Sodium metal handling and necessary design features required for smooth and safe operation of purification unit. This unit was mechanically completed by October, 2019. Subsequent to purification process, 3.0 MT of nuclear grade Sodium metal was dispatched to IGCAR on September 26, 2020. This was a significant achievement of HWB towards making the Stage 2 of INPP self-reliant.

HWP, Baroda continued to synthesize several deuterated versions of Chloroform, Methanol, DMSO, Methyl Iodide, Acetone & Acetonitrile and Benzene using conventional and innovative methods as a part of developmental activities on alternate application of

heavy water. These are sent to BRIT (Mumbai) for marketing. The purity and deuterium content of 99.8% in organic deuterated solvents produced meet international standards and are well accepted by the users.

HWP, Baroda had succeeded in synthesis of Deuterated Methanol from CD_3I route from Tri- Methyl Sulphoxonium Iodide. Though product purity was of IP > 99.5%, this method for synthesis of CD_3OD has very low yield (6%) making it non-economical. Further trials on other routes of synthesis were carried out and it was decided to take up synthesis of CD_3OD from gas route reaction of CO and D_2 gas in presence of CuO/ZnO catalyst at 45-50 kg /cm^2 pressure and temperature 250-270°C. A test reactor was built indigenously with expertise available at HWP, Baroda & operated. GC-MS analysis of this crude product indicated that it was a mixture of different hydrocarbons containing approximately 43.0 % of CD_3OD (Chemical purity). This was further purified using spin band distillation system available at HWP, Baroda. Final product obtained had the desired isotopic purity of Methanol-D4 (chemical purity >99.5%, isotopic purity 97%).

Production of these solvents and marketing through BRIT has substantially reduced their market price, benefiting more than 300 NMR users in India who were dependent on import of these solvents.

Heavy Water Plant, Tuticorin

After resumption of stable operation of M/s. SPIC and assurance of M/s. SPIC on ensuring availability of synthesis and natural gas to the HWP at Tuticorin, revamping jobs for targeted restart up of the plant are in full swing. Two other industrial scale projects are also being set up at HWP, Tuticorin viz Solvent Production Plant (SPP) and Solvent Extraction Plant (SXP).

Solvent Production Plant is being set up for the production of organo-phosphorus solvents like TiAP, DHOA, D2EHPA-II, TBP & TOPO. The design of the plant is based on the operating experience of Versatile Solvent Synthesis Plant and TBP plant of HWP Baroda. Supply of all major equipment, vessels, tanks, pumps, pipe & pipe fittings were completed. Erection of critical



Integrated Solvent Plant, HWP, Tuticorin

equipment like Glass Lined Reactors and Nickel Clad Reactors was completed. This was followed by load testing of EOT crane as per AERB requirement. Work order for civil work on foundation for raw material storage facility was placed.

Solvent Extraction Plant is being set up at HWP, Tuticorin for recovery of rare material from Phosphoric acid to be sourced from M/s. Green Star Fertilizer Limited (GSFL), a nearby Fertilizer plant. The consultant M/s MECON has submitted the preliminary deliverables i.e. Preliminary Review Report of P&I Diagram, Vendor list (first issue), Time schedule bar chart & Project progress reports which were reviewed and finalized. Design Basis Reports and engineering documents were finalized for SXP- GSFL & SXP- HWP, Tuticorin interconnection pipe lines. Geo-technical investigation works in newly acquired land for SXP field work is completed. Siting consent from AERB has been received in September 2020.

Activities on common facilities like installation of biometric access recording for server room, Up-gradation of Process Control & Analytical Lab. of Main Plant, maintenance and upgrading of fire fighting and prevention system, sewage treatment plant were taken up and completed during the period.

Heavy Water Plant, Talcher

At HWP, Talcher, subsequent to ease in COVID-19 lockdown, the TBP production facility operated continuously to meet the targeted production. The plant produced the targeted ^{10}B IP >90% enriched BF_3 Di-ethyl Ether complex in the Boron Exchange Distillation facility. About 100 kg of enriched KBF_4 (^{11}B IP>95%)

was produced in KBF_4 conversion Unit of which 75 kg was dispatched to HWP, Manuguru for further processing. The target of production of ^{10}B IP 65% KBF_4 has also been met.

For obtaining consent for commissioning & operation from AERB for the BF_3 Gas Generation and Bottling facility all requisite documents including additional data desired by AERB has been submitted.

The dismantling of Heavy Water Main plant has commenced from 31.10.2020. Dismantling work for the equipment at the ground level like towers & structures, heat exchangers, transformers, motors and piping are in progress.

For synthesis of Calix Crown – 6, trial batches in laboratory as well as R&D Pilot Plant in 50 lit. glassware set up using the raw material supplied by BARC, is in progress for meeting the requirement of Waste Immobilization Plant, BARC.



Glassware set up for synthesis of Calix Crown-6 in Pilot Plant, HWP, Talcher

Calix Crown-6 (CC-6) is being deployed at Waste Immobilization Plant (WIP), BARC, Trombay for recovery of Cs-137 from Medium Level Waste (MLW) for production of Cesium pencils and waste management. Intended requirement is around 100 kg of CC-6 for 5 year operation in WIP. To counter the high cost of the commercially available material, HWB took up the task of in-house production of CC-6.

CC-6 synthesis is a multistep process involving condensation reaction between p-phenol and formaldehyde to give a cyclic tetramer, till the last reaction where PEG-di-tosylate reacts with 1,3-di-n-octyloxycalix arene (Calix-3) in the presence of Cs_2CO_3 to yield Calix Crown-6. In HWP, Talcher PEG-di-tosylate was synthesized and reacted with Calix-3 to form CC-6 followed by its purification. Yield was enhanced by 30% after improvisation of the process by optimization of solvent quantities and reagents involved and better temperature control during both the reactions. Yield as high as 80% could be achieved. The cost of in-house production is less than the commercially available product and quality of the product has been found suitable by WIP, BARC.

Technology Demonstration Plant

HWB has now ventured in to new technology demonstration initiatives viz. recovery/ production of Gallium, Cobalt, Helium gas and Hydrogen. Facilities for the same are set up at the Technology Demonstration Plant (TDP), Mumbai and a brief on the activities at TDP for the new initiatives are as given below:

Extraction of Gallium

Gallium is widely used in production of semiconductor compounds, LED, Solar Cells, Magnetic Materials and Nuclear industry. During the process of recovery of Aluminium from bauxite ore, the Bayer Liquor gets concentrated with Gallium (100 to 125 ppm) which can be recovered.

NALCO, one of the largest Aluminium producers in the country has entered into an MoU with BARC for developing technology for recovery of Gallium from Bayer's Liquor. BARC has developed an Ion Exchange process for recovery of Gallium from Bayer's liquor involving use of specialized Amidoximated resins. HWB has set up pilot plant at TDP, Mumbai to develop skid mounted unit for NALCO. Presently HWB is carrying out column experiments with functionalized resin having improved mechanical strength which is supplied by BARC. Separation of Gallium from Aluminum and Vanadium has been achieved. It is planned to study feasibility of functionalization of resin at bigger scale (20 L batch) and re-functionalization of spent resin. Accordingly, a skid mounted Pilot Plant will be developed at TDP, RCF-Chembur, which shall be a precursor for the Technology Demonstration Plant for Gallium recovery in NALCO, Damonjodi.



Setup for extraction of Gallium at TDP, Mumbai



Setup for recovery of Cobalt, TDP, Mumbai

Recovery of Cobalt

Another new initiative being taken up at TDP, Mumbai is recovery of Cobalt from spent Ammonia Cracker catalyst, for which experiments were done as per BARC developed hydrometallurgical process. The process involves leaching, solvent extraction and ion exchange. In the Cobalt facility which was shifted from BARC to TDP, first batch of Cobalt Oxalate precipitation was achieved in June 2019. Similar process can be used for recovery of valuable metals from the voluminous amount of MDN alloy scraps generated at MIDHANI (Mishra Dhatu Nigam Limited). The MDN alloy has high concentration of Cobalt and Nickel. It is planned to have a tripartite MoU between MIDHANI, BARC and HWB for processing of their alloy scrap. BARC demonstrated the process at laboratory scale using separating funnel in July 2020. HWB has started to process MDN scrap obtained from MIDHANI for demonstration of cobalt recovery process at TDP on bench scale using mixer settlers.

Recovery of Helium from purge gas

Helium is a valuable inert gas finding significant use in DAE in the processes of fuel fabrication, reactor cover gas system, cryogenic system and leak detection. Helium gets concentrated in the purge gas unit of the Ammonia plant of Fertilizer industries. To assess the prospects of Helium recovery, mapping was carried out by HWB over a period of year in Purge Gas stream from the ammonia based fertilizer plants at GSFC, Baroda, RCF, Chembur & Thal Units, KRIBHCO, Hazira and TCL, Babrala. Helium content was found to be varying from 0.1% to 1.5%. Two processes for Helium recovery are being pursued, one in collaboration with BARC and other with ONGC.

Heavy Water Upgrading plant (UGP) was operated in round the clock shifts during nationwide lockdown. UGP control room was revamped with state-



Vacuum evaporator for sump liquid Clean-up system in UGP



Solid Polymer Electrolyte based Electrolyser used for bottom reflux generation in CECE process

of-the-art facilities for plant operation. A tank type vacuum evaporator and horizontal condenser were installed to recover reactor grade heavy water from high conductivity and high isotopic purity liquid from heavy water upgrading column re-boiler sumps. The system has performed as per design specification and reduced locked-up heavy water inventory in the plant.

Demonstration facility for Combined Electrolysis and Catalytic Exchange (CECE) process for enrichment of hydrogen isotopes was commissioned. Solid Polymer Electrolyte based electrolyser generates bottom reflux in the process, whereas the top reflux is being provided by fresh DM water. Extended trial runs have been carried out in campaign mode for testing the electrolyser performance. Based on the experience, a prototype has been designed and is being installed for decontamination and recovery of valuables from reject heavy water stream of Upgrading plant.

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 2019-20 (November 2019 to October 2020), integrated multi-disciplinary approach has been adopted for uranium exploration with substantial inputs of radiometric, geological, ground & heliborne geophysical, geochemical surveys and drilling (Departmental and Contract). These activities have resulted in augmentation of in-situ resource.

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

In addition, pegmatite belts of Chhattisgarh, Odisha and Karnataka have been explored for augmentation of rare metals and rare earths resources. Besides, the Ambadongar Carbonatite Complex, Gujarat and Siwana Ring Complex, Rajasthan are being explored for REE and Nb resources. The coastal stretches of the country have been explored for augmentation of economic heavy mineral resources.

All the laboratories at AMD Headquarters and Regional Headquarters have been utilised to their full capacity and have contributed actively by providing speedy analytical support to the ongoing exploration programme.

Some of the significant achievements are summarised below:

Uranium Investigations

Geological and radiometric surveys

Reconnaissance (5,945 sq km) and detailed (305 sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

Kangra Sub-basin, Siwalik Group, Hamirpur district, Himachal Pradesh: Sandstone hosted at Masanbal – Biru- Paniali – Nalti tract.



Secondary-U associated with carbonaceous matter in sandstone (Siwalik Basin) along Panav-Satyani Rao tract, Saharanpur district, Uttar Pradesh

Basement crystallines, Anantapur district, Andhra Pradesh: Sheared granite hosted at Peddapalle, Pandulakunta, NE of Jinadalakunta and NW of Kottapalle Tanda.

Dirang Formation, Lesser Himalaya, West Kameng district, Arunachal Pradesh: Sericite quartzite and carbon phyllite hosted near Main Central Thrust at Kharka.

Chhotanagpur Granite Gneiss Complex (CGGC), Balrampur district, Chhattisgarh: Pegmatite Leucosome Mobilizate (PLM) hosted at Dumarpan, Randah and Kundru-North.

Basement Inliers within Chandrapur Group, Bargarh district, Odisha: Fractured/brecciated (Sambalpur) Granite hosted at Jaypur area.

Besides, surveys for helium exploration in Bakreshwar - Tantloi tract, Birbhum district, West Bengal and Dumka district, Jharkhand has indicated up to 0.65% and 0.28% helium in spring water and soil gas samples respectively.

Geochemical Surveys

Geochemical surveys (4,563 sq km) have delineated anomalous hydrogeochemical zones up to 107ppb U and 2,254 ppb Li along Udesar Doli Nerli Timri tract and up to 190ppb U and 3,460 ppb Li around Ghuriyala – Ajbawaton ki Dhani – Bhenaniyon ki Dhani - Judiya tract near the confluence of Saraswati Palaeochannel and Luni River, Jodhpur and Barmer districts, Rajasthan. Values up to 246ppb U and 68ppb U have been analysed along Talupur - Kalichedu tract, Nellore district, Andhra Pradesh and around Juba, Mahasamund district, Chhattisgarh respectively.

Ground Geophysical surveys

Ground geophysical surveys (Regional: 605 sq km; detailed: 342 sq km) have been carried out in potential geological domains of North Delhi Fold Belt, Banded Gneissic Complex, Jahajpur and Vindhyan Basins, Rajasthan; Chhotanagpur Granite Gneiss Complex, Jharkhand; Khairagarh Basin, Maharashtra; Chhattisgarh Basin, Chhattisgarh; Bhima and Kaladgi Basins, Karnataka.

The geophysical surveys have delineated potential high chargeability- low magnetic – low resistivity zones towards north of Rajpura (NDFB), Sikar district, Rajasthan; Great Boundary Fault (GBF), the contact between Vindhyan sediments and Jahazpur Group / Berach Granite in Barliyas-Motipur-Malikhera area, Bhilwara district, Rajasthan; the strike extension of shear/fracture zone with low resistivity and high chargeability in the east of Kanchankayi; unconformity contact between Bijli Rhyolite and Bortalao Sandstone and litho-contact between Bortalo Sandstone and Sitagota Basalt in Bijepar-Ramatola area, Gondia district, Maharashtra.

Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 36,392 line km in parts of North Delhi Fold Belt, Rajasthan & Haryana and Chhotanagpur Granite Gneiss Complex (CGGC), parts of Jharkhand, Uttar Pradesh, Madhya Pradesh and Chhattisgarh.

Ground validation of AGRS data delineated anomalous radioactivity in borewell water near Sewa ki Dhani village in Alwar Basin, Rajasthan. Six (06) discrete curvilinear conductors have been delineated in CGGC terrain. A discrete conductor coincident with the zone of high uranium concentration has been delineated over a length of 8 km near Jhapar, Balrampur district, Chhattisgarh and Sonbhadra district, Uttar Pradesh. Potential targets for subsurface exploration along the



Unconformity contact between basement granite and overlying quartzite (Gulcheru) in Dhone – Kottapalli sector, Kurnool district, Andhra Pradesh



Calibration of instruments before heliborne geophysical survey in CGGC terrain from Miyurpur helibase, Sonbhadra district, Uttar Pradesh

contact between basement granitoids and Gulcheru Quartzite have been delineated near Dhone - Venkatapuram, Kurnool district, Andhra Pradesh.

Exploration by Drilling

A total of 1,86,380m (Departmental: 76,702m and Contract: 1,09,678m) drilling (reconnoitory, exploratory and evaluation) has been carried out to establish (a) additional uranium resource in the known deposits and (b) sub-surface continuity of mineralisation in the new promising areas.

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

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

Loharkar, Hamirpur district, Himachal Pradesh: In sandstone/conglomerate along Middle and Upper Siwalik transition zone.



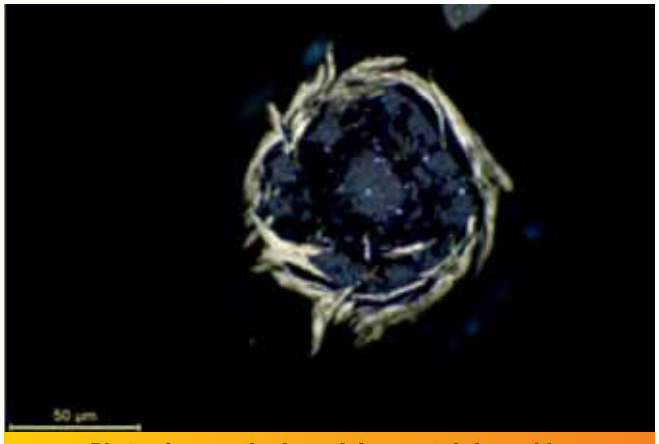
Borehole core of leucosome part of migmatite (CGGC) with uraninite grain showing radiation cracks, Kurludih area, Balrampur district, Chhattisgarh

Tummalapalle sector, Kadapa district, Andhra Pradesh: In Vempalle Dolostone at Motunutalapalle, Tummalapalle-I and Kanampalle.

Kanchankayi East - Hulkal, Yadgir district, Karnataka: Associated with brecciated limestone in the eastern extension of Kanchankayi uranium deposit.

Gujanal - Ankalgi, Belgavi district, Karnataka: Associated with conglomerate proximal to the unconformity contact.

Singhbhum Shear Zone, East Singhbhum and Seraikela-Kharswan districts, Jharkhand: Associated with sheared quartz-chlorite-sericite schist at Narwapahar Deep, Rajdah, Jaduguda (North), Baglasai-Mechua, and Nimdih-Bhatin blocks. Altered peridotite-hosted uranium mineralisation was intercepted in boreholes at Kudada.



Photomicrograph of uraninite crystal rimmed by pyrite in radioactive serpentinite sample from Kudada area, East Singhbhum district, Jharkhand

Rohil and its extensions, Sikar & Jhunjhunu districts, Rajasthan: Associated with albitite zones in North Delhi

Fold Belt (NDFB) along Rohil Central & West blocks, Narsinghpuri, Jahaz, Geratiyon ki Dhani, Ladi ka Bas and Sefraguwar.

Umra, Udaipur district, Rajasthan: Associated with carbonaceous phyllite of Aravalli Supergroup in Umra NE extension area.

Sarangapalli, Guntur district, Andhra Pradesh: Associated with Basement Granite / Banaganapalle Quartzite of Kurnool Group in Palnad Basin.

In addition to the above, potential/significant blocks have also been taken up for sub-surface exploration at Badoh Gagret Ambota, Una district, Himachal Pradesh; Mangalpurwa, Chhatarpur district, Madhya Pradesh; Mallabad Yevur Chyamnal, Yadgir district, Karnataka; Bajhiwala ki Dhani and Chaukri areas, Sikar district, Rajasthan; Thatra, Sehra Sonari and Sabraoli areas, Alwar and Dausa districts, Rajasthan; and Pavati Selpur area, Udaipur district, Rajasthan.

Rare Metal and Rare Earths (RMRE) Investigations

Reconnaissance (745sq km) and detailed (7 sq km) surveys have been carried out for identification and evaluation of Rare Metals and Rare Earths resources in Chhattisgarh, Madhya Pradesh, Odisha, Rajasthan, Gujarat and Karnataka.

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

A total of 7,988 m drilling has been carried out for RMRE in Allapatna-Marlagalla sector, Mandya district, Karnataka; Ambadongar, Chhota Udepur district, Gujarat and Siwana Ring Complex, Barmer district, Rajasthan. Spodumene bearing pegmatite bodies have been delineated over 440m strike length in Allapatna-Marlagalla sector. Strike continuity of REE mineralisation in microgranite dykes has been established over 750m at deeper level in Bhatikhera, Siwana Ring Complex, Rajasthan.



Spodumene crystals (green) in core sample (Pegmatite) from Marlagalla area, Mandya district, Karnataka

3,46,462t Rare Earth Oxide or 95,140t REO (at 2% REO cut-off) and 19,564t Nb_2O_5 (Rare Metal oxide) resources were established at Ambadongar Carbonatite Complex, Chhota Udepur district, Gujarat. Additional resource of 2,078kg of columbite-tantalite was estimated by detailed surveys and assessment of pegmatites near Marlagalla, Mandya district, Karnataka (816 kg) and in pegmatites in the southwest of Jangapara, Jharsuguda district, Odisha (661 kg); Nawatola (297 kg) and Jogiyani (304 kg), Surajpur district, Chhattisgarh .

Beach Sand and Offshore Investigations

Survey (Reconnaissance: 307 sq km and detailed: 13.565 sq km) and prospecting (drilling, sampling and evaluation) were continued along the coastal tracts of Andhra Pradesh, Odisha and Tamil Nadu to establish additional beach sand mineral resources.

Exploration/Evaluation

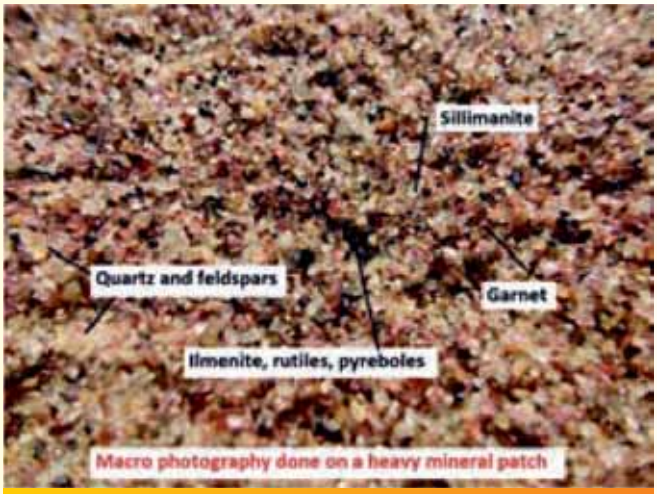
Conrad bunka drilling has been carried out in 1,292 boreholes with a cumulative depth of 6,010m and 4,156 samples have been generated.

The following potential Total Heavy Mineral (THM) zones have been delineated:

Sana Arjapalli-Agastinuagaon (up to 72%), Ganjam district, Odisha

Beypore (up to 63%), Kozhikode and Kannur districts, Kerala

Metturu-Mela Ganguvada (up to 76%), Srikakulam district, Andhra Pradesh and



Photograph of heavy mineral sand between Sana Arjapalli and Agastinuagaon, Ganjam district, Odisha



Red sediments covered by dune sand in between Metturu and Mela Ganguvada, Srikakulam district, Andhra Pradesh

Red sediments of Konnada-Nerallavalasa (up to 38%), Vizianagaram and Visakhapatnam districts, Andhra Pradesh.

Sonic drilling, on contract, has been carried out along Brahmagiri coast, Odisha which established the persistence of sand column up to 40m with up to 34% THM content.

Resources

The country's total heavy mineral resource was updated to 1,231.95 million tonne (Mt) which includes 687.57 Mt ilmenite (including leucoxene), 34.70 Mt rutile, 12.73 Mt monazite, 36.56 Mt zircon, 195.46 Mt garnet and 264.92 Mt sillimanite.

Mining & Mineral Processing

Mining and processing of uranium ore in India is done by the Uranium Corporation of India Ltd. (UCIL).



Sonic drilling in beach sand exploration in Brahmagiri area, Puri district, Odisha

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

The mining and processing of uranium ore in the country is done by the Uranium Corporation of India Ltd. (UCIL) a Public Sector Enterprise under Department of Atomic Energy (DAE). Presently, UCIL is operating

seven underground mines, one opencast mine and three mills located in Jharkhand (in East Singhbhum and Seraikela-Kharsawan districts) and Andhra Pradesh (in YSR district).

For the Financial Year 2018-19, UCIL received MoU rating 'Excellent' with a score of 95.00 from the Department of Public Enterprises, Ministry of Heavy Industries & Public Enterprises, Government of India (Office Memorandum No: 'F. No. M-03/0002/2020-DPE (MoU)' dated 13th March, 2020). During FY 2019 – 20, UCIL once again achieved production as per its rated capacity, thereby paving the way for achieving 'Excellent' rating in MoU performance.

For the first time in its history, UCIL has achieved a major breakthrough in industrial relations front by successfully negotiating a 10 (ten) year tenure settlement of 'Revision of Wages and Allowances' in respect of workmen of the Company in place of earlier 5 (five) year settlement. This was implemented with effect from 4th February 2020. This has brought parity in periodicity of revision of pay and wages between officers & workmen and will eliminate the recurrent anomalies of pay between senior workmen and junior officers which is faced after every wage revision. This will also ensure maintenance of long term industrial peace and harmony which used to be breached during each and every wage revision. In addition to above, several HR related reforms such as modification of VRS, implementation of Sabbatical Leave Policy, manpower rationalization study by NPC, agreement with EdCIL for conducting the recruitment tests were undertaken successfully.

In the "R&D, Innovation and Technology Upgradation" front, UCIL achieved another milestone in April, 2020, by commissioning the facility for the production of 'Heat Treated Uranium Peroxide (HTUP)' in place of 'Magnesium Di-Uranate (MDU) at Turamdih Mill. With this, both the uranium ore processing mills in the state Jharkhand are now producing yellow cake in the form of HTUP which is of about 90% grade compared to around 70% for MDU. HTUP contains lower impurities and is easily soluble in nitric acid, and being of superior grade, will increase the efficiency of downstream processes.

For faster scaling up of mine development and operations, UCIL has taken up a number of initiatives. In this direction, two major long-term mine development and operation contracts have been awarded for Tummalapalle underground mine in Andhra Pradesh (₹ 3,188.38 Crores / Eight years) and Banduhurang opencast mine (₹ 271.85 Crores / Six years) in Jharkhand to ensure sustained production from these two major production units of the Company. For faster development of the lower horizons of Turamdih, Mohuldih, Narwapahar mines, long term contracts of five year tenure have also been awarded. In order to ensure sustained production from various underground mines in Jharkhand, action has been initiated for procurement of new mining equipment and major overhauling of existing equipment.

UCIL has prepared a vision plan with a broad timeline to achieve substantial increase in uranium production by 2031-32 in line with DAE's requirement to fuel various nuclear power plants. The Atomic Energy Commission (AEC) has accorded in-principle approval for 13 new projects costing ₹ 10571.21 Crores in conformity with this vision. The major production centres are planned in Jharkhand, Andhra Pradesh, Karnataka, Telengana, Chhattisgarh and Rajasthan. The pre-project activities for these projects, such as, obtaining of statutory clearances, land acquisition, site development, and carrying out of R&D phase for formulation of the detailed project reports, have been undertaken and are in different stages of execution.

During the year, the Company has achieved significant progress in activities related to different green-field and expansion projects. Upon being nominated by DAE as a prospective lessee, application has been submitted to the Department of Mines & Geology, Govt. of Rajasthan for grant of Letter of Intent (LOI) for Rohil Project in Rajasthan. Geological Reports in respect of Kannampalle (Andhra Pradesh), Kanchankayi (Karnataka) and Jajawal (Chhattisgarh) projects have been submitted to Director, Department of Mines & Geology of concerned states and the concerned Directors have advised the District Authorities for preparation of Cadastral Map and Land Schedule as per rule 5(a) of AMCR, 2016.

UCIL continues to maintain the ISO 9001:2015 certifications for Quality Assurance (valid up to May 31, 2022), ISO 14001:2015 certification for Environmental Management System (valid up to May 31, 2022). UCIL also continues to maintain IS-18001:2007 certification for Occupational Health and Safety Management System (valid up to 24 January, 2021 and is under renewal process).

At IREL, production of minerals increased by 1.6% compared to corresponding period last year, inspite of the pandemic situation.

Operations of chemical plants affected due to disruption in supply chain and closure of downstream industries. Production of Nuclear Grade Ammonium di-Uranate (NGADU) and Mixed Rare Earths Chloride (MRECL) stood at 13.4 tons and 2964 tons respectively.

Dysprosium production facility at RED, Aluva was dedicated to the Nation by Shri K. N. Vyas, Chairman, AEC & Secretary, DAE by virtual mode in commemoration of IREL's Platinum Jubilee celebrations in the presence of Shri. D. Singh, Chairman and Managing Director, IREL (India) Limited.



Dysprosium production facility at RED, Aluva was dedicated to the Nation byShri K. N. Vyas, Chairman, AEC & Secretary, DAE by virtual mode

Statutory clearances for the Rare Earth Permanent Magnet Plant at Vizag have been received from Ministry of Environment & Forest (MoEF&CC), BARC Safety Committee and Andhra Pradesh Pollution Control Board. Site activities have commenced.

Capacity expansion of mineral separation plant of OSCOM unit in Odisha has been initiated on EPC basis. The project will boost the total mineral producing capacity of the Company to 1.0 million tons.

Commenced site activities for civil construction of the Rare Earth & Titanium Theme Park at Bhopal. Activities pertaining to upscaling of laboratory technology developed by BARC to pilot scale has also been taken up.

Uranium mineralization was discovered in albite rich pegmatoidleucosomes at Naktu, Son valley, UP and of unconformity related type in Chitrial, Telengana. The composite ore sample of Naktu was generated by blending of cores from different bore holes (Code: NKT 2 to 33) which assayed 0.03% U_3O_8 and 0.02% REE (Rare Earth Elements). In the case of Chitrial, U3O8 assay was 0.04%. Process mineralogy studies showed uraninite as the chief radioactive mineral in both the cases and siliceous minerals form the major gangue phases. The Naktu ore contained REE of interesting concentration contributed by monazite and rare earth silicates. Oxidative sulphuric acid leaching of ground ore followed by other downstream processing steps like separation and purification on a strong base anion exchange (IX) resin and precipitation of U-laden liquor with hydrogen peroxide was adopted for both the ores, which gave U recovery of about 80 - 82% and the final product, viz., U-peroxide was almost 90 – 92% pure. The REE values occurring in Naktu ore were leached simultaneously with U to an extent of 80%. The REE values were separated from the combined leach liquor in the IX stage. Detailed process flowsheet with complete material balance is generated for up-scaling the process scheme.

The carbonatites of Ambadongar are rich hard rock resource of rare earths and other useful metals such as Mg, Nb and V. Detailed characterisation and bench-scale metallurgical studies were carried out on different bore-hole drill core ore samples of various lithologies of the deposit. The REE values occur in the form of monazite, fluorocarbonates and as apatite in acicular shape at very fine sizes. A conceptual process flowsheet was tested for recovering Rare Earths (RE) values including yttrium and other useful by-products. The metallurgical tests on the process flowsheet comprises of pre-concentration of REE values by physical beneficiation followed by chemical removal of calcite based carbonate gangue using HCl leaching. The upgraded mass fraction was later subjected to sulfation roasting and aqueous leaching. The dissolved

REE values were precipitated as RE-Oxalate compound. The flowsheet gave 50-55% overall recovery of REE values and REE-Oxalate compound was about 90% pure. The flowsheet was tested in semi-continuous mode on scalable technological units on a composite sample assaying 3% REE. The metallurgical test results are being used for making a techno-economic feasibility report for setting-up of a pilot-plant at site.

A novel process for solvent extraction based separation of niobium and tantalum was developed and demonstrated at bench-scale by treating Columbium Tantalite (CT) ore dissolver solution. The feed mainly contains about 100-120 g/L niobium, 60-70 g/L tantalum dissolved in 9.5M hydrofluoric acid. niobium and tantalum are co-extracted from the feed solution using 20% trioctylamine (TOA) in 1:1 dodecane and isodecanol as the solvent, followed by selective stripping to obtain 98.6% pure niobium and 96% pure tantalum.



The dispersion formed during co-extraction of niobium and tantalum with TOA based solvent

Flowsheet to separate Zr and Hf from Zr frit: The process of dissolution of zirconium hydroxide frit in concentrated nitric acid was developed in a 70L SS dissolver, which was further scaled-up to 700 L for continuous operation of pilot-scale mixer-settler cascade. The dissolver slurry was conditioned for acidity and removal of suspended silica. Production of pure Zr and Hf streams was demonstrated in the existing pilot-scale mixer settler cascade using Alkyl Phosphine Oxide (APO) as the extractant. The product solutions were converted to ZrO_2 and HfO_2 with more than 99% purity. Complete flow-sheet for APO based separation of



70 L Frit Dissolver

Zr and Hf was finalized and demonstrated. A new module of the code ANUSim with an easy-to-use Graphical User Interface to simulate the flow-sheet was also developed. The module predicts concentrations of Zr and Hf in the inter-stage streams and exit streams for specified flow rates of the aqueous and organic phases, inlet concentrations of Zr and Hf, distribution coefficients and number of stages in different cascades.

A miniature pulsed stirred column combining air pulsation and mechanical stirring for intensified solvent extraction, were demonstrated for uranium extraction from lean streams (200 ppm uranium) using 30% Tri-n-Butyl Phosphate (TBP) in dodecane as solvent. More than 95% uranium was extracted at high A/O ratio with residence time of about 1 min at aqueous phase flow rate of about 10 LPH. Uranium thus extracted could be recovered by direct precipitation from loaded organic by contacting it with NH_4OH.

Fused Salt Electrolysis Technique was developed for extraction of elemental boron from boron carbide scrap using KCl-KF-KBF_4 salt mixture as electrolyte. The electrolytic cell was designed and fabricated for using boron carbide as soluble anode and boron was electro-extracted on mild steel cathode plate. The electroextraction experiments were conducted at an optimized temperature of 860°C with varying times from 3 to 24 h. About 200 g high purity boron (~98%) powder was electro-extracted. Currently, the technological support is being provided to Ordnance



Set-up for fused salt electro extraction of Boron

Factory Khamaria, Jabalpur for improving the purity of boron.

The technology for production of high purity Yttrium Oxide (99.99%) from Xenotime, a complex phosphate mineral rich in yttrium, was developed and the technical details were shared with IREL for bulk production of high purity Y_2O_3. After beneficiation, treatment with alkali and acid results in the precipitation of hydroxide cake containing 60% Y_2O_3 with other rare earths and impurities. A robust hydrometallurgical process was developed to recover 99.9% purity Y_2O_3 from the hydroxide cake.



Dual Cycle SX Mixer Settler Unit for separation of Yttrium from Xenotime

A huge number of discarded computer HDDs represent a good source of critical neodymium metal. In Nd-Fe-B magnet about 30% Nd is present along with minor fractions of Pr, Tb & Dy. Recycling of HDD magnetic scrap is accomplished by separation processes based on hollow fibre membrane (HFM) and solvent impregnated beads. HFM is a hydrometallurgical process involving dismantling of HDD, demagnetization, crushing & ball milling, leaching of scrap powder in H_2SO_4, separation of iron, precipitation of Rare Earth (RE) double sulphates and conversion to hydroxides or oxalates. A supported liquid (EHEHPA) membrane based HFM was adopted



Process samples of recycling of Nd-Fe-B

resulting in the recovery of REs more than 85% with purity of about 98%.

A molten salt electrolysis using LiCl-KCl/NaCl-KCl electrolyte was developed for production of 99% pure La (Lanthanum) metal in 1kg per batch from LaO supplied by IREL. The electrolytic assembly comprised of a high density cylindrical graphite crucible as electrolyte container as well as anode, and molybdenum rod as cathode was housed in a vacuum tight inconel retort fitted with stainless steel flange. The cell assembly is heated in a tubular vertical resistance furnace. La metal ingot obtained was in full coalesced state free form voids and inclusions. Maximum current efficiency of 70% was obtained in electro-winning the metal by operating the electrolytic cell under optimum conditions.



Electrolytic setup of Lanthanum Metal Produced

Nuclear Fuel Fabrication

Nuclear Fuel Complex (NFC), an ISO 9001, ISO 14001 & OHSAS 18001 organisation under DAE, is engaged in the production of natural Uranium fuel bundles for Pressurized Heavy Water Reactors (PHWRs), enriched Uranium fuel assemblies for Boiling Water Reactors (BWRs), Reactor Core Structurals (calandria tubes, coolant tubes, square channels etc.), Reactivity Control Mechanisms and special materials like Tantalum, Niobium etc. In addition, for Fast Breeder Reactors, NFC produces all the core sub-assemblies and other critical components like fuel cladding tubes, hexagonal wrapper tubes etc. made out of special stainless steels/D9 materials. NFC also caters to the

demand of high quality stainless steel tubes/pipes and titanium half alloy products for critical and strategic applications in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

PHWR fuel

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

NFC has successfully established production facilities for production of 37 element fuel bundles in IAEA safeguarded facilities with modified bearing pads for upcoming 700 MWe PHWRs.

NFC has achieved production of 462 MT of PHWR fuel bundles and 189 MT of pellet packing in addition to bundle production in the financial year till December, 2020. About 103 nos. of BWR fuel assemblies have been produced.

The Uranium Oxide Plant (UOP)

UOP at Nuclear Fuel Complex produces Uranium oxide powder by processing imported Uranium Ore Concentrates. Numerous innovative process development and modifications were carried out which resulted in increasing the plant capacity by many folds without any addition of major infrastructure. Plant has produced 474MT during this period. Major activities carried out during the period were:

Safe Shutdown and Resumption of Plant Operations on account of COVID-19 lockdown

At UOP, following the guidelines of lockdown, the man movement and production activities were stopped completely from 24.03.2020. Towards this, effective planning was carried out to sequentially shutdown all the processes in the plant in sequential manner from 23.03.2020 onwards. This included safe shutdown of solvent extraction system, draining of uranium bearing solutions to dedicated storage tanks, cooling and safe shutdown of rotary furnaces, ammonia cracker, nitrogen generators etc. Furthermore, ammonia vapour holder was isolated to prevent any unwarranted leakages. From May'20, the plant operations were resumed in safe manner. All the ventilation system, electrical and PLC panels were checked prior to the start-up activities. All the rotary furnaces were maintained and process and safety interlocks of all the systems were thoroughly checked prior to start of production activities.

Regeneration of Lean Solvent by using Acidic media

Extensive study was carried out at lab scale to effectively separate the TBP degraded products from the lean solvent by using phosphoric acid. The successful implementation would replace the existing alkali based solvent (soda ash) by the acidic solvent. Plant scale trails were taken up and it was observed that mere 2-3% phosphoric acid solvent is capable to remove the entire degraded products and also bring down the uranium concentration to minimum level.

Conversion of Raw material having high content of Molybdenum impurities

Trials for processing of Uranium Ore Concentrate (UOC) material was initiated in pilot plant scale with Molybdenum content up to 200 ppm. Ferric Nitrate was added during the dissolution operation to inhibit molybdenum pickup by TBP during solvent extraction process. After encouraging results in Pilot scale, the same was taken in plant scale. Approximately 6200 kgs of UOC (3 batches) were dissolved and 10 nos. of UO_2 lots were produced. Molybdenum content in the powder ranges from 2 – 4 ppm which is within acceptable limit. Average Sintered Recovery and Visual Recovery of the pellets obtained from the 10 nos. of UO_2 lots were 95% and 93% respectively which is as per the international bench-mark standards. Subsequently, UOC with higher concentration of molybdenum (550 ppm) were processed in plant scale. Approximately 5000 kgs (2 batches). The resultant 8 nos. of UO_2 lots contained molybdenum in the range of 5-8 ppm and were processed separately. Average Sintered recovery was 99% (Avg. Density: 10.68 g/cc) and visual recovery was 90%.

Online Scrub cake settling and removal system for calcination Furnace

Off gases generated during calcinations of ADU powder is scrubbed in water spray tower to recover uranium particulates. In the earlier system the recovered particulate matter was allowed to settle by gravity in a square tank attached to the furnace. After processing around 10-15 batches, square tanks used to get full with uranium cake which requires immediate stoppage of calcinations operation. Cake is removed manually and transported to dissolution for recycling. In the new system, the entire manual operation is replaced with innovative online scrub cake settling and cake delivery to dissolution tank. The cake & water separation efficiency was improved by replacing gravity settling to centrifugal action based settling. The entire system is automated and controlled through PLC based SCADA system. Open and manual handling of uranium cake is completely eliminated. This has brought benefits of manpower saving, improved availability of operation, conservation of water and reduction in direct exposure of radioactivity.

Installation and commissioning of Batch furnaces

About 3 nos. of old Batch furnaces were refurbished installed and commissioned in a newly developed exclusive facility for UNRC Calcination. The furnaces are of 45 KW capacities each. The facility is equipped with an effective scrubbing system, dedicated blower and a stack of 15 m. The facility will be utilized for calcinations of UNRC (solid waste) in order to remove volatile organics, nitrated, moisture etc. This results in volume reduction of solid waste up to 75%.

Ceramic Fuel Fabrication Plant – Pelletizing (CFFP – P)

CFFP (P) is involved in the production of natural UO_2 sintered pellets from the nuclear grade UO_2 powder received from UOP through conventional powder metallurgy route. The plant has achieved production of about 404 MT of finished UO_2 pellets during this period. Overall recovery is 85% is achieved during the period.

Ceramic Fuel Fabrication Plant –Assembly (CFFP – A)

CFFP-A has produced 205 Te of fuel bundles till the end of December-2020. Mechanism for stepless eccentricity correction during end cap welding has been successfully developed, installed & commissioned in one of the machines and has been under regular production with satisfactory performance with respect to improving quality & recovery.

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

Plant has produced 364 Te of fuel bundles till the end of December-2020. The Achievements during the year were as follows:

Direct Reduction of ADU to UO_2 as process breakthrough

The regular process for stabilized UO_2 powder production from ADU involved Calcination of Ammonium Di-Uranate (ADU) to obtain U_3O_8, Reduction of U_3O_8 to UO_2 and Stabilization of UO_2, operations. In the modified process of Direct Reduction, the Calcination operation was removed and ADU was directly converted to UO_2 in Reduction operation. Required experimental trials for Direct reduction were carried out in the month of August, 2019 and parameters of direct reduction operation was optimized. Sintering grade UO_2 powder was produced with better quality than the conventional route. Sintering recovery was also found to be high and consistent. Since April 2020 onwards the process is being continued. The major benefits of Direct Reduction are saving of 1.5 man shift per MT of UO_2 powder production; Saving of man shift towards frequent seal maintenance of Calcination furnace; Constant temperature reduction operation leading to production of consistent quality UO_2 powder (frequent changing of Reduction Furnace temperature is overcome); Consistent and better powder to pellet recovery; Reduction in number of powder samples to be analysed for Specific SA by elimination of calcination operation; Reduction in radioactive material handling operations due to elimination of one major process and Reduction in air activity in the area by avoiding maintenance prone calcinations furnace.

Recovery of entrapped Uranium in contaminated Aqueous solution and Organic Solvent

30kL of low uranium bearing aqueous solution was precipitated with vapor ammonia for converting the entrapped uranium in aqueous solution to Ammonium Di-Uranate cake (solid). About 1000Kg of Uranium was recovered from the above solution. This has resulted in significant volume reduction. 5kL emulsified/degraded organic solution was treated and recovered into the system. The same treated organic was used for recovering uranium from Uranyl Nitrate Raffinate for generation of Acidic Raffinate Slurry, thus eliminating the requirement of fresh solvent.

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

Automated pellet feeding for Centerless Grinders

Automatic pellet feeding system is commissioned in grinding machine to eliminate manual feeding of pellets for grinding. This development has minimized radiation exposure to the operator and saved 200 man days per month.

Automated granule transfer and integrated blending

Automated granule transfer and integrated blending operation system is being developed and installed in one compaction press. This development has reduced multiple times manual handling of granule container thud minimize operator fatigue. New designed granule container has also reduced air born activity caused due to powder leakages from container.

Natural Uranium Fuel Assembly Plant (NUFAP)

The plant has achieved production of 257 MT of fuel bundles during this period. Assembled 1 No. of Capsule carrier bundle as per the requirement of BARC for conducting different types of tests. The packing of 37 element type PHWR fuel bundles was changed from rolling type to sleeve type. This has reduced consumption of plastic material from 75 gram to 25 grams required for each bundle packing and also reduced consumption of Brown plastic tape drastically. Assembled and commissioned modified Auto Cap Feeding mechanisms in 2 Nos of End Cap Welding Machines. Implemented MAPDPS system at all production and QA stages, which has eliminated bundle card printing and reduced paper consumption considerably.

Equipment Development & Automation (ED&A)

Green Pellet Density Measurement System – 1 & 2

An automatic unit capable of measuring the density of green pellets along with data acquisition has been designed in-house and made at ED&A. The density measurement is achieved by using non-contact type geometric measurements and non-immersive methodology. High-Accuracy LED Micrometer & Analytical Balance are used for measuring the Dimensions and Weight of the pellet respectively. This is first of its kind unit and can cater to handle up to 120 green pellets that are arranged into 10 stacks. Ball screws, servo motors, photoelectric sensors, pneumatic grippers are some of the sophistications used in making this unit. The unit has built-in provisions for data acquisition, storage and retrieval. Report generation facility is also added for enabling data trend analysis at a later stage. The unit is being used in Block-B, Fuels (NUOFP-P) successfully for the last few months.

Boat to Box Sintered Pellet Transfer System

An automatic unit capable of transferring the sintered pellets from Molybdenum Boat to SS box has been made at ED&A. The system eliminates manual transfer of pellets. The system achieves the transfer using optimum rotational speed. Provision is made to vary the speed of rotation. The system is provided with all safety interlocks including a safety light curtain. The system is also provided with a roller platform for easy loading and unloading of Molybdenum boats and SS boxes. The unit is supplied to Block-A, Fuels (CFFP-P).

Enriched Fuel Fabrication Plant (EFFP)

Successfully produced & dispatched 103 nos. of QC & QS cleared enriched fuel assemblies out of the targeted 100 assemblies for meeting the refuelling requirement of Unit 2 of TAPS as per schedule.

Metallic Fuels

U-Mo based Metallic Fuels are being developed for Advanced Nuclear Reactors. These materials favour increased burn-up to make nuclear power economical. U-16 wt % Mo is one such fuel that can be used in fast reactors or for up-rating of existing PWRs. Its negative power and temperature coefficient helps in self shut-down of the reactor in accidental conditions like RIA (Reactivity-Initiated Accident) or LOCA (Loss of Coolant Accident). Metallic U-16 wt % Mo has high thermal conductivity in the range of 30 W/m/k (ensures high power density) vis a vis 2 W/m/K in the case of mixed oxide ceramic fuels. Around 16wt% Mo, isotropic BCC crystal structure is stabilized, which is favourable for lower interaction with clad material and lower swelling and enables operating temperatures to be as high as 500-800 °C. U-16wt.% Mo has a melting point ~1236 °C, which ensures higher safety margin for fuel melting during off-normal condition. The BCC phase also has the advantage of higher solubility of alloying elements, which minimizes fuel constituent migration. FCCI (Fuel-Cladding Chemical Interaction) is still a major degradation mechanism for metallic fuel. Due to contact of fuel slug with the clad, the chemical interaction reduces the effective thickness of the cladding and increases the local cladding stress. FCCI is characterized by the inter-diffusion and chemical interaction of fuel constituents, rare earths, lanthanides and cladding constituents, like Fe. The total interaction layer growth rate in U-16Mo/T91 is significantly lower than other U-Zr and Fe based cladding. This is due to the formation of auto-generated Mo-rich barrier layer (see the figure below) between fuel/clad and thus generating thinner interaction zone.

Thirty one (31) tons of nuclear grade Uranium in the form of metal ingots of 450-850 kg was produced during the year for fabrication of research reactor fuel. A new reaction vessel of boiler quality steel and a chrome plated mould & graphite crucible were developed to increase the batch size to 1000 kg and for better uranium recovery. Two 1000 kg uranium metal ingots were produced with recovery ≥ 98%. About 1000 kg of Uranium was recovered by processing 20 tons of MgF_2 slag which is reused for refractory lining of Magnesio-Thermic Reactor.



1000 Kg U-Metal Ingots

Generally, uranium value is recovered by nitric acid dissolution of SLM, to get Uranyl Nitrate Solution (UNS), which is lean in uranium (2-3 gpl) and therefore difficult to isolate using solvent extraction. UED developed an alternative process resulting in UNS with uranium concentration in the range 10-12 gpl by selectively leaching CaO. Around 4.33 kg uranium was recovered from 300 kg of SLM with recovery rate more than 99.5%.

About 330 samples, including plutonium based materials, corresponding to 2000 analytical determinations, were analyzed as a part of the chemical quality control of nuclear fuels and materials pertaining to PHWR, FBTR and APSARA-U, for constituents such as Hydrogen, Deuterium and trace non-metallic elements such as C, O, N, F, Cl and boron. About 52 (Pu,U)C and plutonium alloy samples were analyzed for uranium, plutonium and gallium contents. About 110 samples were analysed for isotoipc composition of uranium, plutonium and boron.

Carbon content in nuclear materials is determined employing combustion and infrared light absorption techniques.UF4 has high vapor pressure (950 Pa at 1273 K) and gets deposited on the gas lines causing memory effects during subsequent sample analysis. For this purpose, quartz based combustion setup was made and coupled to IR detector. The technique was calibrated using carbon standards in iron powder and subsequently used for quantification of traces of carbon in Uf_4.

Structural Materials & Components

Zirconium activities

Zirconium Oxide Plant (ZOP)

Plant has achieved the targeted production of 345 MT of nuclear grade Zirconium dioxide during the period from April 2020 to December 2020. Plant has carried out improvement in the slurry extraction batteries for zirconium extraction so as to reduce the solvent inventory of about 8000 litres (40%) and thereby reduce the risk of fire load and TBP degradation. Plant has incorporated automated controlled dosing of sulphuric acid for zirconium hydroxide precipitation operation. This facilitated better control of the product characteristics with increased precision of the amount of sulphuric acid being added. A novel air-operated mixer-settler unit with improved features for operational convenience was designed and in-house fabricated for carrying out Zirconium extraction process development studies. This prototype version is first-of-its kind, wherein, the mixing chambers are aligned in a single row for all the stages by modified design unlike the conventional version for which these chambers are positioned at opposite ends.

Zirconium Sponge Plant (ZSP)

The Plant has produced 266MT of reactor grade Zirconium sponge. PLC of 7 Nos. of Kroll's Reduction Units have been upgraded with Redundancy and modified bleeding scheme for improving Productivity in Zirconium Production. Successful trial conducted with modification of one discharge Gate Valve along with exhaust system to discharge $ZrCl_4$ in to Chloride Can which has improved the working environment. Around 3% reduction in Vacuum Distillation cycle time by optimizing distillation stage for increased productivity and reduction in energy consumption has been achieved. Successful trials have been conducted for safe disposal of 5 MT of Ring material containing Zirconium, magnesium and magnesium chloride.

Zircaloy fabrication

3780 MT horizontal extrusion press is a unique facility wherein the hot working of all the materials required for various applications of DAE, Space and Defence are carried out. In addition to regular hot working (extrusion) of zircaloy and stainless-steel materials required for PHWR, BWR and FBR programs, development of hot working for several other strategic materials was carried out. Around 7344 nos. extrusion have been carried out during this period.

Development of Zircaloy Shell Manufacturing Process

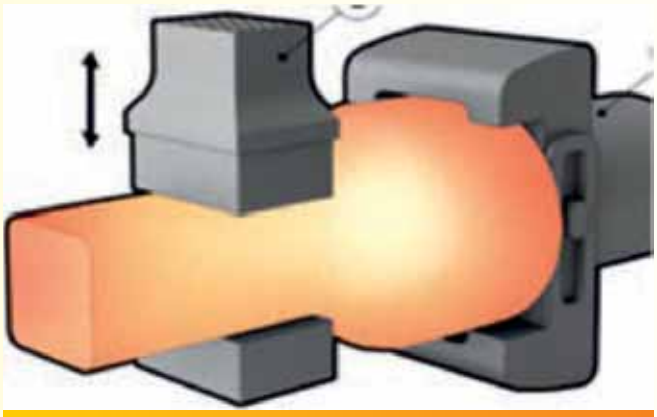
As first of its kind effort, a developmental work carried out to establish novel manufacturing process for manufacturing Zircaloy shell based on the specific requirement for BARC. Accordingly, manufacturing route was conceptualized and executed successfully, including saddle forging process to enlarge Outer diameter & inner Diameter of Zircaloy ingot/hollow. Two shells of more than 500 mm Outer diameter and 420 mm Inner Diameter been manufactured up to the length of 1800 mm.



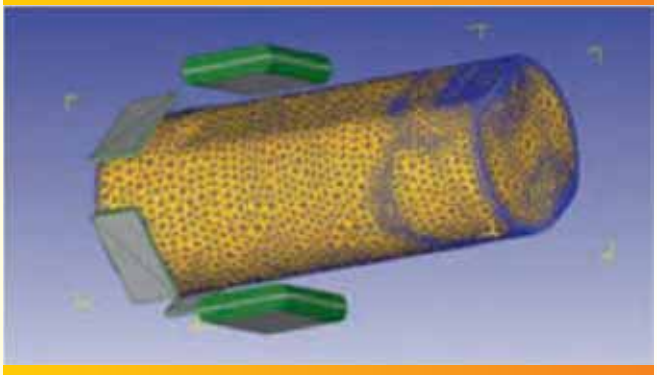
Finished Zircaloy Shell

Successful development of Forging route for manufacturing of Zirconium alloy bar and tubes for PHWRs

A developmental activity was initiated for using open die press forging for first hot deformation of Zircaloy -4 ingots, instead of regular extrusion. Accordingly, four double melted ingots were successfully forged by establishing the forging pass schedule for uniform deformation in each pass. The forged rod thus obtained has acceptable surface finish and excellent straightness. Forged ingots has been converted to billets, beta quenched and further extruded to rods and blanks to produce final product of 19 element and 37 element bar and clad tubes. FEM model was developed and simulated in first pass of forging to obtain temperature, strain & strain rate profile.



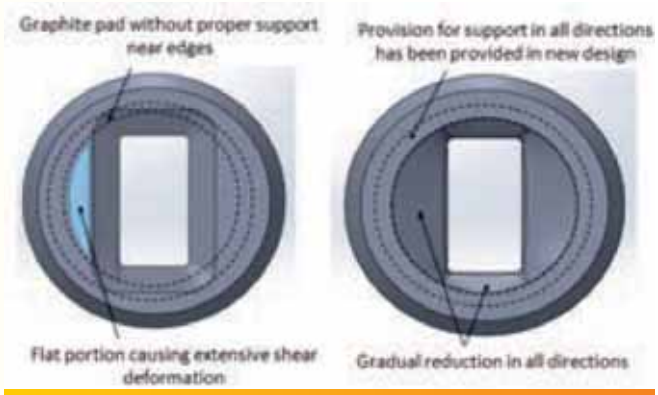
Schematic of open die forging



FEM Model showing ingot shape change during forging

Improvement in slab extrusion by modification in extrusion tooling

Cylindrical Zircaloy-4 ingots are hot extruded to slabs of rectangular cross section, to meet sheet production requirements for various PHWR fuel bundle components. The extrusion process is very critical, considering, inherent non homogeneous deformation during shape change from circular to rectangular cross section. The phenomenon affects extruded slab quality with respect to bending and surface defects, particularly near edges. A new die has been designed for lesser shear deformation, uniform shape changes from all sides along with proper support for graphite pad to reduce frictional forces during extrusion. FEM model was developed to simulate the flow of material for both old die design as well as new die design. The results have shown a lesser stress and strain rate distribution in the deformation zone. Extrusion was carried out with newly fabricated die. The support tools for extrusion were also modified according to this new die design. The extruded slabs produced with modified tooling has shown very less bend and reduced surface defects there by improvement in the recovery.



Comparison of old die design(left) and new die design (right)

Development of Low diameter Zircaloy-4 extrusion For Wire Product development

Process development for extrusion of Zircaloy - 4 has been carried out into 9 mm rod instead of regular 19 mm diameter for first time successfully. The modification in extrusion shall allow reducing the long manufacturing cycle by eliminating incremental thermo mechanical processing of swaging and intermediate annealing to produce finished spacers and wire products for PHWRs.

Extrusion of Niobium for BARC

Round to rectangular slab extrusions and was carried out for production of 2.5 mm thin sheet requirement meant for Quarter wave resonance (QWR) application. Also rod extrusion of 85 mm diameter was carried to develop components for the same application.

Process Development for production of Zr-1%Nb Bars

As first-of-its-kind effort, developmental work was taken up and the manufacturing process was established for production of Zr1%Nb rods (below Dia. 5 mm x 1000 mm) and Titan – 24 rods for strategic applications. As per requirement of BARC, 1000 nos. of Zr1%Nb rods and Titan-24 rods were manufactured and supplied.

Development of process & indigenous bulk production of special material tubes for strategic applications.

- **SuperNi Tubes:** These tubes are of small diameter, extremely thin wall and have stringent specs

wrt dimensional tolerances and metallurgical properties. After initial trials for indigenous development in collaboration with BARC Mumbai, the manufacturing route was established for bulk production. The process consists of production through 10 stages of thermo mechanical processing followed by final finishing operations & stringent quality checks of mechanical testing, ultrasonic testing, dimensional & visual inspection. Optimisation of the process was done using the experience gained on thermo mechanical processing on this special alloy, to achieve significantly improved recovery and productivity. Fuel Tube Division has now significantly scaled up its equipment, for bulk tube manufacturing to meet the high demand and timely supply of the tubes.

- **Installation of new indigenously developed high temperature semi-continuous furnace:** In-house roller type semi-continuous furnace was conceptualized, developed, fabricated, erected and commissioned for heat treatment of higher diameter tubes. Furnace maximum operating temperature is 1200℃ max. The Plant has manufactured & supplied 5000 Nos of SuperNi tubes in current financial year.



Installation of new indigenously developed high temperature semi-continuous furnace

- **Zr-1%Nb tubes:** BARC had approached NFC for the supply of Zr-1% Nb tubes with 14 mm length (One end) flaring with 2 mm OD expansion and tapper machining (other end) for strategic application. Tubes were manufactured and challenges encountered in optimization of the process of end flaring, were resolved with split design fixture and 18 stages stepwise expansion to final size. The Plant has successfully manufactured & supplied 400 Nos. of autoclaved Zr-1%Nb tubes to BARC.



Flared End



Machined End

Tube preparation section

A high capacity Vacuum Baking Furnace (4000 tubes) suitable for baking of graphite coated tubes, was



A high capacity Vacuum Baking Furnace

procured and erected at site. The commissioning work is in progress. The furnace has vacuum pumping systems to achieve a vacuum of 5 x10 $^{-6}$ mbar with leak rate less than 1 lusec and is with temperature control accuracy +/- 1 Deg C.

Structurals

CCTF (Core Component Test Facility) tubes

To set up its Core Component Test Facility, RPD, BARC had placed order on NFC for several different assemblies. For the manufacture of these assemblies, STP has produced two important tube sizes of Zircaloy – 4 (73mm OD X 70mm ID and 82.5mm OD X 80mm ID). These high precision tubes were manufactured for the first time and have successfully met all the critical requirements of dimensions, NDT and metallurgical condition.

SUC (Start-up Counter) tubes

NFC has taken up the project of developing a new Start-up Counter Assembly as per the technical inputs of Design Group of NPCIL. This assembly is smaller than the standard start-up counter assembly and is expected to improve the ease of installation in 220 MWe PHWRs. STP has developed a pilgering schedule for the manufacturing of critical SUC tube of dimensions 67.5mm OD X 0.8mm WT. Several modifications had to be carried out to execute this pilgering pass in which both the ingoing and outgoing tubes are extremely thin walled. Special split bushes were designed and manufactured for feeding of the ingoing tubes. Pilgering was carried out on 150 VMR pilger mill which is not designed to handle such thin walled tubes. Stringent dimensional requirements were met by precise tool design, manufacture, close control and monitoring of all pilgering parameters. These tubes have been cleared in all NDT and dimensional tests and are currently being used for assembly of the newly designed Start up Counter.

SS 321 hexcans

SS 321 hexcans of dimensions 29.5mm A/F X 0.4mm WT have been developed for meeting strategic requirements of BARC. Suitable pilger mill for the manufacture of these hexcans were not available at NFC. Feed and turn gear box of one of the pilger mill was modified to incorporate rotation of the tube as well as the mandrel rod precisely at 600 angle. Tools required for the manufacture of these hexcans were designed and manufactured in-house. The entire process route for these extremely thin walled seamless hexcans has been developed for the first time. One batch of hexcans has been dispatched to BARC.

Special Materials

The Plant has produced 2464 MT of Niobium metal granules. The major achievements during the year includes process development studies for preparation of RRR grade Niobium for superconducting applications. The process involves electron beam melting in 300 kW Electron beam melting furnace inaugurated by Hon'ble President of India; Supplied 440 Sb2O3 capsules required for Source SAs of PFBR; Supplied 300 x 600 x 2.5mm Niobium sheets to NPD, BARC for accelerator applications. Preparation of additional 13 Nos. is in process. Preparation of 70mmΦ x800mm & 45mmΦ x 300mm Niobium rods for accelerator applications in process; Process developed for preparation of ultra-fine Zr metal powder (3-8micron) based on the request from Ordnance factory to meet critical requirement of Department of Defence; Process developed for indigenous preparation of ultra-fine Zr-30%Ni alloy powder for Ordnance Factory, Department of Defence for applications in strategic applications. SMP, NFC is the only manufacturer of the product in India; Supplied 2 kg of 50mm x 0.5mm thk and 25m x 0.5mm thk Silver Strips to BARC, Mumbai; Supplied 30 kg of high purity, special grade Zirconium oxide to AFD, BARC for strategic applications; Supplied various high purity materials such as POCl3, selenium, tellurium, Ti powder, Zirconium hydride, Nb metal powder etc. to BARC, industries, educational institutions as per the demand and Modification & installation of shaftless flexible screw conveyor system for better flowability of Niobium oxide during rotary calcination.

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 with scope for future expansion of 500 TPY fuel and 100 TPY Zircaloy products.

Major Events/Milestones

Basic site infrastructural activities are completed and construction of Plant and Non plant Buildings is in progress. Commitments worth ₹ 636 crores are made and commitments to the tune of ₹ 155 crores are awaiting final approval for placement of order. Physical progress of the project as on November 2020 is 38.86%. Cabinet Committee on Security accorded approval for the revised project cost of ₹ 4256.20 crores with completion period of July 2022 in October 2020. Chairman AEC & Secretary DAE inaugurated few of the Buildings namely Administrative Building (Vikram Sarabhai Bhavan), Meltshop, Workshop & Extrusion Shop on 06-10-2020. Major Machinery such as Extrusion Press, Vertical Vacuum Annealing Furnace, Forge Press, Distribution Transformers and Air Compressors were received at Project site during August 2020 – October 2020. Construction of Plant buildings, Electrical works at Main Receiving Substation, Substation for PFFF plants, air conditioning works at a few buildings, pipe rack for Utilities, Site Grading and Construction of Compound Wall for Township area are in progress at Project Site.



Administrative Building



Work Shop



PFFF Module 1 Wet Section



Main Receiving Substation

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). Around 290 MT of nuclear pure zirconium oxide and 142 MT of Reactor grade zirconium sponge have been produced during this period.

Magnesium Recycling Technology Development & Demonstration Facility

Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF) is being set up under a MoU between NFC, HWB and DMRL. Civil works for buildings, roads, drainage system etc, for cell area / office building, electrical sub-station, instrumentation control room, foundation and structural work for cell area has been completed. Procurement of various equipments are in various stages of the process.

Study of Zirconium extraction with an alternate solvent in bench scale set up

At present Tri-butyl Phosphate (TBP) is used as the solvent for extraction of zirconium from crude

zirconium nitrate slurry. The solvent has some limitations like limited loading capacity, degradation due to acidification and loading of zirconium, etc., and to overcome these limitations, ZC has embarked in finding alternate solvents in place of TBP which will help in increasing the productivity besides reducing effluent generation. Laboratory studies with two solvents, viz., Tri-iso amyl phosphate (TiAP) and Tris 2-ethyl hexyl phosphate (TOP) gave encouraging results with respect to extraction as well as degradation of solvents. In order to collect further engineering data, a bench scale unit has been set-up in Oxide Production Facility (OPF) with 20 mixer settler stages. Trials are planned in this unit for study on extraction of zirconium, scrubbing and stripping with an alternate solvent. The trials commenced with TiAP and one cycle of extraction, scrubbing and stripping were completed. Further studies are in progress.

Atomic Energy Central School

Atomic Energy Central School (Classes up to 7th standard) is functional. Permanent school building has been constructed and was inaugurated by the Chairman & Chief Executive, NFC on 30th November 2020.

Community Hall at ZC Township

In order to cater to the recreational requirements of the families of ZC employees and CISF, a Community Centre is being constructed. Foundation stone was laid by the Chairman & Chief Executive, NFC on 30th November 2020 and work is in progress.

BACK END FUEL CYCLE

Fuel Reprocessing

Vortex mixer is a maintenance-free mixer for carrying out mixing/ reactions. As the first step of development of a comprehensive model of mixing and reactions, gas-liquid flow in a batch vortex reactor was simulated. An Artificial Neural Network (ANN) model was used to predict vortex shapes for different operating conditions. The vortex shapes were then used to construct computational domains so that single-phase CFD simulations could be carried out. This approach of combining ANN with CFD significantly reduces computational time and the results were validated with the particle imaging velocimetry data.

Ruthenium was recovered from alkaline media using commercial strong base anion exchange resin with a quaternary ammonium group (Dowex 1x8) in a simplified way with very high K_d values (40,000-50,000). The reductive property of RuO_4^{2-} to RuO2.xH_2O was used and the slow precipitation of RuO_4^{2-} to RuO_2.xH_2O in alkaline media was found to be higher at the resin surface. Ru from the resin surface was recovered by NaOCl washing followed by elution with 8M HNO_3. Near 90% recovery was achieved in column operation with good reproducibility and good reusability of the resin.

Waste Management

Di-tertiarybutyldibenzo 18 crown 6 (DTBDB18C6) is the precursor in the synthesis of Di tertiarybutyldicyclohexano18 crown 6 (DTBDCH18C6), which is used for separation of strontium from high level radioactive waste. A process for purification of DTBDB18C6 by loading it on silica gel in a 6 inch chromatographic column followed by elution using ethyl acetate dissolved in petroleum ether was demonstrated. The solvent is recovered by evaporation of eluent solution while purified DTBDB18C6 is recovered as white powder. Up to 90% pure DTBDB18C6 could be obtained starting from about 50% pure crude DTBDB18C6.



Array of six chromatography columns used for purification of crude DTBDB18C6 crown ether

Agglomeration Onset Detection System (AgODS) was developed for continuous monitoring of the bed condition of a fluidized bed reactor. A 9 channel high frequency data acquisition system acquires pressure fluctuation data of fluidized bed reactor and implements an attractor comparison algorithm to compute a statistical metric 'S' - a measure of the fluidization state. AgODS was tested during operation of lab-scale fluidized bed thermal denitration reactor with sodium nitrate solution. Agglomeration could be detected 30–40 min earlier than with conventional methods based on changes in bed pressure drop.

Ammonium nitrate is one of the most common wastes generated in both front and back end nuclear fuel cycles. Accurate and online estimation of ammonium nitrate concentration assumes importance in denitration processes for treatment of this waste. An ultrasonic based system is developed for online estimation of ammonium nitrate concentration in process vessels. A 5MHz ultrasonic sensor detects the reflected signal to measure the Time of Flight (TOF) across a known distance and estimate the speed of sound in the medium. The effect of temperature on the results is studied in detail. A linear calibration equation predicts concentration at a given temperature. The system is capable of measuring concentration in real time. Applicability of the system is also tested with other nitrate bearing media. The system is ready for installation at thermal denitration plant for treatment of waste.

Purification of Am containing trace amounts of Eu was demonstrated at Nuclear Recycle Board, Tarapur using a TODGA based extraction chromatography column from two waste solutions of different compositions, where Am3+ was washed out in the presence of water soluble BTP (with four sulphonic acid groups) as the strippant while Eu was selectively held onto the column. Recovery of Am was > 99% with >99.8% Eu removed from the product with a DF value close to 10^5.

Safety Performance of Reactors

NPCIL is performing the safety analysis including deterministic and Probabilistic Safety Assessment (PSA) of nuclear power plants for design, siting, commissioning of new projects; and safe operation, periodic safety review, extension of operating license/life management of operating plants, and also for obtaining regulatory clearance for the projects and operating stations.

After completing revision of accident management guidelines for PHWRs, revision of accident management guidelines for TAPS-1&2 is completed in year 2020-21.

Scheme for online estimation of critical heat flux margins is developed for 700 MWe PHWRs and successfully tested in KAPP-3&4 (700 MWe) simulator.

After thermal and radiation ageing as per requirement of Primary Heat Transport (PHT) Pump room environment, Intumescent paint coated sample was exposed to flame torch; and the paint has been qualified for fire protection of In-Containment structural steel within Reactor Building.

Level-1 PSA studies of KAPP-3&4 were completed and submitted to AERB as per the regulatory requirements for First Approach to Criticality.

Computational Fluid Dynamics (CFD) analysis was carried out for the Fuelling Machine Vault (FMV) cooling system of KAPP-3&4.

HEALTH, SAFETY AND ENVIRONMENT

At BARC, a Plastic Scintillator based coincidence system was indigenously developed as a primary standard for radioactivity measurement. The system consists of Plastic Scintillator and NaI(Tl) for beta and gamma detection respectively. Pre-amplifier signals from the detectors are processed and fed to a computer. The performance of the system is comparable to the existing 4 πB-y coincidence system using a standard ^{60}Co source.

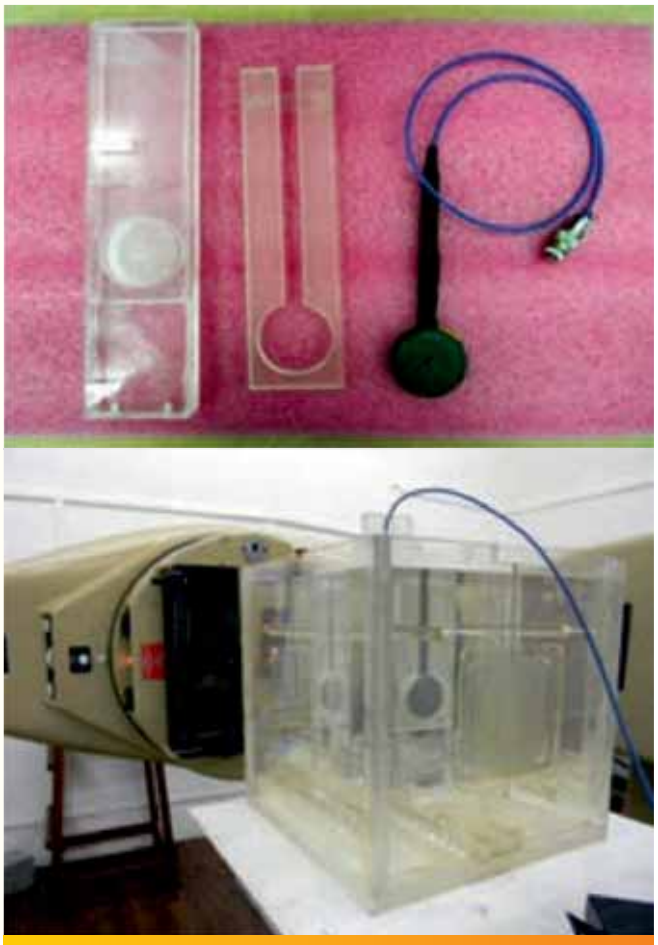
The ionization chamber developed is based on the BIPM (Bureau International des Poids et Mesures; The International Bureau of Weights and Measures) standard for absorbed dose to water for Co-60 gamma rays. The chamber is a flat cylindrical box and the cavity is divided into two parts - each of depth 2 mm by a



Development of Plastic Scintillator based 4πB-γ coincidence system

circular plate of thickness 1mm. The chamber front and back walls are of 2 mm thickness and the volume of the chamber is around 6.9 cm3. Preliminary studies such as ordinary leakage, charge leakage, ionization saturation study, polarity effect, short term stability and stem effect were carried out with the chamber. The ionometric standard will be developed as a Primary Standard for recognition of Radiation Standards Lab of BARC as a Primary Standard Dosimetry Laboratory.

Nuclear Recycle Group, BARC developed ^{106}Ru eye plaques consisting of an Ag backing plate, an Ag substrate on which ^{106}Ru is deposited followed by a 0.1 mm thick Ag window. These plaques used in the treatment of eye cancer were standardized. Sensitivity Coefficients (SF) in pA/MBq of various radionuclides have been determined for a standard geometry of 1 ml radioactive solution in an injection glass vial. The activity of the standard eye plaque source was 0.62 MBq as on 13th July 2019 at 12:00 hrs IST. SF of an eye plaque source was evaluated as the ratio of the current to the known dispensed activity and was 4.54 pA/MBq, which was used for standardizing eye plaque sources.



Ionization chamber

The radiological safety of general public is priority during design, construction and operation of nuclear facilities. Environmental Survey Laboratories (ESLs) are established at each facility for periodic monitoring of environmental matrices. ESLs are equipped with state-of-the-art instruments to analyze extremely low levels of radioactivity in environmental samples. Samples of various environmental matrices such as soil, sediment, air particulate matter, water, milk, food items, sea food, grass, etc., upto 30 km from a facility are collected and analyzed for activity. The results clearly indicate that the dose to the member of public at fence post (1.6 km) is only a small fraction of the regulatory limit of 1000 micro Sv/year. The ESLs at Nuclear Power Plants (NPP) participate in regular public awareness programmes and act as Emergency Response Centres. A Geographical Information System (GIS) based database has also been developed covering areas around 50 to 100 km of NPP sites using open source data to assist response action planning during emergency conditions.

Occupational radiation protection and environmental safety surveillance in and around the front end of nuclear fuel cycle facilities was provided at the operating units of Uranium Corporation of India Ltd in Jharkhand and Andhra Pradesh, Indian Rare Earths Ltd. (Kerala, Tamil Nadu, & Odisha) and Nuclear Fuel Complex (Hyderabad). During the last year, 8699 occupational workers were monitored for external and internal radiation exposures. In-plant radiological survey and radiation dose evaluations were carried out to ensure compliance with regulatory norms. The occupational radiation doses to workers in underground uranium mines and Thorium handling facilities are well within regulatory limits.

In the event of an injury in a Pu handling facility, information about Pu and Am activity in the wound and its location is required for medical treatment. A wound phantom using tissue equivalent material with ^{241}Am disc source was developed to calibrate HPGe detector for 17.6, 26.3 and 59.5 keV energies of ^{241}Am photons for different depths varying from 0 to 20mm. Using the calibration factors, ^{241}Am activity at a given depth can be determined. The Pu/ ^{241}Am ratio can be determined by alpha spectroscopy after radiochemical separation of Pu and Am in the tissue sample collected from the wound.



Satellite Communication based Environmental Radiation Monitor (ERM-SAT)

Solar powered, GSM based Environmental Radiation Monitors (ERMs) are working for more than 15 years under countrywide Indian Environmental Radiation Monitoring Network (IERMON). To mitigate GSM related communication issues and to achieve near real time data reception, ERM with Satellite Communication (ERM-SAT) was developed. The system communicates through dedicated carrier on Data Relay Transponder (DRT) onboard INSAT-3D as primary mode of data transmission with GSM as backup data channel. The data transmitted from ERM-SAT systems are secured using in-house developed encryption algorithm. 40 units of ERM-SAT have been fabricated in the first batch and installed at respective sites.

Environmental Gamma Radiation Monitoring around DAE facilities is carried out using Thermoluminiscent Dosimeters (TLDs). The environmental gamma radiation levels are being measured on quarterly basis using 600 TLDs deployed in and around the DAE installations. TLD-recorded data reflects the natural environmental gamma radioactivity distribution patterns and seasonal variations in the radiation levels above ground.



Machine vision based automated image analyzer system



Bonner sphere spectrometer deployed at HARL, Gulmarg

Personnel Monitoring at DAE facilities is carried out by TLD laboratories of RPAD, BARC. This includes gamma and beta dose monitoring using TLDs and neutron monitoring using CR-39 based Solid State Nuclear Track Detectors (SSNTDs). A 2D barcode based neutron badge tracking and dose database management software - ANU-KOSH were developed and introduced in neutron personnel monitoring programme. The software maintains details of a neutron radiation worker, institutional details and dose database to generate various reports. The throughput in monitoring is significantly increased by developing a machine vision based automated image analyzer that can read up to 100 neutron dosimeters in 30 min. Special instructions for handling the dosimeters and guidelines to be followed during the COVID-19 pandemic were issued to all laboratories that provide personnel monitoring services to the institutes under the non-DAE sector.

Cosmic ray dose rate and neutron spectrum are studied using the Bonner sphere spectrometer deployed at High Altitude Research Laboratory (HARL), Gulmarg, J&K. Cosmic ray dose is expected to increase with altitude. It was found that the cosmic ray neutron dose rate varies in the range of 24-34 nSv/h depending upon the season.

G0-PCC helps chromosomal aberration analysis and quick dose estimation within four hours after blood collection compared to conventional methods requiring 48 hours. The quickest way is to stain chromosomes and count number of chromosomal bodies per cell excess to 46 (normal number of chromosomes) and estimate the dose. The assay combined with whole chromosome painting further helped multi-parametric detection of chromosome specific breaks, translocations and insertions. Dose response curve and repair kinetics were also studied to establish the technique as a rapid biodosimetry tool. The method helps to estimate dose in case of any radiological incidents involving doses exceeding 500 mSv.

The rapid identification of individuals exposed to high radiation doses is important for initial triage and medical treatment decisions. Ionizing radiation induces DNA Double Strand Breaks (DSBs) which can be visualized and quantified by γH2AX immune-staining. Response curves were generated with ex vivo irradiated human blood samples, in the ^{60}Co-γ dose range of 0 - 4 Gy. To study effect of post irradiation repair, blood samples were incubated for 1 to 96 h and processed. Accordingly, nine dose response curves were generated, which were deployed for biodosimetry, if the blood samples were obtained within 96 hours of exposure. The technique was validated with dose blinded samples and standard cytogenetic tools.

A novel method for estimating thoron concentration using the in-situ measured thoron exhalation rates from surfaces of dwellings is developed. This method eliminates the uncertainty associated with one-point measurement due to its inherent non-uniform concentrations in houses. A vacuum based wall mounting accumulator was designed for in-situ measurement of thoron exhalation rate. The method, validated through systematic measurements in twenty five dwellings of two regions of India, showed that it is feasible to estimate indoor thoron dose.



Vacuum based wall mounting accumulator

NPCIL has recorded about 539 reactor years of safe operation of reactors by the end December 2020. 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.

NPCIL is committed in the implementation of ALARA (As Low As Reasonably Achievable) principles in all radioactive works carried out at NPPs to ensure that occupational exposures and releases of radioactive effluents from NPPs are maintained well within the limits stipulated by AERB. Radiological Safety Performance Indicators (RSPI) have been developed for the assessment of Plant performance based on radiological parameters. NPCIL continue to maintain low radiation exposure in the public domain due to operation of nuclear power stations.

At operating stations of NPCIL, certified Environmental Management System (EMS) as per ISO-14001:2015 and Occupational Health and Safety Management System (OHSMS) as per IS-18001:2007 are maintained and regular audits (internal, external and management) were carried out for continual improvement.

Ministry of Environment, Forest and Climate Change (MoEFCC) accorded Environmental Clearance (EC) and National Board for Wildlife (NBWL) accorded Wildlife Clearance for Kaiga Atomic Power Project units-5&6 (2x700 Mwe, PHWRs). Environmental Impact Analysis (EIA) report & subsequent NPCIL responses to the observations of Expert appraisal Committee (EAC) for EC for Mahi Banswara Atomic Power Project (4x700 MWe, PHWR) are under appraisal with EAC, MoEFCC. For Nuclear Power Project (NPP) at Kovvada, three season environmental monitoring reports and draft EIA report based on three seasons data are under preparation. Process of obtaining Environmental & CRZ Clearances for Away from Reactor (AFR) for KKNPP-1&2 is in progress.

Industrial and Fire Safety aspects is being ensured through comprehensive Oversight and Support functions. NPCIL is maintaining a safe workplace by minimizing the risk of injury, fire and exposure to ill health for all employees and contractors. NPCIL is strongly committed to convey safety culture and safety values to the employees. Operating Plants and Construction Projects of NPCIL received various awards, National and State level recognitions from National Safety Council of India.

The Environment Stewardship Programme (ESP) is a voluntary activity of NPCIL for the conservation of nature in and around our sites. ESP focuses on the scientific study and conservation of the bio-diversity in and around the Exclusion Zones (EZs) of NPPs.

The association of NPCIL with various expert Institutions like Bombay Natural History Society (BNHS), Wildlife Institute of India (WII) and others, has enhanced its' ESP activities manifold. With WII, NPCIL has done public outreach activities on Clean Ganga Mission. Different activities like, educating fishermen, displaying posters, lectures on clean Ganga to villages, awareness to students on clean Ganga, rescue and rehabilitation of species for clean Ganga mission etc., are done in association with them. The Turtle facility at NAPS is also enhanced by the expertise help of WII. Bird marathons are being organized periodically at Kaiga Generating Station (KGS), KKNPP and NAPS to update database on the bird species found in the region with the active participation of professional environment conservation agencies. The artificial Mud-Flat is developed and mangroves are planted in and around township and plant areas at KKNPP with the expert help of Bombay Natural History Society (BNHS).

Overall safety management was excellent at all the Heavy Water Plants.

RESEARCH & DEVELOPMENT

NPCIL is engaged in setting up of R&D Facilities and carrying out experimentation, development & qualification of remote tools for inspection/ maintenance of Nuclear Power Plant (NPP) components/ equipment, indigenization and adoption of state-of-the-art technologies. These activities are required for achieving continual enhancement of nuclear & radiation safety, reliable operation, Vendor base broadening, product development and cost reduction of Nuclear Power Plants. For the financial year 2020-21, major achievements/ progress achieved are as follows:

R&D Facilities

Primary Coolant Pump Test Facility (PCPTF)

PCPTF is being set up at R&D Centre, Tarapur for design qualification and performance evaluation of indigenously manufactured PCP for future 700 MWe reactors.



PCP Test Facility Structural Building

PCP Condition Monitoring instruments & Centrifugal pumps are already manufactured and delivered.

Fuelling Machine Test Facility (FMTF)

The dedicated FMTF at R&D Centre facilitates full scale operation simulation and performance evaluation of 700 MWe Fuelling Machine (FM) Heads, including simultaneous operation of a pair of FM Heads. Subsequent to calibration, testing and delivery of two KAPP-3 Fuelling Machine (FM) Heads, similar activities for the FM Head from new Vendor for RAPP-7&8 are being carried out at FMTF.

Environmental Qualification (EQ) Activities

During 2020-21, more than 100 items were subjected to environmental qualification testing for NPP application at the EQ Facility of NPCIL R&D Centre.

Qualification of Air Washer Spray Nozzle by Experiments

In Indian PHWRs, air washer systems are widely used to maintain the temperature and humidity of the air supplied to different areas in Nuclear Power Plant. Evaporative air conditioning is used in 700 MWe PHWRs. In direct evaporative equipment or air washers,



Air Washer Spray Nozzle Experiments

reduces dry bulb temperature of air, raising humidity. For the effective evaporative cooling, In order to optimize spray nozzle parameters without affecting the performance of the system, wide range of studies were conducted on a number of spray nozzles with different configurations with a test facility and parameters have been optimized.

Remote Tooling

Coolant Channel Life Management Related Activities

In-Service Inspection (ISI) campaign of PHWR coolant Channel Pressure Tubes using BARCIS was carried out with integrated Inspection Heads at 220 MWe and 540 MWe Operating Stations.

Design and Qualification by Analysis of 220 MWe Pressure Tube Shielding Flask

Design of the 220 MWe Pressure Tube Shielded Flask for transport is completed, performance tested, qualified.



3-D model of Pressure Tube Shielding Flask

Remotely Operated Delivery System (RODS) for 220 MWe Moderator Hxs

In-house development of RODS for inspection of 220 MWe Moderator Heat Exchanger Tubes is in progress. Assembly of RODS with standard industrial Robot is being taken up, which will be followed by integrated testing and qualification.

Cobalt Adjuster Rod Dismantling System (CARDS)

Cobalt based Adjuster Rod assemblies (Co-ARs) have been designed for 700 MWe PHWR units, with a view to generate Co-60 sources for further utilization by BRIT. A Cobalt Adjuster Rod Dismantling System (CARDS) is being developed for carrying out under water dismantling of irradiated Co-AR assemblies. The system is designed for remote underwater dismantling, using a custom built pneumatic tool, of irradiated Co-ARs in Spent Fuel Storage Bay and retrieval of Cobalt Bundles, for transportation and further processing at BRIT. The CARDS assembly is under advanced stage of fabrication.

Indigenization

Indigenous development and Vendor base broadening for various critical components and equipment continue to be pursued for self-reliance. Commercialization is in process for adopting indigenous technologies developed in the recent past for future reactors.

700 MWe Main Steam Line Venturi

Indigenous development of 700 MWe PHWR Main Steam Line Venturi for measurement of steam flow rate, between the Steam Generators and Turbine, required for power measurement was completed



Venturi under forging



Venturi under heat treatment



As forged Venturi under machining



Venturi under UT profile machining



Main Steam Line Venturi

successfully as a single piece carbon steel forging. Calibration of the full size Venturi has been completed successfully.

Boiler Feed Pumps for 700 MW reactors

Indigenous development Boiler Feed Pumps (BFP) for 700 MWe reactors by Vendor is in progress. Endurance testing of Booster Pump, type and routine testing of motors completed.

R&D In Electronics, Control & Instrumentation

Design of identified Computer Based System Input/ Output modules and Alarm Modules improved and work initiated to obtain manufacturing information for the updated design. In light of COVID-19 and the nationwide lockdown, alternate arrangements were made with KAPS-1&2 site team, for KAPP-3 site validation activities. The new site validation task forces were trained through video conferencing and completed the mandatory requirements of AERB for criticality of KAPP-3. Upgradation of computer based protection system was done at KAPS-1, Reactor Regulating system at KGS-2 and Emergency Injection testing system at KGS-2 and KGS-3.

Engineering

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

Electrical

Requisition for procurement has been raised for Emergency Diesel Generators for GHAVP-1&2. Requisitions for Power Transformer and 400kV Reactor packages for GHAVP-1&2 are in advanced stage of release.

GHAVP-1&2

C&I Specifications for Control center instrumentation are completed and requisition for procurement is raised. C&I Specifications for Field instrumentation are nearing completion.

Information Technology

NPCIL Recruitment Portal is enhanced to use Artificial Intelligence. An Electronic file / proposal system called 'eNote' has been adopted which is being used across NPCIL for electronic movement of files helping in faster decision-making process.

Simulator

The first 700 MWe Full Scope Replica Operator Training Simulator (FSTS) with KAPP-3 as the reference plant was enhanced. Phase-1 of Fuel Handling System (FHS) simulations were also added to make the simulator cater to training of FHS operators, before first criticality of KAPP-3.

The layouts of NTC and simulator facility have been finalized for the 700 MWe FSTS for GHAVP-1.

The layout of simulator facility for the 700 MWe FSTS for Kaiga-5 has been finalized and issued.

R&D relating to PHWR

Fabrication and testing of heavy water upgrading column sections of second heavy water distillation tower of KAPP-3&4, NPCIL was completed. Reduction of noise level (by installation of sound proofing panels) during pneumatic grinding step from 90 dB to 75 dB has improved the ergonomics of the process and safety of the workers against noise pollution.

The methodology involves identification of a single structural component such as an end-fitting, estimation of the activation flux seen by it, and application of the radio-nuclide inventory code ORIGEN2. For some components like end fitting, end



Packed upgrading column sections ready for dispatch to NPCIL site

shield, etc., the component is divided suitably, to account for the neutron flux variation to estimate the activity. The activities of various radionuclides are generated for different in-core components. An irradiation period of 40 years is used for all the components except coolant tubes, garter springs, end fittings, shield plug and fuel locator. En-Mass Coolant Channel Replacement (EMCCR) is proposed for these five components at the end of 20 years. A capacity factor of 85% is used for all the components. The activities calculated for all the components are followed for a decay period upto 50 years after shut-down. The components removed in EMCCR would be followed up to 70 years. The ORIGEN 2 code also gives the 18 group photon energy spectrum for each component which is used to estimate radiation field on using Monte Carlo based code. The result of the present study shows that the shutdown activity of the Zr based alloys is determined mainly by Zr-95 and Nb-95 in the initial decay period of half a year and later by C-14, Co-60, Ni-63 and Nb-94 in the. For the stainless steel components, the initial activity (half year) is determined by Co-60, Ni-63, Fe-55 and Cr-51 and in the later stage (50 years or more) by the Ni-63, Co-60, Ni-59 and C-14. Among various components studied, end shield is the hottest component initially and over the medium term, where the activity is controlled almost entirely by the decay of Co-60. In decommissioning work, the most of the activity comes from Co-60 in the near to medium term.

A system to measure vibration and pressure pulsation in the Primary Heat Transport (PHT) system of 700 MWe PHWR capable of real time data acquisition & processing and remote monitoring for configuration, data & parameter viewing with data filtering and data saving options was developed. The software to analyze the structural vibration and pulsation signals works both in online and off-line modes. The Graphical User Interface provides various parameters extracted from the data in real time. The system was integrated and tested with transducers and remote monitoring system and ready for field trials.

In Service Inspection (ISI) to detect defects using Ultrasonic Testing (UT) and characterise them, is an important part of PHWR Coolant Channel Life Management. Apart from defect detection, UT is capable of dimensional measurements such as size and location of the defects. Depth of a defect is estimated by comparing the echo amplitude with that of a standard



TOFD Inspection Head with 5 probes



BARCIS Inspection in TAPS 3 & 4

defect. In order to characterize large defects a new tool based on UT Time of Flight (TOF) technique was developed. BARC Channel Inspection System (BARCIS) inspection head with 5 probe TOF detection cluster was developed and qualified in lab conditions and deployed for ISI. New calibration spools with 2%, 5% and 10% of wall thickness deep defects were designed and manufactured. The spools were incorporated into the loop of full scale mock up facility at TAPS 3&4. It was observed that the depth of defects estimated by ToF technique for large defects were in close agreement with metrology reports.

Post Irradiation Examination (PIE) helps in generating data on irradiated pressure tubes, which are cut inside a hot cell, to make samples for detailed examination. Aspects like extent of corrosion, hydrogen pick-up, hydride platelet distribution and orientation were microstructurally examined for nearly twenty different pressure tubes or its rolled joints, from five different reactors. Heq analysis, fracture toughness, delayed hydride crack velocity and threshold stress intensity factor were evaluated. Heq pick up in the PT stubs received from various reactors was analyzed for performance evaluation by Differential Scanning Calorimetry (DSC).

Fracture toughness and Delayed Hydride Crack (DHC) growth velocity, for irradiated Zr-2.5Nb pressure tubes, were determined at different temperatures, depending upon the number of specimens available from the length of rolled joint stubs. Tests were carried out using 22.22 mm width Disc Compact Tension (DCT) specimens (around 100 specimens were used for fracture toughness and around 20 specimens for DHC velocity measurement). Different steps involved in fabrication of DCT specimens, were trepanning of 30 mm diameter disc coupons, drilling and notching of the coupons to get DCT specimen and then welding of four Zircaloy wires to each specimen, for online crack monitoring during the tests. The specimens were pre-cracked using load-decreasing method before fracture toughness and DHC tests.

Large number of rolled joint stubs, from double melted pressure tubes from KAPS-2 and F-10 of KAIGA PHWR, were evaluated for fracture toughness from ambient temperature to 2500C. The toughness was found to be much higher, even at ambient temperature, for quadruple melted rolled joint stubs from TAPS-4 and it didn't change much with the increase in temperature up to 2500C. The lower bound toughness for quadruple melted Zr-2.5Nb tubes was found to be higher for the entire test temperature range.

DHC tests were carried out, at different temperatures, on specimens without any additional hydriding of the stub specimens. The DHC velocity showed increasing trend with temperature and the values were in the same range for double melted and quadruple melted pressure tube stubs. Until past few years, the data available in literature on the properties of irradiated Zr-alloys was used in the design calculations and safety evaluation. However, in recent years, extensive infrastructure development and augmentation of mechanical testing of irradiated materials has resulted in determining various parameters and properties related to irradiated pressure tubes within BARC itself. Henceforth, all the design and safety evaluation will be based on in-house determined database on fracture toughness, DHC velocity, H-pick-up, etc.

During LOCA there is insufficient cooling and rise in temperature of cladding tube. The fall in the outside coolant pressure and the increased inner fission gas pressure cause ballooning. Literature review and PIE experiments on irradiated cladding had shown the effect of irradiation getting annealed out and ductility being restored at 600ºC. So, burn-up effect on the ballooning-burst behaviour of the PHWR fuel cladding boils down to the effect of oxide layer and the hydrogen picked up during service only. Clad tubes were preoxidised to two sets of different oxide layers and will be used for ballooning and burst test.

Effects of oxygen and temperature on transverse mechanical properties of Zircaloy-4 cladding were investigated. Ring tensile specimens with gauge sections were preoxidised to different thicknesses (to simulate burn-up effect on cladding) and tested from room temperature to 600°C. Mechanical properties derived from these tests will be utilized as input parameters for modelling and simulating the ballooning and burst behaviour of fuel pins.

Ring tension tests were performed on the hydrided cladding (25-400 ppm) from room temperature to 600C. SEM fractographs of the cladding having 300 ppm of hydrogen show no remarkable effect of hydrogen on mechanical properties viz. YS, UTS and total elongation as seen in the figure below, but the effect of temperature could be seen. Increasing temperature caused significant reduction in yield and tensile strength, and an increase in total elongation. These data will be used as input for predicting transient deformation behaviour of cladding under LOCA condition.

Three healthy steam generator (SG) tubes from KAPS-1 (61/44), RAPS-3 (R32-C69) AND KGS-2(R41C66), which had seen different years of operations, were cut and sent for PIE to analyse metallurgical damage. The only difference between the three SG tubes was the extent of deposits on OD and ID of the tubes, which were confirmed to be Iron oxide by EDS, and the SG tubes were found to be fit for service. OD deposits above rolled region were seen on all SG tubes. The OD oxide deposits were not adherent while the ID oxide was relatively more adherent and thick. The grains of ID oxide were large compared to those of OD. There was no evidence of microstructural damage beneath the oxide deposits. There was no metallurgical degradation near the OD surface due to the oxide deposit. The chemical analysis also pertains to the Incoly-800 specification. The microstructure of the Incoloy-800 contains many precipitates (Titanium) which are as expected in this alloy.

Post Irradiation Examination of Fuel bundles were carried out inside hot cells using various non-destructive and destructive techniques. Visual examination, leak testing, profilometry, ultrasonic testing, gamma scanning, eddy current testing can identify the location of the fuel pins. Destructive techniques like fuel pin puncturing and fission gas analysis, microstructural examination using optical and Scanning Electron Microscopy (SEM) were carried out to understand the behaviour of the fuel under irradiation. Mechanical testing of the clad using Ring Tension Test (RTT) was used to assess the extent of ductility loss due to irradiation. Radiochemical burn-up analysis of the fuel was carried out to estimate the fuel burnup. The feedback from PIE is used by the fuel designer, fuel fabricator and the reactor operator to bring about suitable changes for improved performance of the fuel. PIE of PHWR fuel bundles irradiated to varied burnups has been carried out.



Irradiated PHWR fuel bundle inside the hot cell
Dimension measurement of fuel bundle



Irradiated PHWR fuel bundle inside the hot cell
Dismantling of fuel pins

R&D relating to LWR

The forged ring parts of the reactor vessel of low alloy steel corresponding to western grade composition 20MnMoNi55 were manufactured and characterized for the Ductile to Brittle Transition (DBT) at various locations and orientations of the forgings using the procedure outlined in ASTM 1921-15 to determine the reference temperature T_o. A minimum of six specimens were tested below ambient temperature and the temperature dependence of the fracture toughness parameter, KJC in the DBT temperature regime incorporating the limits corresponding to 5% and 95% Weibull failure probability levels have been generated.

An indigenous high sensitivity 10B lined proportional counter with super screened peek cable for low noise performance with neutron sensitivity of 4.5 cps



High sensitivity ^{10}B lined PC for LWR



Prototype Reactivity Meter for LWR

/ nv was developed for LWR. The Proportional Counter is suitable for fuel loading with low strength neutron source.

Prototype Reactivity meter for reactivity-worth estimation in LWR was developed and tested. The meter comprises of Signal Conditioning Unit (SCU), Reactivity Computation Unit (RCU) using Kalman filter based algorithm to compute reactivity worth.

Integrated Test Facility for Radiation and Gas Monitoring System (RGMS) for LWR is established at site for Training, Operation, Maintenance and Verification of System.

Reactor Pressure Vessel (RPV) Surveillance specimens from Kudankulam VVER along with the archive basket set containing type and number of specimens of virgin RPV material (for generating baseline data under similar test conditions) were received for examining degradation in mechanical properties due to thermal embrittlement. Three different types of specimens namely round tensile specimens, Charpy V-notch impact specimens and Compact Tension (CT) fracture toughness test specimens were part of the specimen sets received. The material properties have been evaluated in detail from sub-zero to elevated test temperatures. Changes in mechanical properties of surveillance specimens were found to be small ensuring the structural integrity of the RPVs.

CHAPTER 2



Overall view of PFBR from East Side

NUCLEAR POWER PROGRAMME STAGE-2



An Annular Linear Induction Pump (ALIP) installed in sodium test loop

FAST REACTORS

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

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

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

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

Prototype Fast Breeder Reactor

Government of India accorded administrative approval and financial sanction for setting up of 500 MWe Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, in September, 2003.



Overall view of PFBR from East Side

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), a Government Company was established on 22nd October 2003 at Chennai, Tamil Nadu, as a Special Purpose Vehicle, for implementing the India's first Prototype Fast Breeder Reactor (PFBR) project.

The major activities that have been completed during the reporting period and the plan ahead for the current financial year are as follows:

After successful operation of both the secondary sodium loops, from March 2019 till October, 2019, it was shut down for initiating rectification & in-situ modification of the large rotatable plug bearing. Presently, the bearing rectification/modification has been completed, which required innovative & meticulous planning by both designers (from IGCAR) and commissioning teams (from BHAVINI) and also necessitated R&D and technology development efforts for manufacture of large diameter spacer balls through an MSME. Further, the Transfer Arm (which forms a part of the fuelling machinery), which had been suitably modified and re-installed back on pile, was also tested extensively, for confidence building. Further, during the period of secondary loop operation, extensive vibration measurements were carried out on the Secondary Sodium Pumps (SSP), at various speeds of operation, and also on the piping and Intermediate Heat Exchangers (IHX), in order to closely validate their theoretical designs and performance at high operating temperatures.

Considering that there have been a number of performance shortfalls and equipment faults, during the past four years of commissioning efforts, a graded approach is being undertaken, wherein the commissioning of the various systems & equipment are being taken up, systematically & sequentially, in incremental steps and their performance checked at each step. A detailed design validation exercise was also undertaken, by expert teams from BARC and also other units of DAE, since all the PFBR Sytems, Structures & Equipment (SSE) are First-of-a-Kind (FOAK) design, and the graded approach being undertaken for commissioning, were also closely reviewed and approved. Presently, testing & commissioning of the various systems & equipment of both the primary systems and fuel-handling systems,

are progressing in parallel and at various stages the commissioning procedures and associated safety aspects are being closely formulated/reviewed along with the design teams and regulatory teams. Further, various other on-pile testing jobs and minor in-situ reactor-assembly modifications, are in progress, as a pre-requisite to commissioning of the primary system.

Modification of Guard Pipe Nitrogen Circuit pipe lines of Decay Heat Exchanger & Intermediate Heat Exchanger lines are in progress for design improvement.

The activities that are planned to be completed for the remaining period of this financial year i.e. from January, 2021 to March, 2021 are Modification of Guard pipes for the remaining two Decay Heat Exchangers (DHX) and four Intermediate Heat Exchangers (IHX); Deployment of Reactor Core Viewing system towards inspection of surfaces of dummy core subassemblies and the grid plate top; Completion of manufacture of indigenously developed spacer balls for Small Rotatable Plug bearing; Preparatory works for modification of Small Rotatable Plug bearing and Modification of labyrinth clearance of one Primary Sodium Pump based on Secondary Sodium Pump operational feedback, analysis & experimental validation.

Presently, works are in progress for modification of Guard pipes for the remaining two DHX and four IHX and replacement of balls in the bearing of Small Rotatable Plug (SRP). Commissioning of fuel handling system is in progress in parallel. After completion of modifications in SRP bearing, pre-heating of reactor assembly will be done towards commencement of sodium filling in Main Vessel. This will be followed by isothermal testing and fuel loading.

During the year, for supply of first and second core sub-assemblies and special sub-assemblies required for PFBR, the many items were manufactured and supplied by NFC towards 2nd Core requirements.

RESEARCH & DEVELOPMENT FOR FAST REACTORS

Fast Breeder Test Reactor (FBTR)

At IGCAR, the 29th irradiation campaign with core of 56 fuel subassemblies (48 Mark-I + 8 MOX) was conducted with the mission for continued irradiation of four types of metallic fuel pins and long-term irradiation of structural materials. The first ever valving-in operation, improved the thermodynamic efficiency of the steam cycle with an increase in Turbo Generator (TG) output of 500 kWe. During the campaign, reactor tripped due to fault in Ward-Leonard drive system and the fault was identified and rectified. The reactor was restarted and TG was synchronized with the grid. Subsequently, the reactor underwent SCRAM on 'DN (Delayed Neutron) activity high' parameter in both loops. By following the standard procedure, the failed fuel subassembly was identified and shifted to in-vessel storage location for cooling before its discharge.

One of the control rods and its outer sheath which have seen its design fluence limits were discharged from the core and new qualified outer sheath and control rod were loaded. In order to facilitate outer sheath removal, six adjacent subassemblies were shifted to the peripheral locations after creating six vacancies by discharging six burnt subassemblies in storage locations.

In Ward-Leonard drive system of primary sodium pump, existing flywheel assembly having split housing prone for high vibration and premature bearing failure has been replaced with Plummer block flywheel assembly which gave improved performance.

All the major surveillance checks including efficiency testing of Reactor Containment Building (RCB) exhaust filter banks were carried out.

COVID-19 guidelines viz. ensuring the usage of masks & hand sanitizers, disinfection of plant entrances, turnstiles, security & corridors, control rooms (keypads, panels, handsets, telephones, etc.) are being done regularly.

Safety report for the 30th irradiation campaign with a mission to raise power to its designed power of 40 MWt is under regulatory review and review comments are being addressed. Production of B_4C pellets (B^{10} IP-50%), for the four poison subassemblies required for the 40 MWt core, is in advanced stage of completion at HWP, Manuguru.

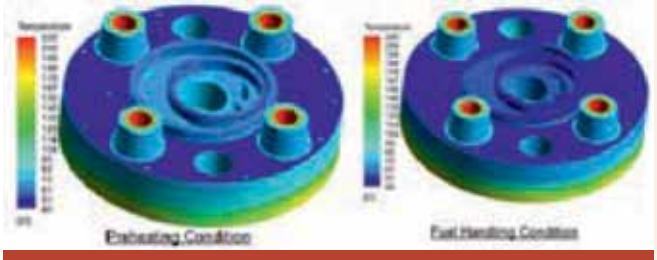
For the 40 MWt operation of FBTR, it is proposed to use 70 numbers of Mark-I Sub-Assemblies (SA) in the core together with four numbers of Poison Sub-Assemblies (PSA). These PSAs contain 50% enriched B_4C. Hydraulic characteristics have to be established for these subassemblies, which includes characterization of pressure drop, flow induced self-lifting and cavitation. Towards this, a full-scale dummy PSA was manufactured and tested in water. The picture shows the test setup and pressure drop obtained experimentally through the subassembly for different flow rates. The tests for lift of PSA also indicated a large margin with respect to nominal flow. The PSA was also found to be free from cavitation even at a flow corresponding to 110% of nominal flow.

R&D relating to PFBR

Technical Support Related to PFBR Commissioning

Three-Dimensional Thermal Hydraulic Analysis of Top shield

A detailed three-dimensional Computational Fluid Dynamics (CFD) study of top shield (roof slab, Large & Small Rotatable Plugs (LRP/ SRP)) was carried out to estimate the circumferential temperature distribution near LRP and SRP bearing races under preheating and fuel handling conditions. The analysis was computationally intensive and required fine meshing. The picture shows the circumferential temperature distribution on the top race and bottom races of LRP and SRP bearing during preheating and fuel handling conditions. Maximum circumferential temperature gradient predicted in the bearing races of SRP and LRP during preheating and fuel handling conditions is 6oC with forced air cooling provided within top shield.



Temperature distribution in top shield

In-sodium Performance Evaluation of Primary Sodium Purification Circuit Electromagnetic Pump

The main vessel holds approximately 1180 T of sodium. The purity of sodium has to be maintained as per specifications to avoid precipitation of impurity in certain narrow sodium flow paths in the primary circuit precluding flow blockage. Hence a sodium purification system is provided, which is used to maintain the sodium purity. An Annular Linear Induction Pump (ALIP), one variant of electromagnetic pump which does not have any mechanical moving parts are used for pumping the sodium in the purification circuit. The ALIP of capacity 50 m^3/h flow at 4 bar pressure drives the sodium into sodium purifying device called cold trap. In-sodium performance testing of this ALIP was carried out to generate its operating characteristic and to verify its adequacy to meet system requirements. Tests were conducted at the operating sodium temperature of 450°C including endurance testing of 2000 hours at pump rated operating condition. Hydraulic characteristic curves (Head vs Flow) of ALIP obtained through the performance evaluation test is depicted in the picture.



ALIP installed in sodium test loop

Evaluation of Rotor dynamics Coefficients of Secondary Sodium Pump through CFD Analysis

In Secondary Sodium Pump (SSP), there are two wear rings (plain seals) provided, called as suction wear ring and discharge wear ring, to reduce the backflow of high-pressure sodium from discharge side. The rotor dynamic coefficients of the suction wear ring and impeller-casing region of SSP were determined

using CFD technique. In this analysis, the rotor is excited with a known sinusoidal perturbation and the time varying response forces on the rotor surface are estimated using general purpose CFD software, from which the rotor dynamic coefficients are computed. CFD methodology is validated against the experimental data as well as analytical and numerical data for rotor dynamic coefficients available in literature. The following picture shows the variation of stiffness and damping coefficients with increasing SSP speeds. It has been observed that the rotor dynamic coefficients increase with increasing speed. Stiffness coefficient increases steeply as compared to damping coefficients with speed. The results of these studies were used as input for detailed dynamic analysis of the pump.

Estimation of fission product dilution at the inlet of FFLM sampling tubes

Analysis has been carried out towards estimation of concentration dilution in delayed neutron precursors during sampling of each subassembly while deploying Failed Fuel Location Module (FFLM). A three-dimensional CFD model of hot pool has been developed to estimate the dilution at the inlet to FFLM sampling sleeves. Discrete inlet boundaries to represent subassembly outlets at core top have been modeled. Each FFLM sleeve along with thermo-wells for each monitored fuel and blanket subassembly have been modeled. From these studies, fission product dilution is found to be insignificant for all fuel subassemblies. A maximum dilution of 0.2 % is observed during sampling for fuel subassemblies situated at peripheral locations of reactor core. A low dilution ensures reliable and accurate sample collection for failed fuel localization. However, for blanket and peripheral fuel subassemblies, large dilution is observed. This aspect will be considered while sampling and analysing peripheral core locations.

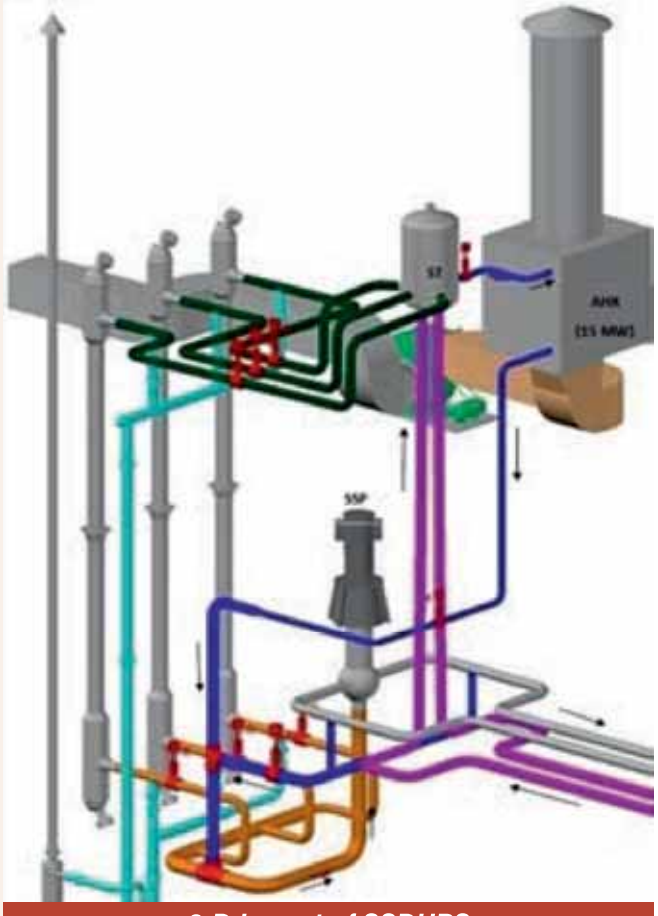
Simulation of Pressure Transient during Turbine Trip Event

The steam lines of steam water system have been modeled using FLOWNEX code along with the pressure relief valves (Safety Relief Valves-SRVs), Instrumented Relief Valves (Atmosphere Steam Discharge Valve-ASDVs) and high-pressure bypass valve for the as-built conditions in the plant. The event of turbine trip has been simulated using the model to estimate the maximum pressures in the steam lines due to pressure transient. Event simulation has been carried out using 2 bounding approaches. The maximum pressure reached in the steam lines during the event is 14 % higher than the nominal value in both the approaches which is within the permissible level.

Design of Future FBR

Design of Secondary Sodium based Decay Heat Removal Circuit

PFBR has two diverse paths for removing decay heat namely, Safety Grade Decay Heat Removal System (SGDHRS) and Operation Grade Decay Heat Removal System (OGDHRS). OGDHRS requires availability of at least one secondary sodium circuit, steam water circuit and off-site power supply for removing decay heat. SGDHRS is operated when OGDHRS is not available. For future FBRs, an alternate option of decay heat

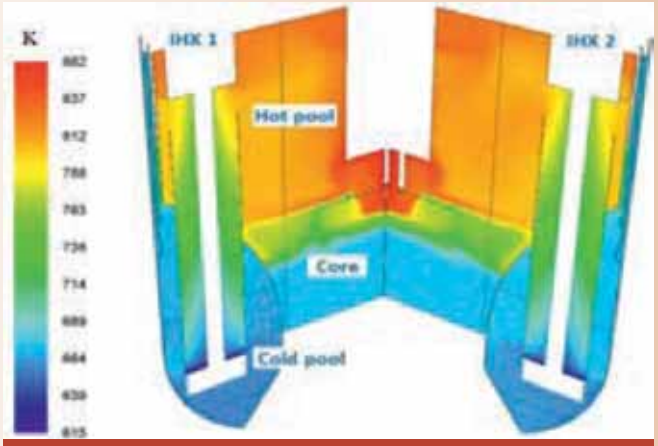


3-D Layout of SSDHRS

removal through secondary sodium main circuit was studied, thus reducing the dependency on SGDHR system. The reliability of this system is higher as compared to OGDHRs due to its independence of off-site power supply and steam water system components. Secondary Sodium based Decay Heat Removal System (SSDHRS) is designed for a heat removal capacity of 15MWt/loop in forced circulation mode in both sodium and air sides. The schematic arrangement of SSDHRS is shown in the photograph. Heat removal capacity of the system with passive mode of operation (both sodium and air-side) has also been studied and found to be 60% of that of active mode. Thermal hydraulic analysis has been carried out to establish the performance of the system under steady state and transient conditions. Steady state performance of SSDHRS have been analyzed by varying the temperature of hot pool sodium in the range of 200°C to 650°C and the results are shown. The heat removal capacity is estimated as 15.17MWt at the normal steady state operating hot pool temperature of 544°C. Heat removal capacity increase with sodium temperature is found to be nearly linear. Analysis has also been carried out to study the performance of the system during off-site power failure event in the plant. Evolutions of hot pool and cold pool temperatures under this condition are shown. The maximum hot pool and cold pool temperatures reached are 513°C and 498°C respectively, which are well within the design safety limits for the event.

Thermal Hydraulic Analysis of Hot and Cold Pools

A three-dimensional computational fluid dynamics model that includes both hot and cold pools along with all major immersed components has been developed to enable integrated thermal hydraulic reactor pool studies. Development of a three-dimensional model is a challenging task due to the large dimensions, several immersed solid structures and requirement of modelling components with widely different scales. Further inclusion of internal structures like spherical headers, primary piping etc. complicates the task of mesh generation. Using the developed model both steady state and transient analyses have been completed. The main focus of this work is on resolving temperature distributions of important

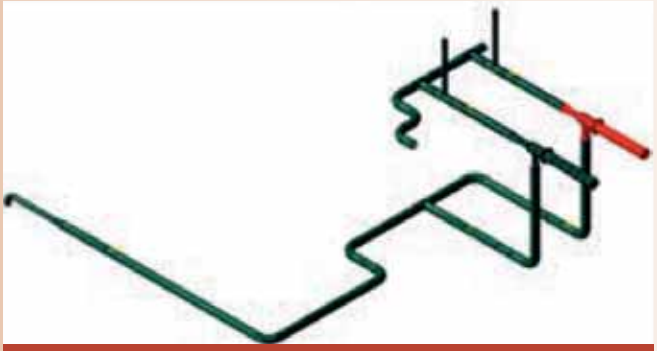


Temperature contours at radial sections through IHX-1 and 2

structural components, viz., inner vessel, main vessel, primary piping, pump and heat exchanger standpipes, headers etc. during full power operating conditions of reactor. The maximum temperature difference across inner vessel thickness is found to be 85°C. Heat bypass from hot to cold pool through inner vessel is another important quantity estimated from this study and is found to be 15.4 MW for full power operation. Other important aspects predicted include cross flow velocity patterns in cold pool; free surface velocity profile in hot pool and velocity & temperature distributions at the inlet and outlet windows of Intermediate Heat Exchangers (IHX).

Vibration Limits for EM Pump in Secondary Sodium Fill & Drain Circuit

The vibration measurements carried out on Electro Magnetic (EM) pump dished end, suction and discharge locations of secondary sodium fill & drain circuit in PFBR show that the vibration in EM pump contains predominantly high frequencies. There is a possibility of fatigue at critical locations due to internal vibration of EM pump or its connected piping. In the absence of qualitative force data, measured accelerations data are used as guiding source for generating forces in EM pump. In a series of dynamic analysis, forces in EM pump at the various locations are applied and scaled, such that the measured acceleration can be reproduced. In the piping region, surface traction is applied in suction and discharge sides, with applicable piping frequency to create resonance on both sides, such that bounded velocity response attained due to resonance is 12 mm/s. With



Integrated piping EM pump layout with pump with solid elements shows in red colour



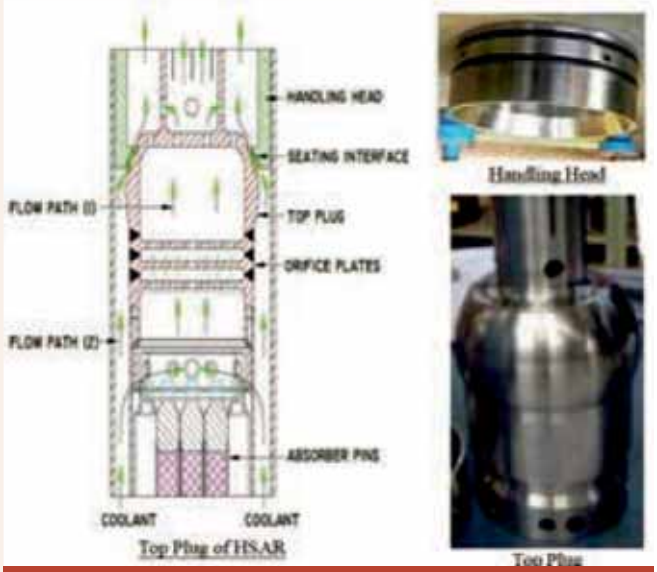
von Mises stress (Pa) distribution in EM pump nozzle location

these generated forces, detailed dynamic analysis of integrated model is carried out to assess fatigue damage. The maximum stress range (ΔΣ) is found to be 84.8 MPa. The stress amplitude computed from stress range as per ASME Sec-VIII, Division-2 is 60.5 MPa, which is less than endurance limit of S-N curve. Based on dynamic analysis, in suction and discharge piping layout, vibration velocity of 12 mm/sec is acceptable. The vibration accelerations on EM pump dished end, less than 25 m/s^2 in vertical direction, 15 m/s^2 in horizontal direction and 15 m/s^2 in axial direction are acceptable. The measured vibration values are within the estimated limiting values.

R&D on FBRs

Design Validation of Top Plug of HSAR by Hydraulic Testing

Hydraulically Suspended Absorber Rod (HSAR) is a passive device, which can shut down the reactor in case flow through the HSAR subassembly drops to a pre-defined fraction of the nominal flow rate. It is planned to introduce HSAR in the future FBRs to take care of Untripped Loss of Flow event (ULOF). 50% of the nominal flow rate is selected as the condition for dropping of HSAR into the reactor core. Coolant enters into the HSAR subassembly sheath through grid plate sleeve. After passing through the absorber pins and



Hydraulic Validation of Top Plug of HSAR



Bellows Test Rig

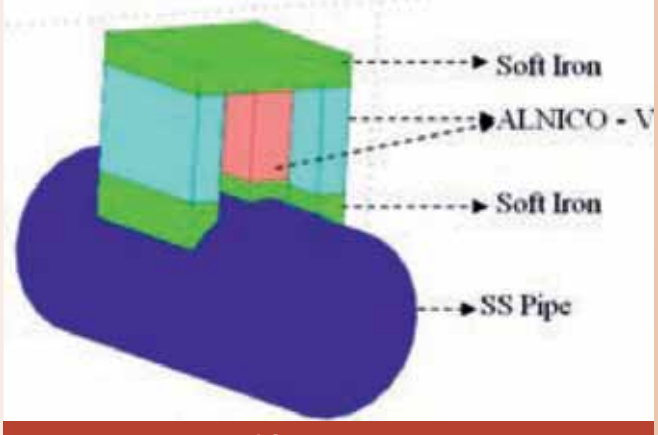
annular space, it exits through the top plug of HSAR. The differential pressure across pressure drop device inside the top plug provides the required drag force to keep the HSAR in suspended condition under normal conditions. The pressure drop device provided is an assembly of four multiple orifice plates. The experimental validation of the pressure drop device to generate the required pressure drop at given flow rate was carried out. The seating interface between top plug and handling head plays a crucial role in the reliable operation of the HSAR. A full-scale top plug assembly with pressure drop device and seating interface was fabricated. The hydraulic testing of top plug assembly with seating interface has been completed. It has been found that the pressure drop device is generating the designed pressure drop and keeps the HSAR in suspended condition till nominal flow rate is reduced to 51%, which is nearly equal to the target flow rate set for HSAR drop. Thus, the hydraulic design of the top plug of HSAR has been validated.

Testing of 800 NB Inconel-625 Bellows in Sodium

Towards possible use of bellows in secondary sodium main circuit, particularly at the inlet of secondary sodium pumps, indigenous development of the large-sized bellows (size 800 NB, material Inconel-625) has been carried out. The manufactured bellows were tested in air at 3 bar pressure for 500 cycles. The movement of the bellows was applied through a hydraulic drive system with all safety and control features. Subsequently, the bellows were tested in sodium at 3 bar pressure and 530°C for 2730 cycles. Sodium testing of the bellows was carried out in Test Vessel-2 (TV-2) of Large Component Test Rig (LCTR). After sodium testing, the bellows were dismantled, sodium cleaned and then subjected to Helium Leak Testing (HLT), which was found to be acceptable.

Design and Development of 200NB Sidewall Permanent Magnet Flowmeter (PMFM)

Permanent Magnet (PM) flowmeter is used for measuring sodium flow. Conventional PM flowmeter is constructed with magnets placed on opposite sides of the pipe. Heavy weight, large space requirement and high manufacturing cost of such a flowmeter are the main problems faced during the sodium flow measurement. Instead a sidewall flowmeter for a 200 NB pipe with a lesser size & weight and which can be fixed on one side of a large pipeline has been developed. ALNICO-5 is selected as the magnetic material. 3D modeling of the flowmeter was made using COMSOL software and the average flux density near the central limb was estimated to be 0.055 Wb/m2. Three ALNICO-5 magnet blocks, Mild steel (MS) pole faces and MS rectangular block were used for making the magnet assembly. MS pole faces were fixed to south pole side of the central magnet block and north pole side of the either side magnet blocks. MS rectangular block was placed over the three ALNICO-5 magnet blocks and fixed. This is providing the path for magnetic flux. Three pairs of electrode wires were welded axially on either side of the central magnet block at an angle of 20 degrees with respect to central line of central magnet block and routed to the terminal connector. Electrodes are of 4 mm dia, Stainless Steel (SS) sheathed MgO insulated SS conductor. These electrodes are used to collect the millivolt output generated during sodium flow. The entire assembly was covered with perforated SS cover plates. To get a stable flux density distribution,



3-D Model of Sidewall PM Flowmeter



200NB Sidewall PM Flowmeter

magnet assembly was subjected to magnetization, stabilization by alternating current knock down and temperature stabilization by rapid and gradual heating cycles. Estimated sensitivity based on model analysis and theoretical studies are found to be 0.01377 and 0.02532 mV/m3/h respectively. Accuracy of the sensitivity estimate is within 7 %. Overall weight of the 200 NB sidewall flowmeter is found to be 145kg and this is 50% lesser than that of conventional ALNICO-5 based 200 NB flowmeter.

Severe Accident Studies

As a part of Severe Accident Research, an experimental facility was setup for studying Molten Fuel Coolant Interaction (MFCI) in sodium. The facility consists of a high temperature melt generation system, sodium systems with necessary auxiliary circuits and instruments. The melt generator produces simulated corium (molten mixture of alumina and iron) at 2500 °C by aluminothermy process. A 450 KV X-ray imaging system along with a digital flat panel detector was augmented for depicting the MFCI scenario. The experimental chamber is suitably provided with necessary radiation shielding. Experiments are being conducted by releasing about 2 kg of simulated corium into 40 kg of sodium maintained at 400 °C. The MFCI event was captured using X-ray imaging and analyzed through image processing software. The generation of large vapor pockets at melt jet-sodium interface and fine fragmentation of melt were observed through X-ray imaging. The fragmented debris were retrieved and analyzed for particle size distribution. Attempts are being made to deduce fragmentation mechanism by subjecting the debris particles to metallographic investigation. Assessment of debris composition towards defining the source term is in progress. Computational modeling on MFCI phenomenon is being carried out by considering direct contact of molten corium with coolant sodium from the active core region following an unprotected transient and undergoing fragmentation resulting in debris. Transient heat transfer studies have been carried out using FLUENT code. From the results of heat transfer analysis, a correlation has been developed between Stefan number and dimensionless solidification time. Thermal stresses are evaluated on the surface of the solidifying oxide fuel during MFCI. Studies are in progress by considering development of crack on the surface and its progression leading to fragmentation.

STUDIES ON MATERIALS FOR FBRs

Development of Oxidation and Corrosion resistant pyrolytic graphite coatings and corrosion studies of FBR materials

Using a newly installed Chemical Vapor Deposition (CVD) facility, highly oriented pyrolytic graphite coatings are produced on High Density Graphite (HDG) crucibles with near theoretical density (2.23 g/cm^3) for induction melting of U-Zr alloy. Also, pyrolytic graphite coating is developed on internal surfaces of low-density graphite crucibles used in cathode distillation process, for easy release of solidified ingot. The pyrolytic graphite coated components are shown in picture.



Pyrolytic Graphite coated HDG crucible and LDG mould release

In order to qualify Commercial Reagent (CR) grade nitric acid (HNO_3) for reprocessing application, the effect of impurities in HNO_3 solution on corrosion rate of dissolver material in the liquid, vapor and condensate phase were carried out. The effect of impurities in HNO_3 indicated that the corrosion rate in the presence of impurities like SO_4^{2-}, SiO_2, and Cl- is more, while the presence of Fe^{3+} ions in nitric acid lowered the corrosion rate. Corrosion rate was significantly lower when multiple impurities were present in HNO_3. The study showed that Ti exhibits superior corrosion resistance (below 10 mpy) under all conditions, including very high concentrations of impurities.

A new sulfamic acid-based formulation was developed for the effective chemical cleaning of

modified 9Cr–1Mo steel as a replacement for the conventional corrosive nitric acid (HNO_3) and HydroFluoric acid (HF) mixture. The optimal composition for efficient cleaning, with least base metal loss, was found to be 10 % sulfamic acid +2 mM MBI (Mercapto Benzim Idazole).

Creep Crack Growth Studies in Boron added Mod. 9Cr-1Mo steel weld

Towards structural integrity assessment, the Creep Crack Growth (CCG) behaviour has been evaluated in the HAZ (Heat Affected Zone) of boron added mod.9Cr-1Mo steel (P91B) weld at 898 K and compared with HAZ of P91 weld. Relative to CCG rate in HAZ of P91B weld, the crack growth rate in P91HAZ is found to be threefold. The extent of creep damage HAZ of P91B weld is found to be relatively lower than P91HAZ.

The extent of creep damage in the form of cavity distribution, cavities link-up and micro crack formation in HAZ of P91B weld is found to be relatively lower than P91HAZ as shown in picture. In P91HAZ, heavy cavitation damage & micro-crack formation are found whereas the cavity distribution saturates after 800m from the crack plane in HAZ of P91B weld. This study testifies slight improvement in the CCG resistance by boron addition of about 100ppm to P91 steel.

Evaluation of flexural strength of EB4C for FBTR absorber and poison rod

Flexural strength of 50% and 90% Enriched Boron Carbide (EB4C) was evaluated and the corresponding flexural strengths were found to be 409 and 407 MPa, respectively. These values were well above the design requirement of 150 MPa. Thus, it is meeting the required flexural strength criteria for the intended purpose.

Assessment of Transferability of Ductile Damage Parameters from Compact Type Specimen to Pipes of 316LN Stainless Steel

The transferable fracture parameters evaluated from compact type specimens have been used to predict the crack growth behavior of pipes. A close agreement between experimental and X-FEM simulations results shows that the crack initiation and growth parameters established for 316LN SS is suitable for crack growth analysis in pipes. The experimental setup of four-point bend test for pipes with insert of tested specimen is shown in picture. The maximum fracture load predicted from simulations for pipes is within 17% of experimental values.



Four-point bend test-setup with insert of tested specimen

Development and demonstration of manufacturing process for mass production of long seamless tubes of Ni-based super alloy 617M

IGCAR, as a consortium partner in the Indian Advanced Ultra Super Critical (AUSC) mission has led efforts to indigenously develop and produce long, seamless boiler tubes made of Ni-based superalloy 617M. Increased length of boiler tubes reduces the number of welds and facilitates higher thermal efficiency of 46% with 18-20% lower CO_2 emission. The ability to indigenously manufacture long seamless tubes at mass production levels has positive implications on DAE Gen-IV goals, such as their use as secondary heat exchanger tubes in the Super Critical Water Reactor (SCWR). Towards this goal, IGCAR, in collaboration with NFC and MIDHANI, developed the seamless tube manufacturing process for 9.5m length tubes, which are an improvement over current 7m tubes produced internationally. The tube manufacturing process includes alloy melting and refining, followed by multi-stage working of the billet, including hot forging, hot deep hole expansion, hot tube extrusion, multistage cold pilgering, along with the corresponding heat treatments. Individual stages were developed in



Key stages in the indigenous manufacturing of 9.5m+ long seamless tubes of Ni-based super alloy 617M

laboratory, and integrated at a mass-production scale, yielding 52 mm OD x 12 mm WT X 9500 mm long seamless tubes, which qualify all boiler requirements for high temperature and pressure AUSC boiler. The key stages in the indigenous manufacturing of 9.5m+ long Ni-based super alloy and the properties of the tubes are shown in picture.

Establishing Ultra High-Resolution Analytical Transmission Electron Microscope

A state-of-the-art Ultra High-Resolution Analytical Transmission Electron Microscope (UHRATEM) has been successfully established. The microscope is corrected for probe spherical aberration and is fitted with a Wien filter type monochromator. The microscope has 4-quadrant Energy Dispersive Spectroscopy and high-speed Electron Energy Loss Spectroscopy detectors for high resolution analytical work. Apart from High Angle Annular Dark Field Detector for z-contrast Scanning Transmission Electron Microscope imaging, there is also a Bright Field (BF), Low Angle Annular Dark Field and a four segment Annular Dark Field detector for differential phase contrast imaging.



Ultra High-Resolution Analytical Transmission Electron Microscope with control room and screening microscope

Plasma nitriding of large sized FBR components – alternate surface hardening technology

Controlled plasma nitriding of chromium plated model SS316L casing ring of the secondary sodium pump of PFBR has been carried out, without any dimensional distortion of the component. The nitrided case depth is of the order of 80 to 100 microns, and the plasma nitride layer possessed with a maximum hardness of about 860VHN (Vickers Hardness Number). Only a minor reduction in hardness, in the range of 560-700 VHN was observed upon prolonged high temperature exposure to molten sodium. The nitrided layer maintained satisfactory integrity under sodium exposure, suggesting a high stability of the plasma nitrided layer.

Thermophysical property measurement of 90% enriched boron carbide for FBTR Absorber Rod (AR) application

To achieve an enhanced neutron absorption and also to increase the resident life time of AR, 90% enriched B_4C (90% EB_4C) has been proposed for FBTR absorber rod. However, qualification of the material requires precise estimation of its thermal conductivity at reactor operating temperature. In this regard, an in-depth study has been taken up to characterize the thermophysical properties, such as heat capacity, thermal expansion, density and thermal conductivity of 90% enriched B_4C, from room temperature up to 1262 K.

FBR - FRONT END FUEL CYCLE

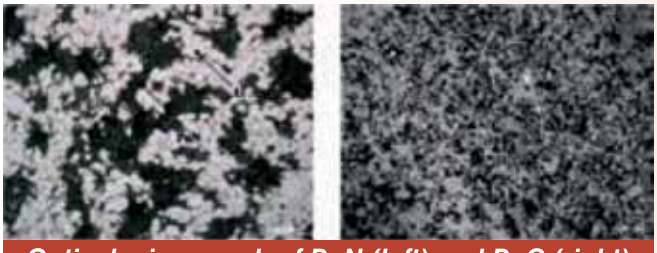
Development of CERMET (CERamic and METal) fuel for fast reactor

CERMET fuel is a composite containing fissile ceramic particles dispersed in a metallic matrix. A new concept in fast reactor fuel design, CERMET is designed to have the properties such as high temperature resistance, characteristic of a ceramic, high thermal conductivity and mechanical properties that are characteristic of a metal. Conventional powder metallurgy techniques such as mixing of ceramic particles with pure and fine U metallic powder followed by compaction were used to produce the pellets. The

pellets were sintered to 75-80% of theoretical density. CERMET fuels have a great potential in enhancing fuel performance because of low internal fuel temperatures and low stored energy.

Thermo physical properties of the CERMET fuels were studied with the fissile material varying from 15 to 25%. The stability of PuC bearing CERMET is better compared to U-PuO_2 CERMET. PuN bearing CERMET has the best physical appearance and stability. The lowest solidus temperature was seen in the case of U-PuC CERMET. U-20wt%PuN is found to have the highest solidus temperature for similar fraction of ceramic particles.

U-PuC CERMET has the highest thermal conductivity, which increases with temperature for all the fuels, which is suitable for low centre line operation. The solidus temperature of all the CERMET falls with increasing Pu content. Thermal expansion of Pu bearing CERMETs are comparable to fast reactor metallic fuel which is good for safe operation. The physical appearance of U-PuO_2 CERMET pellet was observed to be unsatisfactory and stability of PuO_2 in U matrix was poor.

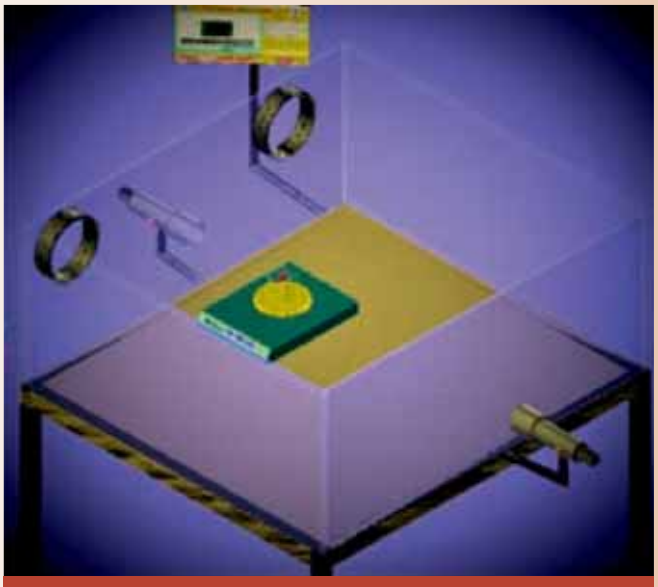


Optical micrograph of PuN (left) and PuC (right) ceramic particles in Uranium matrix

Machine vision based FBTR fuel Pellet Inspection system

Digitization of NDT techniques have been implemented in the quality control of FBTR fuel. Strenuous manual inspection was replaced by an automated machine vision-based software aided technique without compromising on any Quality Assurance parameters, rather reassuring measurability with one touch operation with this technique.

Inspection of fabricated nuclear fuel in glove box condition is both time consuming and important



A schematic of the system inside the glove box



Glove box operation



System setup outside the glove box

from man rem consideration. The present system has been designed in such a way that it suits to operation under glove box condition with minimal contact for fuel pellets inspection. Manual inspection and measurement of each pellet is eliminated by the automated software aided machine vision system consisting of an arrangement of concentric lens and LED illumination source along with an image capturing device. The vital

measurement of length, breadth and diameter were measured with accuracy better than 10 microns.

Inspection of FBTR pellets is carried out inside a leak tight glove box in nitrogen atmosphere at negative pressure. Algorithms were developed to measure both diameter and length with desired accuracy in a short time. The system was validated by a large number of manual measurements on the pellets. All hardware such as glass V block, focusing and parallax error removal mechanism were designed and developed indigenously.

An Automated magnetic pulse welding system

An Automated magnetic pulse welding system was developed for welding PFBR fuel pin T91 tube of 2.58 m length and 6.6 m OD to T91 end-plug. The process involves movement of tube and press fitted rod on inclined tray, segregation of one pin from array of pins, opening and closing support. Suitable arrangements are also made using gripper and rollers to hold the pin rigidly while applying the high magnetic pressure on the pin. After magnetic pulse welding of the pin, it will be removed and transferred to separate tray.

FBR- BACK END FUEL CYCLE

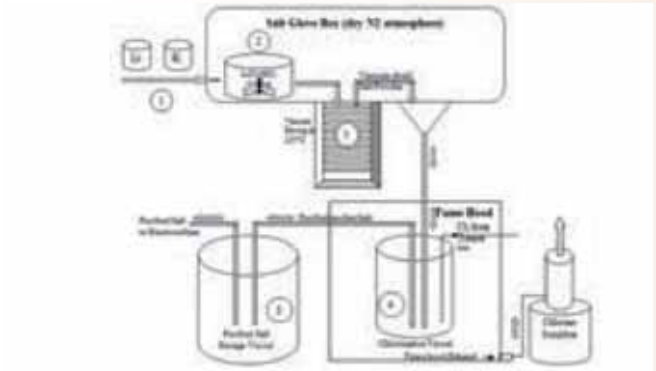
Recovery of Zr from Raffinate solutions using Tri-n-butyl Phosphate and Tri-iso-amyl phosphate solvents

In the recent past, aqueous reprocessing-based method using PUREX process as an alternate to the pyro-processing of metallic fuels has been examined. In this method U-Zr and U-Pu-Zr metallic fuels were dissolved in nitric acid medium followed by separation of U and Pu from zirconium (Zr) using Tri-n-Butyl Phosphate (TBP) and Tri-Iso-Amyl Phosphate (TiAP) based solvents. A solution of Zr in nitric acid medium (raffinate) is generated. Recovery of Zr from raffinate is important with respect to waste management. Solvent extraction studies in the cross-current mode were carried out to recover Zr from raffinate solutions. Flow sheets for the extraction and stripping of Zr with 1.1M and 1.47M Trialkyl Phosphates (TalP, namely TBP and TiAP) in n-dodecane from Zr feed solutions in cross-current mode have been evaluated. The concentrations of Zr in the feed solution were about 5 gpl (grams per litre), in 4M and 6M HNO3. The cross-current experiments were carried out until the quantitative extraction and stripping was achieved. The extraction of Zr (IV) by TBP and TiAP was found to be higher from 6M compared to that of 4M nitric acid (Fig.25 and 26). The extraction of Zr by 1.47M TalP is higher than that of 1.1M TalP. However, the extraction of Zr by TBP based systems is higher than that of TiAP.

Subsequently, Zr was stripped from loaded organic phase using 0.01M HNO_3 in cross-current mode. Quantitative stripping of Zr (>99%) was observed in 3 stages. It is concluded from these studies that the extraction of Zr is higher in the case of 1.47 M TalP/n-DD and was found to >99% within 5 stages for both TBP and TiAP from 6M HNO_3; whereas in the case of 1.1M TalP/n-DD-4M HNO3 system, the quantitative extraction (>99%) of Zr was achieved in 7 and 8 stages, respectively, for TBP and TiAP systems. However, the extraction of Zr from 4M HNO_3 in the case of 1.1M or 1.47M TalP/DD systems, quantitative extraction of Zr could not be achieved even up to 10 stages. Based on the results of cross-current experiments, mixer-settler runs were carried out with 1.47M TBP/n-DD using Zr feed solution (~ 5 gpl in 6M HNO_3). Quantitative extraction (6 stages) and stripping of Zr (3 stages) was achieved in these experiments. These studies pave way for the development of flow sheet for the recovery of Zr from raffinate solutions.

Eutectic Salt Preparation, Purification, Transfer and Storage

Pyro-Process R&D Facility (PPRDF) is being set up for demonstrating electrorefining and cathode product consolidation steps of the pyro-process flow sheet. Demonstration will be done using alloys of natural uranium at 10 kg per batch scale. The electrolyte used in electrorefining is a eutectic mixture of LiCl (44.5 wt.%)-KCl (55.5 wt%) salt. Approximately, 900kg of this salt mixture is required for initial campaigns of electrorefining in PPRDF. Commercially available LiCl & KCl cannot be directly used as it can contain significant amount of moisture, particularly after long storage at site. LiCl is highly hygroscopic and therefore all operations have to be conducted in a dry atmosphere (< 50 ppm of moisture). Hence, a Salt Handling &



Flow sheet of Eutectic Salt Preparation, Purification, Transferand Storage



Glove Box for salt mixing & vacuum drying



Chlorination Vessel inside fume hood

Purification System (SHPS) was set up in PPRDF. With this preparation of 1000 kg of eutectic salt with requisite purity towards engineering scale demonstration of Pyro



Chlorine scrubbing system



Purified Salt Storage Vessel

processing technology has been accomplished.

Reprocessing of mixed carbide spent fuel of FBTR

The Compact Facility for Reprocessing of Advanced Fuels (CORAL) has been operating as per approved procedures and scheduled number of reprocessing campaigns of FBTR spent fuel with 155 GWD/t burn-up have been completed with very

significant reduction in man-rem expenditure. Towards hot-commissioning of the Demonstration Fast reactor fuel Reprocessing Plant (DFRP), special purpose remote handling equipments have been designed, fabricated and tested. Process instrumentation and radiation monitoring systems, security systems and electrical systems at DFRP have been successfully installed. Radiometry of the hot cells; an essential AERB requirement for shielding integrity assessment is also in progress.

R&D on Fast Reactor Fuel Reprocessing

The 56th campaign of Compact Facility for Reprocessing of Advanced Fuels (CORAL) was completed during this lockdown period with excellent recovery and the lowest ever dose expenditure was achieved. The radiation health of CORAL was maintained at an excellent condition through constant surveillance in shifts even during the Covid-19 lockdown period.

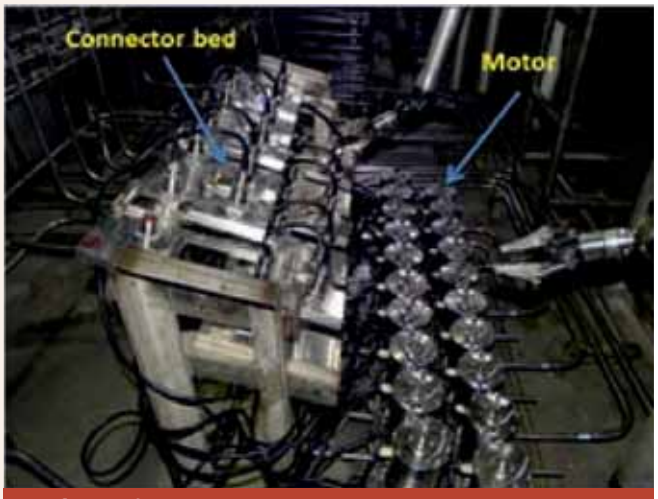
A continuous precipitator has been developed, commissioned and deployed in the CORAL facility and is in operation for the past 4 campaigns with an excellent reduction in man-rem expenditure. The uranium product obtained after reprocessing has been purified by a process developed "in-house".

Seismic re-evaluation of the civil buildings of Process Plant Facility (PPF) and Waste Tank Farm (WTF) of the Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP), an important prerequisite for ensuring regulatory compliance, has been completed. Acid runs and its associated documentation have been completed. Design approvals have been provided for construction of Fuel Reprocessing Plant (FRP), at the Fast Reactor Fuel Cycle Facility (FRFCF) and the construction of WTF of FRP, FRFCF is in an advanced stage.

A novel customized remote sampling station was developed and tested. Fabrication of the units to be deployed at site is in an advanced stage. As an improvisation, the lead screws that facilitate the long travel of the crane have been successfully replaced with ball screws. The movement of the bridge on these screws has been synchronized by using a variable frequency drive.

A "fist of its kind" flowmeter has been commissioned in the exhaust duct of the DFRP gaseous effluent stack with wireless communication. Towards bolstering the "fire safety measure", a new wireless network has been implemented, with which the water level in the central firewater tank at IGCAR could be remotely monitored and displayed at both CORAL and DFRP. A "first of its kind" special purpose LED lighting system for lead cells using heat pipe technology has been validated for performance in DFRP cell.

An ultrasonic de-choking system suitable for de-choking the bowls of the Centrifugal Extractors (CE) was developed, tested and deployed in DFRP. To ensure uninterrupted operation of the CEs which are the key equipment in FBR fuel reprocessing, a fault tolerant "inclined overflow" modification was designed. This



Centrifugal extractor bank installed in DFRP



Top view of the CE bank installed in DFRP



Ultrasonic cleaning bath test set-up

would help to complete the extraction process without shutting down the entire cascade.

Fast Reactor Fuel Cycle Facility

FRFCF, a multi-unit mega project of DAE, is being built with the objective of closing the fuel cycle and ensuring sustained fuel supply for Fast Breeder Reactors at Kalpakkam. It is a joint effort of IGCAR, BARC and NFC. The construction of infrastructure buildings (including training centre, the first Green building in DAE), utilities and service buildings have already been completed.

In the nuclear island, despite COVID pandemic, construction activities have progressed well by adhering to all safety precautions. Civil construction of the Core Sub-assembly Plant (CSP) building reached (+) 19.0 m elevation, Waste Management Plant (WMP) building reached (+) 10.5 m elevation while two zones of Fuel Fabrication Plant (FFP) & Reprocessed Uranium Oxide Plant (RUP) reached (+) 4.5 m. Hematite ore-based temperature-controlled heavy density concrete (3.6g/cc) part slabs in waste tank farm of Fuel Reprocessing Plant (FRP) Block-1 have been completed. Purchase orders have been placed for all long-delivery equipment and components required for commissioning of various plants of FRFCF and the items are being received at site in a phased manner. Lead ingots for radiation shielding, first batch of optical slabs & stainless-steel plates, pipes & rounds for manufacture of process vessels & tanks have been received at site. The glove box integration works of ion-chromatography, thermo-gravimetry and fuel pin gamma scanning system for analytical certification laboratory have progressed significantly. The manufacture of Over Dimensional Consignment (ODC) tanks has been completed and equipment for solid waste compaction have been received at site.

During the pandemic, all measures were effectively implemented for safety, welfare and transport of migrant labour working for the FRFCF project and pre-COVID working levels of construction have been attained.

NFC is also setting up two plants i.e., Reprocessed Uranium Oxide Plant (RUP) & Core Sub-assembly Plant (CSP) under the project "Fast Reactor Fuel Cycle Facility" (FRFCF) at Kalpakkam.



Core Sub-assembly Plant



Fuel Fabrication Plant



Waste Management Plant



Passive gamma fuel pin scanning system

REPAIR & INSPECTION TECHNOLOGIES

Post-irradiation examination of tungsten carbide for lower axial shielding of FBTR Fuel Sub Assembly

To study the irradiation behavior, tungsten carbide, tungsten pellets and disc specimens were irradiated in an irradiation capsule in FBTR to a peak fluence of 1.64×1022n/cm2 followed by Post Irradiation Examinations (PIE) to evaluate dimensional changes, volumetric swelling and chemical interaction with 316SS clad mate of the capsule. Neutron radiography indicated that the W and WC pellets were intact after irradiation, while the disc samples had disintegrated, which is attributed to thermal stresses from reactor operation. Density and dimensional measurements of the irradiated WC/W pellets did not show significant swelling. The maximum volumetric swelling measured for WC and W pellets are 4.6% and 2.7%, respectively at irradiation location corresponding to core mid-plane. The microstructure of the inner surface of clad material adjacent to WC pellet did not show any evidence of chemical interaction. Based on the results of PIE, it is concluded that WC can be considered for lower axial shielding in the FBTR fuel sub-assemblies to reduce the neutron dose to the grid plate, thereby extending its life.

Examinations on Irradiated Surveillance Specimen of End-Shield Material of MAPS -1 (Madras Atomic Power Station)

Towards assessing the irradiation induced changes in the mechanical properties of end shield material of MAPS-1 reactor, surveillance coupons in the form of pre-fabricated half size Charpy impact specimens of the 3.5% Ni steel were retrieved from the optical sight plugs. The surveillance coupons were exposed in MAPS-1 to an estimated fast neutron fluence of 1.13×10^{21} n/cm^2 over 6555 Effective Full-Power Days (EFPD). Shear area fraction and lateral expansion measurements reveal brittle mode of failure at 50-100°C and ductile failure mode at 175°C.

NDE contributions towards PFBR commissioning and Repair and inspection technologies

Non-destructive testing methodologies using ultrasonic guided wave and saturation based eddy current techniques have been developed and successfully implemented for qualification of 51 nickel tubes used for fabricating hydrogen sensor assemblies. Industrial videoscope has been deployed to assess Intermediate Heat Exchanger, quantitative characterization of dent marks on the top and bottom races of LRP, remote visual inspection of LRP seals and to detect and characterize leak source in a biological shield cooling system pipe. To enhance the defect detection sensitivity in fuel pin end plug welds, a modified digital X-ray inspection methodology using High Contrast Sensitivity Radiology calibration correction procedure has been developed. An immersion ultrasonic inspection technique has been developed for the first time to qualify the Magnetic Pulse Welded fuel pin end plugs.

Quality Assurance and NDE services for R&D and demonstration projects of IGCAR

Effectively planned Quality Assurance (QA) & inspection activities have been implemented during the fabrication of various components and fulfilled the specification requirements of PFBR and applicable ASME code requirements. QA & Inspection activities, metrological measurements and testing services were also carried out for FBTR and FRFCF. Ultrasonic testing of corner joints and Special fixtures and fabrication of DSRDM & CSRDM and cold drawn seamless nickel tubes from NFC for PFBR was carried out with eddy current testing.

Radiography examination using X-ray were carried out for revealing sodium level in indirect temperature monitoring devices for test irradiation in FBTR, finding internal details in Yttria pellets for stack level measurement for IDEAS section, explosive weld joints for SG tube plugging for PFBR, digital radiographic inspection of sodium pressure measurement devices for sodium void measurements. Phased array ultrasonic examination on foot to hexcan welding on fuel subassemblies, immersion ultrasonic testing on colmonoy-5 (RNiCr B) and stellite hard faced sleeves control rod sheath assembly. Level measurement of Sodium-Potassium (NaK) liquid, and pulse-echo contact test for several stainless steel nozzle weld joints, butt joints, Mod. 9Cr-1Mo. forgings and in-service inspections of test loops were carried out and the results were evaluated. Helium leak tests under vacuum was conducted on nickel diffuser assemblies of PFBR, sodium sampler for FBTR and D9 end plug welds. Horizontality measurements of LRP bottom raceway, top surface during bearing rectification works of PFBR are measured using optical alignment telescopes.

HEALTH, SAFETY & ENVIRONMENT

Radiological and Industrial Safety

Radiological surveillance to all nuclear facilities in IGCAR is continuously being provided by Health Physics Unit stationed at each facility. Health physicists are carrying out radiation surveys, radioactivity monitoring and measurement of radiation exposure on day-to-day operation to meet the regulatory requirements. About 1200 radiation works are being monitored for radiation exposures. Radiological Work Permit (RWP) system is followed for controlling the exposures. Cumulative dose expenditure for all nuclear facilities in 2020 was 133 PmSv. Effective health physics surveillance was provided in 24x7 basis without any interruption including Covid-19 lockdown period. During the operation and shutdown/fuel handing period of FBTR, radiological work permits were issued for fuel handling operations and Iodine retention efficiency testing of reactor containment building filter banks. Liquid effluent samples analyzed for radioactivity prior to transfer to Centralized Waste Management Facility. During the operation of KAMINI reactor, study on reactor tank water activity saturation level and neutron measurements were carried out. In Post Irradiation Examination facility, gamma spectrometric analysis of irradiated samples from MAPS end shield were carried out using LaBr(Ce) detector and ^{60}Co was identified as a major radionuclide with activity of about 10 mCi.

In 2020, four reprocessing campaigns were carried out in CORAL with a collective dose of 123 PmSv. No occupational radiation worker exceeded the monthly, quarterly or annual dose limit. There was no radiological issue in the plant. The effluent release through stack was <1% of authorised limit. Training to plant personnel on radiation protection was provided in virtual mode. In DFRP, Health Physics lab is being established and all the radiation monitoring systems were integrated to radiation data acquisition system and their performance was evaluated. Iso-kinetic sampling probe for DFRP stack monitoring was designed, fabricated and tested for its performance. A manual on emergency preparedness for DFRP plant is accepted by AERB. Reports on radiological status of operating facilities were submitted to AERB periodically in every quarter.

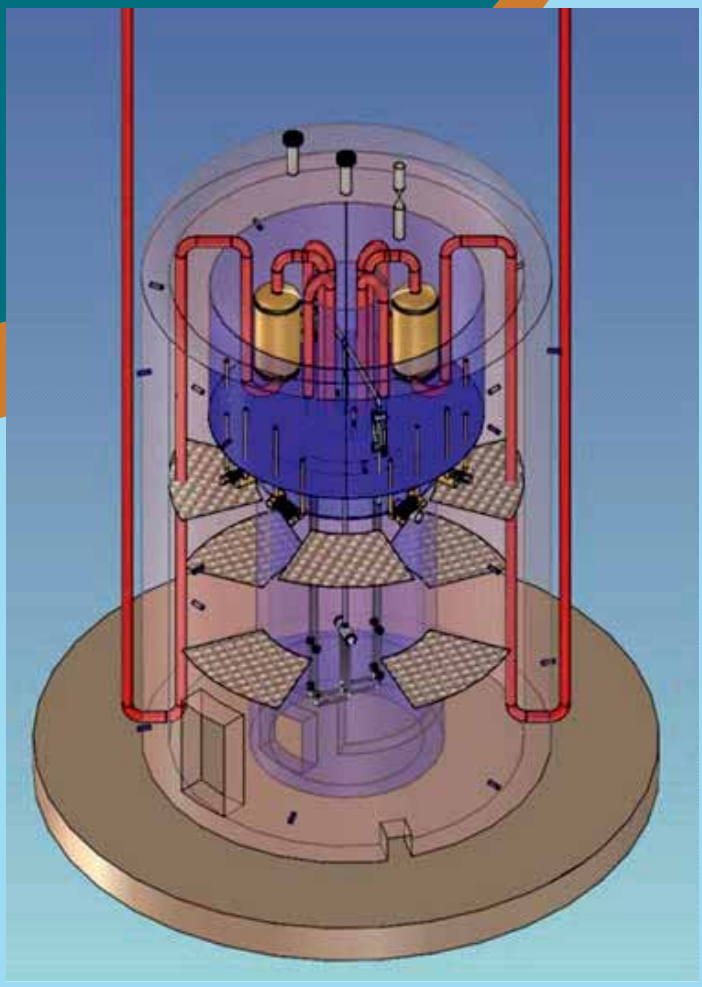
Industrial & Fire safety inspections and physical hazard surveillance for maintaining safe work environment is being carried out on regular basis in all nuclear facilities in IGCAR. Industrial safety trainings were organized to enhance the awareness of safety among officers/ engineers, supervisors of IGCAR.

Safety induction training, Height pass test & training were conducted for all construction site workers. Safety, Health and Environment report and Fire Occurrence report are prepared and sent to AERB periodically. During Covid-19 Pandemic, in-house prepared hand sanitizers were provided to all the facilities/ laboratories in IGCAR. Periodic sanitation of buildings, CISF main gates, buses and all department & hired light vehicles were executed.

R&D in radiological safety, dosimetry, environmental monitoring and radiological services

Radiological and environmental safety of the fast reactor program involves R&D in dosimetry, environmental safety, improved uninterrupted monitoring services for personal safety and societal applications of radiation. Significant developments are In-vivo and in-vitro monitoring of occupational workers, Nuclear Counting Facility (NCL), Retrospective dosimetry technique, Radon and Thoron emanation study, Organically Bound Tritium Measurements of the Soil, Passive sampling method for C-14 Monitoring, Environmental monitoring of coastal biodiversity, Time dependent source term in the atmospheric dispersion model of the Decision Support System, HEPA test facility, Regional Calibration Facility (recognised by AERB and accredited by NABL), sodium aerosol studies for RIA, Evaluation of metallic composition of deities in temples and elemental analysis of archaeological samples, Gamma irradiation services, public awareness programme and Covid-19 related research- Evaluation of filtration efficiency of various types of facemasks such as N-95, surgical mask and cloth masks etc.

CHAPTER 3



Schematic of CONSIST facility

NUCLEAR POWER PROGRAMME STAGE-3



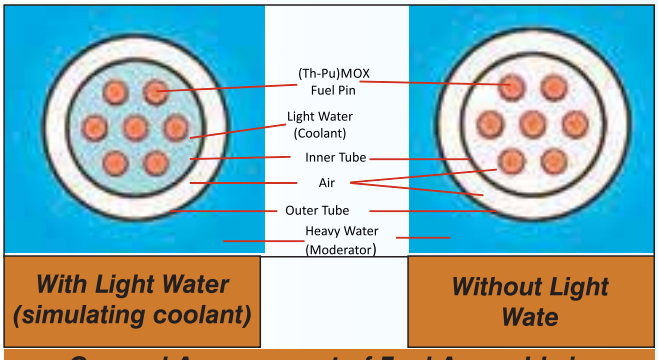
Concreting of dome of CONSIST

THORIUM BASED REACTORS

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

ADVANCED HEAVY WATER REACTOR

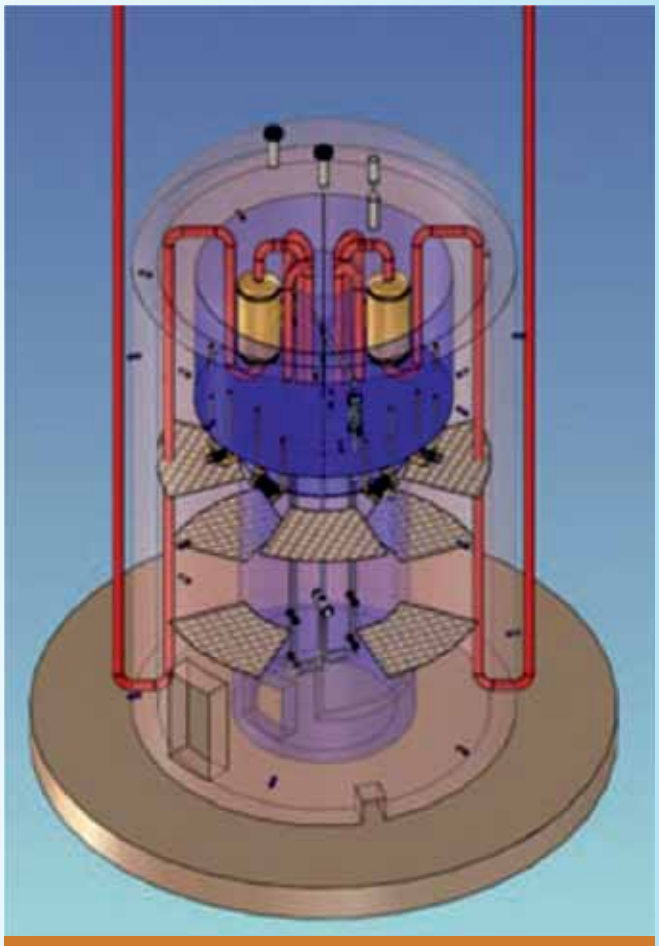
Void reactivity experiments were carried out in AHWR-Critical Facility as part of reactor physics validation studies. A fuel assembly and handling procedure was developed for carrying out the experiment. The fuel assembly consists of seven AHWR type fuel pins assembled together with structural components like spacers and tie-plates. The fuel pins have (Th-Pu)MOX pellets encapsulated in zircaloy clad tubes. The cluster of fuel pins is placed inside aluminium containers whose inner and outer tubes represent reactor core structural components viz. Pressure Tube and Calandria Tube respectively and isolate the light water coolant from heavy water moderator



General Arrangement of Fuel Assembly in two experimental configurations

The experiment was carried out with fuel assembly in two configurations i.e. with light water and without light water as shown in Figure-x. The reactivity load of light water estimated from the experiment was 1.5 mk.

Thermal-hydraulic iterations were carried out for power distribution by external coupling of FEMFOL and ARTHA for AHWR initial, transition and equilibrium core. Average coolant density was slightly lower at 0.4257 g/cc than the earlier value of 0.45 g/cc. As a result of orificing in the core, the core flow gets reduced by 18% and the core exit quality gets enhanced to around 24%. The maximum channel power can be considered as 2.8 MW, a conservative limit for thermal margin and safety calculations. The xenon dynamics study of intermediate core of AHWR was carried out with FEMFOLXe after introducing reactivity perturbation. Two kinds of reactivity perturbations were considered for the study, viz., withdrawal of single regulating rod and refueling of fuel channels. Oscillations were controlled by the feedback. Stability analysis in linear and non-



Schematic of CONSIST facility



Concreting of dome of CONSIST

linear domains is an important part of reactor dynamics. The stability curve has been obtained considering variation of fuel temperature co-efficient and void reactivity co-efficient for full burn-up range of equilibrium fuel clusters. It was observed that AHWR operates in stable region. A numerical model for point kinetic equations with thermal hydraulics feedback has also been developed for simulations to actually mimic the behaviour of reactor during small perturbations.

Channel power measurement technique for AHWR was demonstrated in AHWR Thermal hydraulic Test Facility (ATTF) in Tarapur. Differential pressure transmitters were used in vertical and horizontal legs of tail pipe to evaluate the exit void fraction. The calibration curve between void fraction and quality generated in ATTF can be used to evaluate the channel power of AHWR. The Experiment has been conducted at 23 bar and 31 bar.

Civil construction of Containment System Integral Simulation Test (CONSIST) facility was completed at Tarapur. AHWR design incorporates the containment with various passive safety features, the performance of containment and its associated systems need to be demonstrated. An integral test facility is being constructed for containment thermal hydraulics studies.

THORIUM FUEL CYCLE

Physics Design of Indian Molten Salt Breeder Reactor (IMSBR)

Molten Salt Reactor (MSR) is a promising reactor concept. The circulation of molten fuel salt leads to drift of precursors in the reactor and influences core dynamics very differently compared to the solid fuelled reactors. 5 MWth IMSBR (Indian Molten Salt Breeder Reactor) core is being designed and analyzed for neutronic feasibility. The reactor core is modeled using a combination of indigenous and open source codes, to analyse $^{233}UF_4$ and LEU based fluoride molten fuel LiF-CaF_2-ThF_4-UF_4. A computational tool SARRA is being developed for the analysis of online refueling and reprocessing of circulating fuel systems. New physics modules are developed to analyze any composition of fresh (e.g. UF_4) and feed (e.g. ThF_4) fuels. The choice of feed fuel can be from simple ThF_4 to the used spent fuels from reactors like LWR. The in-house 3D reactor analysis code ARCH is being augmented with new modules to analyse the dynamic behaviour of graphite-moderated molten salt reactors. A computer code MSDyn is also being developed to analyse the dynamic behaviour of graphite moderated molten salt reactors with thermal hydraulics feedbacks.

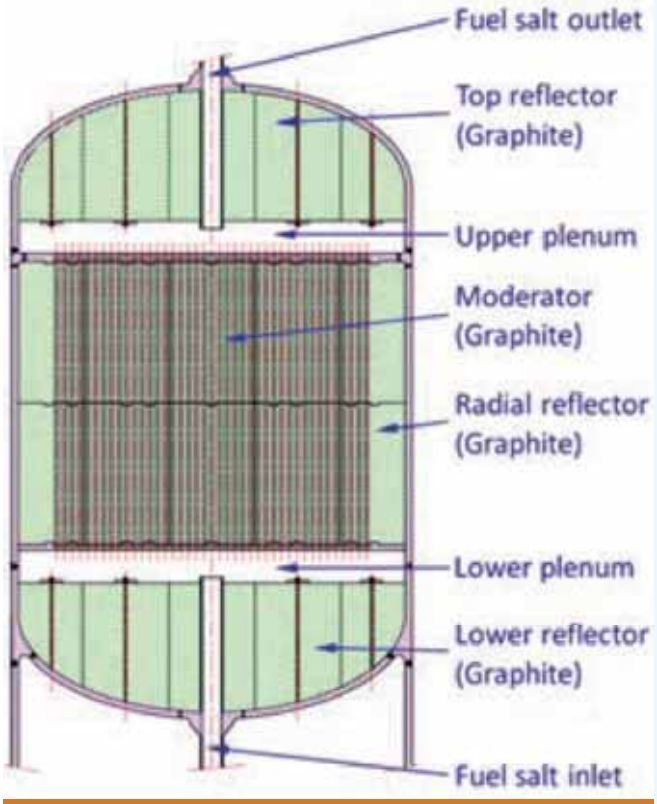
Development of advanced reactor physics codes for HTRs and MSRs

3D multi-physics code ARCH-TH was developed and validated for the studies of the operational and accidental transients in CHTR (Compact High Temperature Reactor) under the natural circulation of LBE (Lead Bismuth Eutectic) coolant. The code has fully implicit and IQS based neutronics modules for full core reactor transients. The postulated case of Unprotected Loss of Heat Sink Accident (ULOHSA) in CHTR has been investigated. The core has been observed to be shutting down passively due to

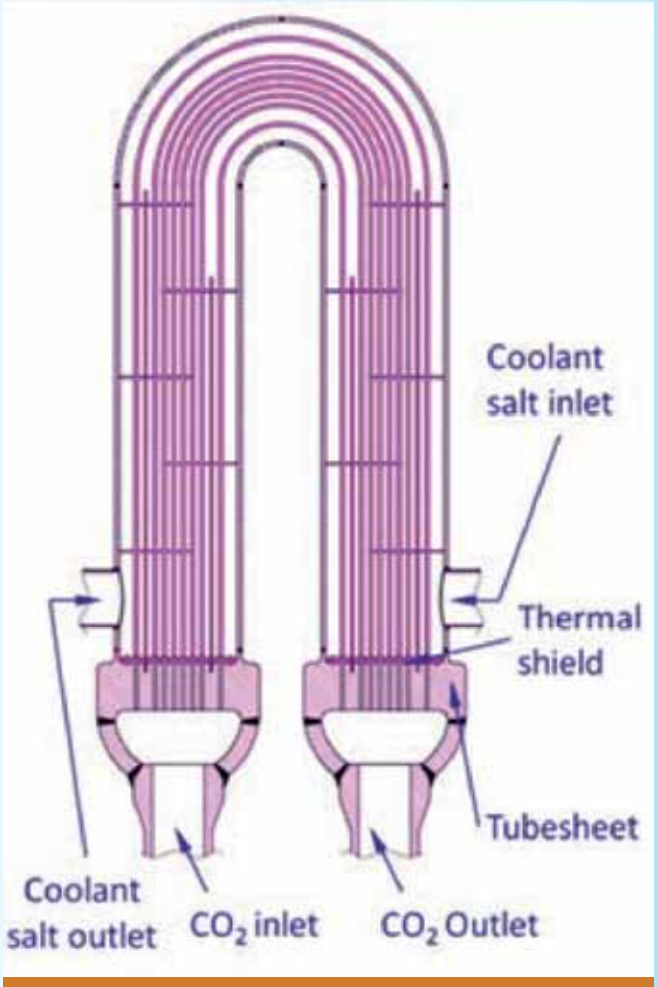
temperature feedbacks with peak temperatures varying much below the safety limits. MSDyn code capabilities are based on the solution of modified zero and one dimensional Delayed Neutron Precursors (DNPs) balance equation with the convection term. The pump start-up transient is induced by DNPs drift along with fuel flow. During the fuel pump start-up, DNP drifts due to increasing fuel flow and results in net loss of reactivity from the core. Variations of reactor power and reactivity are calculated using MSdyn during the pump start-up experiment. It is evident that reactor shows damped power oscillations for both U-235 and U-233 based fuel salts due to DNP recirculation in core through external loop.

Design of reactor vessel and salt-CO_2 heat exchanger for 5 MWth IMSBR

5 MWth IMSBR is a demonstrator for technologies required for a larger reactor for thorium utilization in the third stage Indian nuclear programme. Design of the reactor vessel and coolant salt - supercritical CO_2 (S-CO_2) heat exchanger were completed. The reactor vessel is subjected to high temperature (700°C) irradiation under molten fluoride

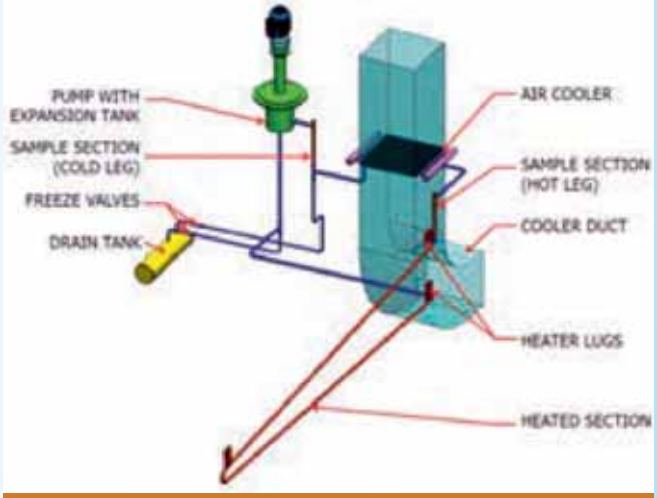


Reactor Vessel



Salt CO_2 Heat Exchanger

salt environment. Ni-Mo-Cr-Ti alloy – the material compatible for these conditions, was indigenously developed in collaboration with Materials Group, BARC and MIDHANI. The S-CO_2 heat exchanger was subjected to high pressure and large temperature variations.



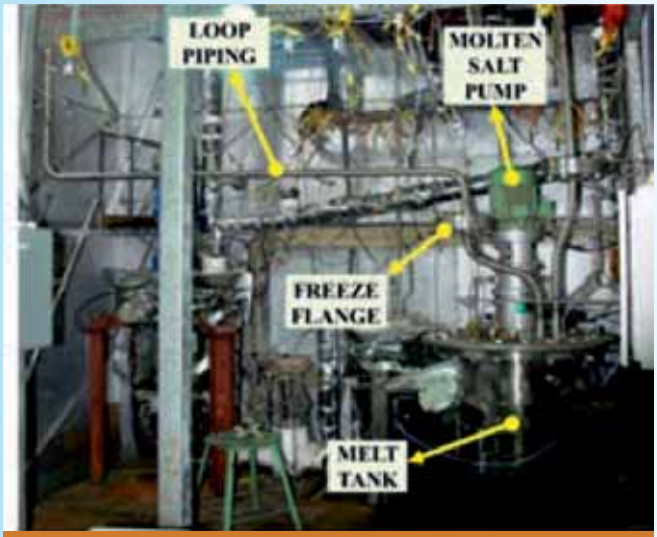
Layout of Fuel Salt Corrosion Test Loop

Material and Equipment test Facilities for 5 MWth IMSBR

Development of IMSBR involves novel technologies and experimental facilities for qualification of materials and specialised instruments. Process design of fuel salt corrosion test loop, fuel salt-graphite compatibility test facility and molten salt flow test facility was completed. Figure shows the layout of the fuel salt corrosion test loop with capability to test materials with radioactive fluoride salt environment at high temperatures.

Commissioning of Forced Circulation Molten Salt Loop (FCMSL)

FCMSL (Forced Circulation Molten Salt Loop) was established to study thermal-hydraulics related to IMSBRs to develop/test various high temperature components such as molten salt pump, freeze flange, etc., and instruments such as flow sensors, level sensors, etc. The loop has been charged with 200 kg of nitrate salt and commissioned. It operated at 350oC with freeze flange and molten salt pump performing satisfactorily.



Forced Circulation Molten Salt Loop (FCMSL)



Control Console of Forced Circulation Molten Salt Loop during operation

KAlpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) continued to operate successfully at a maximum power level of 30 kWt. It is serving its unique role as a facility for neutron activation studies, Neutron radiography and testing indigenously developed neutron detectors.

CHAPTER

4



Control Room of NUCON PLC Test Facility

ADVANCED TEHCNOLOGIES AND RADIATION TECHNOLOGIES AND THEIR APPLICATIONS



Gamma scanning of condensate collector header being carried out at slug catcher II

Advanced technologies and radiation technologies development and their applications, is one of the major programmes of the DAE's research organizations such as BARC, Mumbai, IGCAR, Kalpakkam, RRCAT, Indore, VECC, Kolkata and the industrial organization BRIT, Mumbai.

These organisations have developed a number of advanced technologies, hi-tech facilities and various sophisticated equipments over a period of time under this programme. This includes Research Reactors, Accelerators, Lasers and laser based equipment, Synchrotrons.

Applications of radiation technologies are immensely beneficial in the areas of healthcare, nuclear agriculture, food preservation and industry.

DAE has been working in close cooperation with other organizations of the Government of India to widen the reach of the technologies for the benefit of common man.

The Tata Memorial Centre which functions through its three units viz., Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) and Centre for Cancer Epidemiology (CCE) and provides the Cancer Diagnostic and Treatment Services to the masses. It also engages in the programmes aimed towards Cancer awareness and it's Prevention.

RESEARCH REACTORS

APSARA - Upgraded

Apsara-U was operated for development of emerging theranostic (Therapentic + Diagnostic) radioisotopes and irradiation of samples as per researchers' requirement. Twenty irradiated cans were delivered during the year. The reactor beam lines have been allotted to various researchers and process of setting up the facilities has been initiated. Feasibility of producing Neutron Transmutation Doped Silicon (NTD-Si) and fission moly are being explored.

DHRUVA

Dhruva operated at a high level of safety and availability. The reactor logged 65% Availability Factor during the year, despite remaining shut down for about one and half months due to COVID-19 pandemic. Dhruva continued to be the major facility for radioisotope production and served as a national facility for neutron beam research. The reactor was operated even during lockdown conditions and about 500 irradiated cans were delivered. Some of the special jobs done during the year include Test irradiation of newly developed dispersion fuel experimental assembly; Testing of new prototype Ion chambers; Delivery of high specific cobalt activity samples to BRIT; Commissioning of new Seawater chlorination system and Commissioning of new spent fuel storage buggy vertical drive.

CIRUS

Cirus reactor remained in 'Safe Storage' mode, for deferred decommissioning. A 100 Ci/batch I-131 processing facility is being constructed in Cirus reactor hall and is likely to be commissioned by mid 2021.

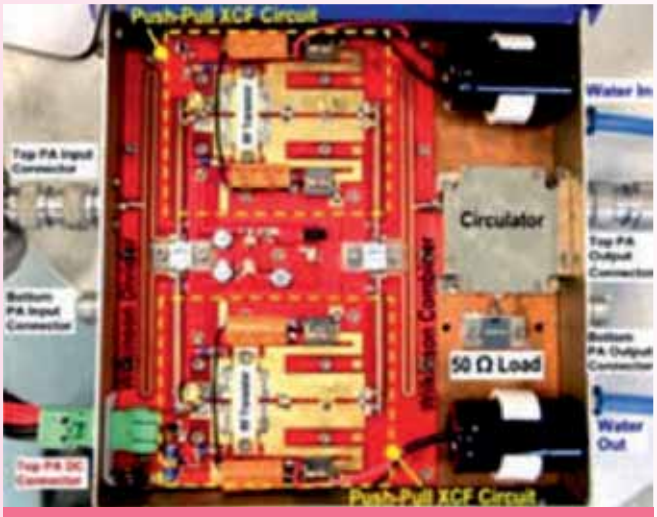
Critical Facility

Critical Facility for Advanced Heavy Water Reactor was operated on 52 occasions during the year. Coolant void reactivity measurement with 7-pin (Th-1%Pu) MOX experimental cluster at central location was carried out. Critical Facility was also used for testing of six nuclear detectors and irradiation of 35 large samples for Neutron Activation Analysis.

ACCELERATORS

At RRCAT, a 150 kW, 325 MHz pulsed (2-5 ms) solid-state RF amplifier was designed and developed for RFQ with three amplifier units of 50 kW each combined using 3-way high power RF combiner. The main features are its modular and scalable design architecture, comprising of 123 Extended Continuous Class F 1.5 kW amplifiers, energy-efficient two-tier radial power dividers as well as combiners, compact dual channel power sensors and aperture-coupled directional couplers. All RF sub systems and components were fabricated and assembled along with electrical wiring. Novel 3-way high power RF combiner to combine three amplifier cabinets of 50 kW each to get 150 kW RF power at 325

MHz was designed and fabricated. The RF power testing of moderate power (1.5 kW) amplifier modules on test bench was completed. 150 kW Solid State RF amplifier was assembled with three racks 50 kW RF amplifier cabinets using 3-way high power RF combiner. Necessary tests like DC test, pulse characterization and high-power RF test of 150 kW solid state RF amplifier was carried out with variable pulse width from 1 ms to 5 ms, at 50 Hz of pulse repletion rate. Its pulse amplitude droop measured at 1 ms is 0.46 dB.



1.5 kW X 2 power module



325 MHz fabricated 40-way radial two-tier combiner

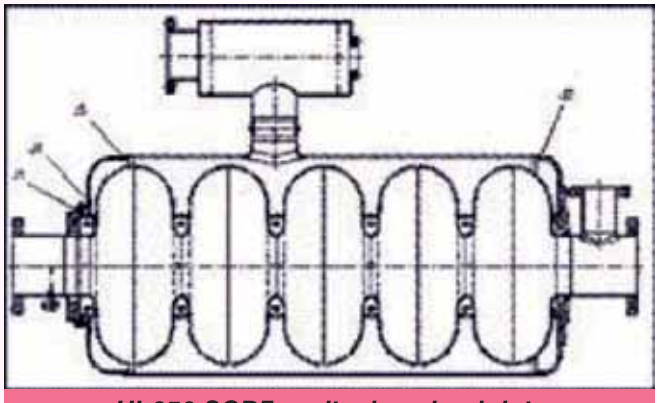
A Horizontal Test Stand (HTS) facility for testing of dressed Superconducting RF (SCRF) cavities at 2 K was installed at RRCAT. A five-cell 650 MHz SCRF cavity was dressed for the first time using an in-house developed facility. The dressing of a cavity includes welding of helium vessel, mounting of low temperature tuner etc. The dressed cavity was integrated with the HTS cryostat and various cryogenic transfer-lines. The cool down of the cavity in the HTS facility was carried out with liquid helium to achieve temperature up to 1.94 K.



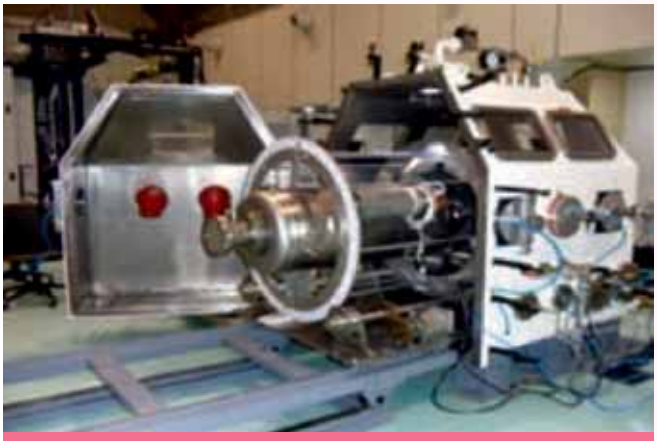
Assembly of dressed cavity in HTS cryostat

This was achieved by simultaneous liquid helium filling and helium vapor pumping to maintain a sub-atmospheric pressure of 30 mbar. Liquid helium was successfully transferred in both saturated liquid and supercritical mode. Slow and fast tuners for the cavity were tested at 4 K and 2 K temperature. Indigenously developed RF Protection Safety Interlock (RFPI) system and low-level RF system were integrated with 40 kW solid state RF amplifier. Commissioning trials of the HTS Facility were carried out. The cool-down & testing was monitored and controlled using the in-house developed control system.

Welding of helium vessel, bellows and end caps all made of Ti Gr2 material on bare high RRR niobium SCRF cavity and integration of tuner is termed as dressing. The dressing joints uses different weld configurations using TIG welding designated as J1, J2, J3 and J4. Various infrastructure were deployed during jacketing include, controlled environment welding glove box, insertion assembly bench, online frequency monitoring and alarm system. An important milestone was achieved with successful dressing of 650 MHz,



Hb650 SCRF cavity dressing joints



Cavity coming out after jacketing

β=0.92 five-cell (SCRF) cavity in the indigenously developed controlled environment welding glove-box. The completed dressed cavity has been qualified in accordance with ASME BPV code being a pressure vessel. Further the cavity has qualified for vacuum leak test <1E-10 mbar-lit/sec. The post dressing field-flatness is 92% (required> 90%) and change in frequency -86 kHz, within tuning range of 200 kHz.

Tuner is a device that keeps the SCRF cavity within operating frequency bandwidth i.e tune the cavity. SCRF cavities has very high quality factor limiting the frequency of operation to a very narrow band width hence required to tune these cavities using special tuning mechanism. For this purpose, lever tuner is developed at RRCAT and it is assembled with 650 MHz Five-cell SCRF cavity for its qualification at 2 K in horizontal test stand (HTS). Slow tuning operation is performed by excitation of stepper motor while fast tuning operation is performed by excitation of Piezo-actuators. During slow tuning operation, stepper motor has been rotated for compression (forward) and expansion (reverse) of the cavity and change in cavity frequency has been recorded. In slow tuner resolution test, stepper motor rotation is carried out in precision of 25 steps and change in cavity frequency is recorded. The theoretical resolution for this tuner with HB650 cavity is 0.8 Hz / step and the achieved resolution is 0.76 Hz/step, which clearly shows a better resolution. Further, piezo actuators are excited with DC voltage initially and change in cavity frequency has been recorded. The successful testing with stepper motor and piezo actuator at 2 K has paved the way for operational control of the SCRF cavity by tuner during high power testing in HTS.

The control system for HTS handles signals from various sub-systems like cryostat, vacuum, radiation, cryogenics etc. The system was used successfully to test the cryogenics operation of the cryostat. As per the need to include additional signals related to 5-cell SCRF cavity and RF power coupler in the system, development of control system software & hardware was carried out for necessary augmentation. Twenty-four temperature sensors of different types including Cernox and PT-100 and five magnetic sensors (Fluxgates) were mounted at various places of cavity and coupler. The radiation monitors were integrated with the control system and tested using radioactive source. For the five fluxgate sensors added in the system, multiplexer hardware module was developed which interfaces to up to 6- fluxgates and connects them to the readout unit one-by-one in time division multiplexing



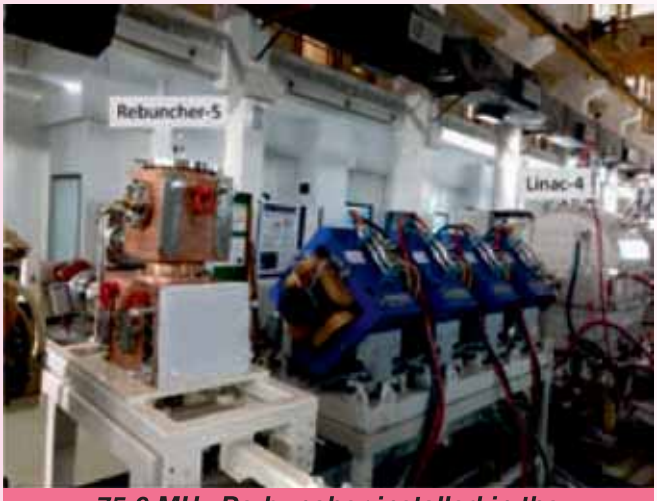
Instrumentation rack with added devices and readout units



In-house developed Fluxgate multiplexer units for magnetic sensors

fashion. With this control system augmentation, cavity cool down below 2 K was achieved successfully and an initial low power RF testing was done.

In the post-accelerator chain of the RIB facility, RF Re-bunchers are required for longitudinal matching of 415 keV/u ion-beam accelerated in the 3rd LINAC module to the acceptance of the 4th LINAC module. The Re-buncher has a lambda/4 coaxial line structure shorted at one end and capacitatively loaded at the other end by drift tubes. The electric field is concentrated mainly in the drift tube gaps and is used for bunching of ions. RF power is fed to the resonant cavity using an inductive coupler. Two such RF Re-bunchers have been recently fabricated in an industry at Bengaluru. The main resonant structure of the Re-bunchers i.e. drift tubes and inner conductor, has been fabricated from solid blocks of copper whereas other components such as beam ports, bellows, tuner assembly etc are made from stainless steel. After fabrication, individual components have been thoroughly cleaned with de-ionized water and alkaline soap solution in an ultrasonic bath inside class 10,000 clean-room at RIB annex building. The cleaned components have been assembled, aligned and the final assembly was vacuum tested. Thereafter



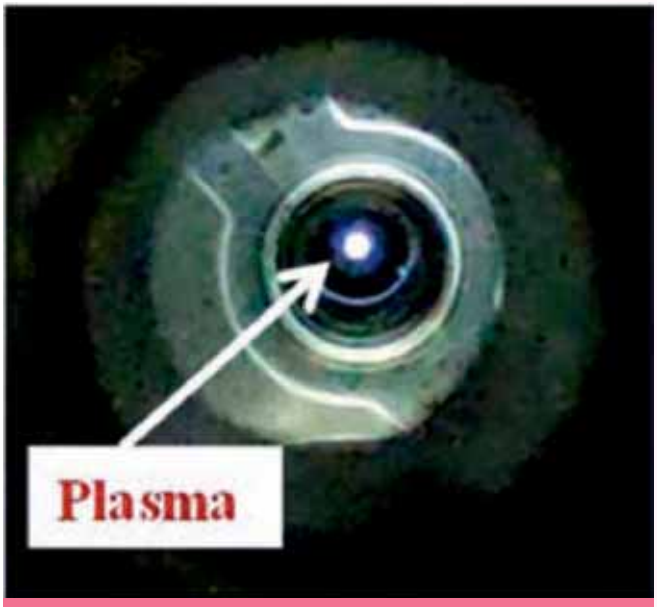
75.6 MHz Re-buncher installed in the beam-line at RIB annex building at VECC

measurement of axial field along the length of the Re-bunchers using bead-pull method was completed. The assembled Re-bunchers have been installed in the beam-line – a photograph of one Re-buncher is shown below. The measured Q value is 4628 which is in excellent agreement with simulated value of 4940. The Q value of second Re-buncher also closely matches with this value. The operating frequency is 75.6 MHz, matching with that of the LINAC modules whereas the frequency tuning range for the tuner was measured to be 2.2 Mhz.

A new 2.45 GHz ECR ion source has been indigenously fabricated, installed and tested. The ion-source consists of two ring magnets that create the resonance magnetic field of 875 Gauss and also the magnetic mirror field required for axial and radial confinement of plasma. These ring magnets have been designed in-house and fabricated using NdFeB permanent magnet blocks [Grade N45H, Br = 13.200 kGauss, Hc = -11600 Oe] in a local industry at Kalyani, West Bengal. The ring magnets are assembled on water cooled, stainless steel plasma chamber connected to a beam extraction chamber that is pumped using a 350 lps turbo molecular pump. The plasma chamber floats at high voltage to enable extraction of ions using a grounded extraction electrode. High voltage isolation between microwave generator and plasma chamber is provided by a DC break that has also been fabricated in-house. A locally fabricated WR340 copper ridge waveguide coupled to an E-H tuner ensures the impedance matching between the microwave generator and plasma chamber. A quartz vacuum window is placed in the microwave feeding line for maintaining vacuum inside the plasma chamber. Typically measured



New 2.45 GZ ECR ion-source



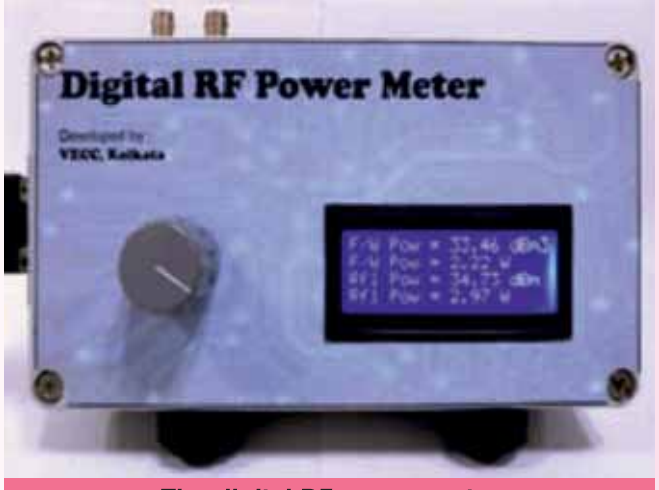
Plasma formed inside ECR chamber

beam current for Argon 1+ ions is 1.2 mA at extraction voltage of 8 kV and microwave power of 45 Watt.

Radio Frequency (RF) power is an important parameter to be measured continuously for any particle accelerator for its energy efficient operation. A Dual Directional Coupler (DDC) with off-the-shelf power meter is commonly used for measuring the forward and reflected RF power to optimize the RF system parameters. Hence development of DDC along with RF power meter for measuring power over wide dynamic range and wide band, an import substitute, is an important step towards reducing the operational cost of accelerators. In view of the above, a RF power monitor with wide dynamic range (1kW to 20kW) wideband (30-115 MHz) is designed and developed. The RF power monitor is comprised of a DDC and a digital RF power meter for in-situ and remote monitoring of forward and reflected RF power. The DDC is designed using CST and it is fabricated using in-house facility. The DDC can be used over a frequency range of 30-115MHz. The dual channel Digital RF Power Meter is designed and developed for the measurement of forward and reflected power simultaneously. The meter along with the DDC with a coupling factor around 60, is capable of measuring RF power up to 25 kW over a frequency range of 30 MHz-120MHz. The some of the salient features of meter are four-line LCD for displaying forward and reflected power in dBm and watt, a multipurpose knob for configuring coupling factors &



The DDC installed in system

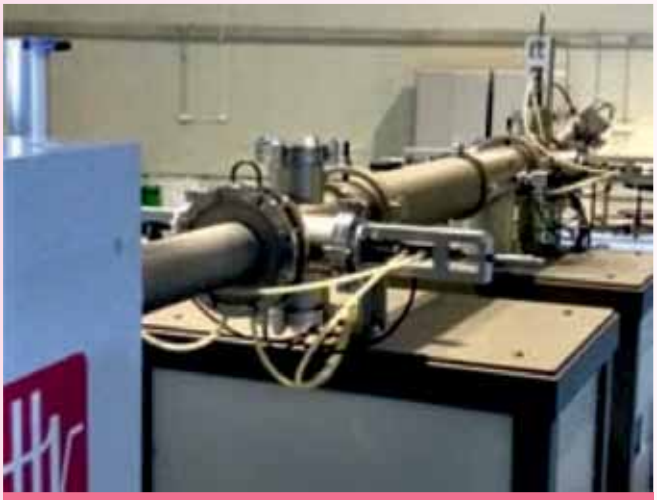


The digital RF power meter

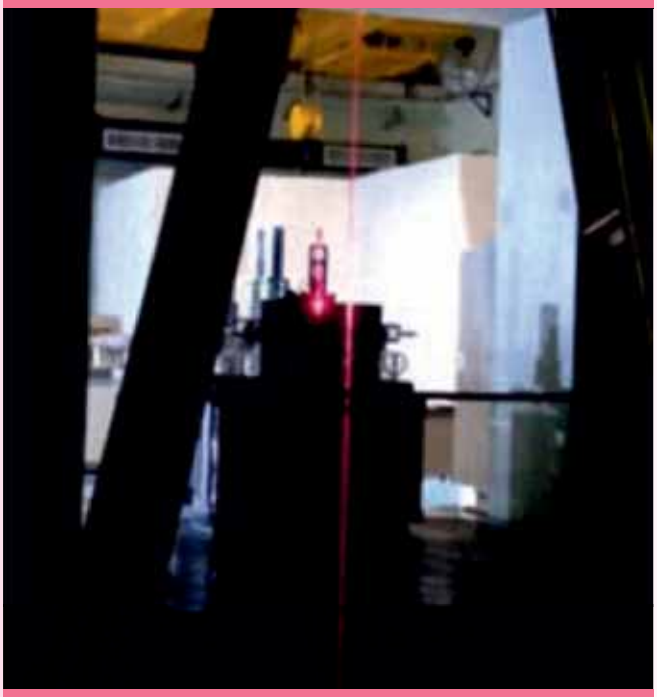
frequency range and serial and wireless connectivity for remote measurement and configuration of the meter using PC. The combination of power meter and DDC is tested at 37.8MHz in the RF line with amplifier at the RIB facility in VECC up to 5kW of RF power and it is found satisfactory.

At BARC, a dual energy Linac was developed for cargo scanning application. It is capable of producing good contrast for materials of low atomic density such as plastics, explosives and other organic materials. The Linac was commissioned and qualified for reliable operation at 100 Hz at 3% stability. The X-ray system has been qualified for Focal spot size (FWHM) of $\leq$2.0 mm; Measured LE and HE mode energy of 4 and 6 MeV and Preliminary analysis shows that material discrimination is achieved from the calibration scans.

The FRENA (Facility for Research in Nuclear Astrophysics) Accelerator at SINP has been tested for



Short Astrophysics Beamline

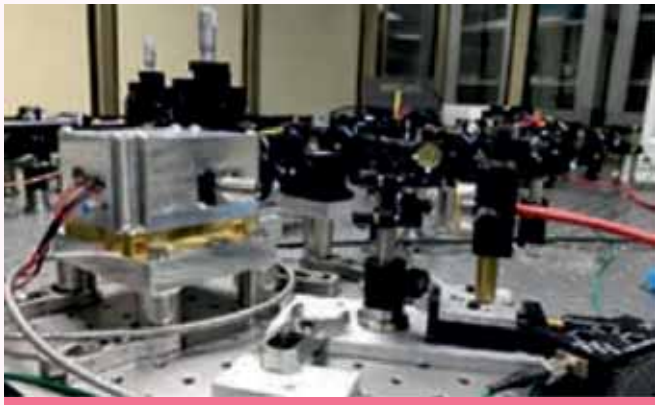


Ongoing Laser Alignment of short beamline

Carbon and Hydrogen beams at the maximum and the lowest terminal voltages. In both cases the guaranteed currents have been observed. The testing of Helium beam could not be completed because of the return of installation engineer due to Covid-19 pandemic. In the meantime, the Area Monitors for monitoring the radiation levels have been calibrated, as per the requirement of AERB for the accelerator laboratory, and interlock devices have been placed at specific locations and made operative. The report on the radiological safety protocol has been submitted to AERB for approval. Fabrication of a reaction chamber for target mounting has been completed. The setup will be used for initial calibration test run once the approval from AERB is received. The alignment procedure in the existing short astrophysics beam line is in progress for the test runs.

LASER TECHNOLOGY

An engineered version of ultra-narrow linewidth diode pumped Non Planar Ring Oscillator (NPRO) has been designed, fabricated and characterized for use as a light source for 10 m arm length prototype laser interferometer being built at RRCAT for technology development and expertise building related to gravitational wave detection. The developed NPRO laser has a linewidth of 51 Hz integrated over a time period of 1 sec measured using the heterodyne beat frequency method, when operating at 5.5 W output power at 1064 nm wavelength. The complete NPRO oscillator is assembled as a single integrated module comprising NPRO crystal, actuating PZT, temperature control TEC and the biasing magnets, inside aluminum housing. The opto-mechanical assembly has been designed such that it is air-tight and can be evacuated if required in the future, to minimize acoustic noise coupling from external sources. A detailed characterization of the engineered NPRO laser has been done which includes measurement of line-width and intensity noise.



Monolithic NPRO Laser system on the test table (aluminum box on the left)

In high energy and high power laser chain, a number of High Reflectivity (HR) mirrors are required for applications such as end mirrors, beam steering optics, beam transport etc. These large size optics are not readily available from international vendors, hence developed indigenously. Four numbers of raw fused silica optical substrates of size 125 mm x 125 mm were



High reflectivity high damage threshold mirrors

polished and surface figure of $\lambda/10$ @ 589 nm and roughness better than 5 Å were achieved. A 25-layer high reflectivity mirror coating was designed and deposition of alternate SiO_2 and Ta_2O_5 layers has been carried out. Parameter optimization of dual ion beam deposition was carried out before making the final coating and 25 layers have been deposited in a single run of 23 hours. Reflectivity of the coated optics achieved is 99.8 % 0.1% at center wavelength of 1053 nm and laser damage threshold was found to be 1.3 J/cm^2 @ 1 nsec. These mirrors have been developed for high energy physics prototype Nd: Glass amplifier system.

An engineered version of 500 W all-fiber Yb-doped CW fiber laser operating at 1080 nm has been developed with optical to optical conversion efficiency of 70%. Single transverse mode laser output emitted through 20 micron core diameter is coupled to large mode area delivery fiber. For packaged engineered



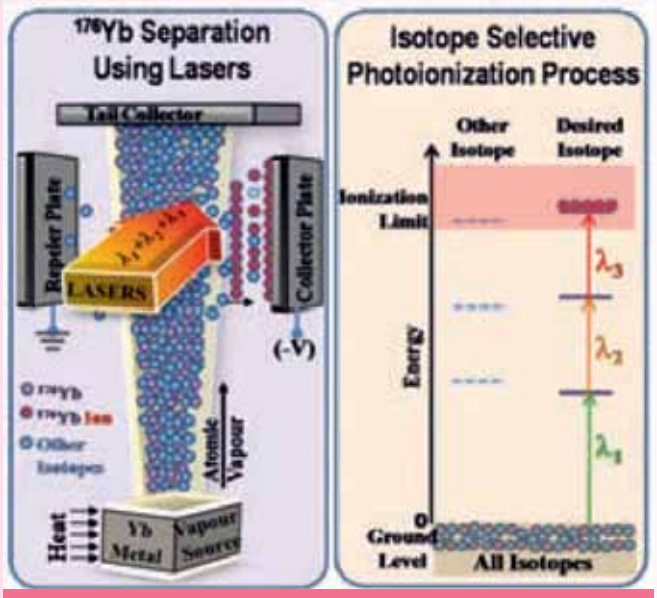
In-house developed 500 W single mode Yb-doped CW fiber laser



IR-FEL setup installed inside a 60 m long and 5 m wide radiation shielded area

version, a flat compact water cooled heat sink structure for spooling and packaging of fiber laser components has been designed and fabricated. This laser is pumped at 915 nm instead of 975 nm to minimize effect of variation at pump wavelength with change in diode temperature and diode pump current, since absorption peak at 915 nm is spectrally broad as compared to sharp absorption peak at 975 nm. Laser output was found to be stable within 1.5% over 1 hour of continuous operation. Laser has been tested on table top and a packaged in a cabinet.

The Infra-red Free Electron Laser (IR-FEL) at the Raja Ramanna Centre for Advanced Technology (RRCAT) has lased at a wavelength of 28 micrometer with a maximum continuous wave average out-coupled power of 7 mW at 2 Hz pulse repetition rate. This corresponds to a peak saturated power output 4.6 MW in 10 picosecond pulses. The IR-FEL was recently upgraded with a new injector electron linac system, which was operated at an electron beam energy of 24 MeV with a peak current > 50 A in 10 picosecond long pulses repeating at 29.75 MHz for a macro-pulse duration of 5 microseconds. This electron beam was transported through a 2.5 m long pure permanent magnet undulator with 5 cm period, which is located inside a 5.04 m long optical cavity whose length and alignment were fine-tuned precisely during the experiments using a remote controlled six-axis hexapod. The peak power output from the IR-FEL, the measured Gaussian transverse optical mode profile and the detuning length of 37 micrometer all agree well with the results predicted by FEL simulations considering experimental parameters. The IR-FEL is the first free electron laser in the country to lase and achieve saturation.

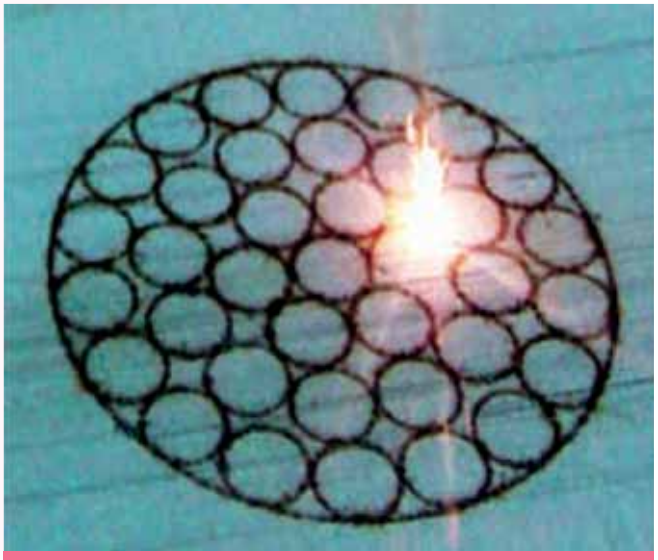


Schematic of ^{176}Yb Separation Technique based on Laser based Photoionization Process

^{176}Yb was separated using Laser Isotope Separation (LIS) in ATLA (Advanced Tunable Laser Application) facility. Metallic Yb is heated up to generate well collimated beam of atomic vapour. A composite laser beam of narrow line width ($\Delta/ < 1$ppm), three precisely wavelength tuned, high repetition rate pulsed dye laser beams were used to selectively photo-ionize 176Yb and the ions are collected by applying an electric field onto a collector plate. Multiple intermediate grids with suitable voltages reduce deposition of undesired isotopes on the collector plate. 3mg of 176Yb / hour of isotope purity better than 96% was produced from its natural abundance of 12.8%. In presence of high temperature thermal field of plasma and insufficient oxygen, carbonaceous material gets converted into CO and H_2. The process is called plasma gasification.

Laser Applications

The Laser Additive Manufacturing Power Bed Fusion (LAM-PBF) system has been deployed to successfully build spacers for electrically heated fuel bundle simulator as required by the BARC. Photograph (a) shows in process LAM-PBF for spacers and Photograph (b) presents a typical photograph of Mesh type spacer having 101.57 mm outer diameter and 10 mm depth with 37 holes of diameter 14 mm. After qualification of defects, geometry and dimensions, 25 spacers have been built and delivered to BARC. Photograph (c) presents the image of assembly of



(a) In Process LAM-PBF



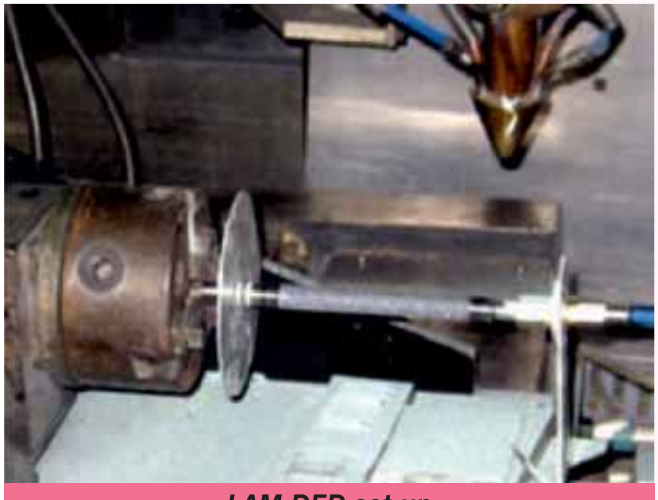
(b) As-built Mesh Type Spacer



(c)Assembly of spacers at RED, BARC

spacers at RED, BARC. These were conventionally made using wire-cut Electric Discharge Machining (Wire-EDM) in several weeks. This time has been reduced to less than three hours with the LAM-PBF system resulting in significant saving of time, energy and material.

A 2 kW fiber laser based laser additive manufacturing using directed energy deposition (LAM-DED) was deployed for cladding of 0.2 mm thick SiC clad layers on Zircaloy-4 tubes (Figure IV.2(a)). The work aims for accident prevention studies for the generation of Hydrogen from Zircaloy under high temperature steam environment. SiC clad layers of thickness 0.2 mm on 10 mm diameter x 0.6 mm thick x 100 mm length Zircaloy-4 tube were carried out using LAM-DED. Various laser-processing parameters were optimized. During initial trails, it was observed that the lower thickness (400 ㎛) of Zr-4 tubes is major challenge as it yields excessive dilution or thermal damage/ burning. The control on excessive dilution and thermal damage/ burning is achieved by cooling the tube from inside by flowing Ar gas at flow rated of 20 l min^{-1}. The interface between SiC clad layer and Zircloy is characterized using different techniques (optical microscopy, scanning electron microscopy and x-ray diffraction) to access the homogeneity, uniformity, defects and to identify different phases formed across the interface. The clad layer is found to be consisting of SiC, $ZrSi_2$, ZrSi and ZrC type of phases. The optimized parameter yielding defect free SiC cladding is laser power density of 4.52 kW cm^{-2}, powder feed rate 2.71 g min^{-1} and scan speed 325 mm min^{-1}. Six numbers of clad tubes were delivered to BARC for further examination.



LAM-DED set-up



SiC clad layers on Zircaloy tubes

The customized Fiber Bragg Gratings (FBGs) were fabricated at RRCAT and delivered to Lab To Market (L2M), IISc Bengaluru, for validation purposes in intended applications in the field of Indian railway safety monitoring system. The required specification of the FBG were, gauge length - 3 mm, FWHM bandwidth - 0.5 to 0.6 nm, reflectivity - more than 70%, cable type - bare fibre, cable length - 2 meter and Bragg wavelength varying from 1530 nm to 1560 nm. These gratings with required specifications and at different wavelengths, were fabricated using RRCAT developed FBG workstation. The FBG workstation consisted of high repetition rate UV radiation generated from the second harmonic frequency conversion of Copper Vapour Laser (CVL), FBG writing optical system and FBG monitoring set up. To understand the train wheel response, various qualification experiments were carried out with the FBG strain sensors supplied by RRCAT by a team of L2M, IISc Bengaluru. Different FBG sensor configurations with vertical load sensors, vibration sensors and lateral load sensors were carried out at stabling line at Bengaluru Railway station. The Wheel Impact Load Detection system (WILD) system,



Bare FBG attached to the web of the rail to record the strain



In-house developed 500 W average power fiber coupled pulsed Nd:YAG laser system for welding of waste management canisters

based on FBG strain sensor, was developed to detect the flat wheel of the rail. It was observed that the impact load was higher for larger wheel flat. Many a times, flat wheels are responsible for train derailment and consequent damages. This study demonstrated the suitability of FBG based strain sensors in railway safety applications.

A 500 W average output power and 10 kW peak power fiber coupled pulsed Nd:YAG laser using double lamp ceramic reflector pump chamber has been developed. An electrical to laser conversion efficiency of 5% and beam quality factor M2~65 was achieved. Laser pulse duration can be varied in the range of 2-40 ms and repetition rate in the range of 1-100 Hz. The system also includes development of a 10 kW average power laser power supply and controller to drive two flash lamps in the pump chamber synchronously. Laser beam has been delivered through 400 μm and 600 μm core diameter optical fibers with 90% transmission efficiency. Laser system has been equipped with three time shared fiber ports, one for welding trials outside hot cell and two ports for welding inside hot cell. Using this laser system, laser welding parameters were optimized for 4 mm thick SS plates provided by BARC and welding was performed successfully without any cracks and porosity. The photograph shows in-house developed 500 W average power fiber coupled pulsed Nd:YAG laser system for welding of waste management canisters.

ADVANCED TECHNOLOGIES

Powered Air Purifying Respirators (PAPR) consisting of respirator unit, snorkelling mask and



Belt-mount Powered Air Purifying Respirators

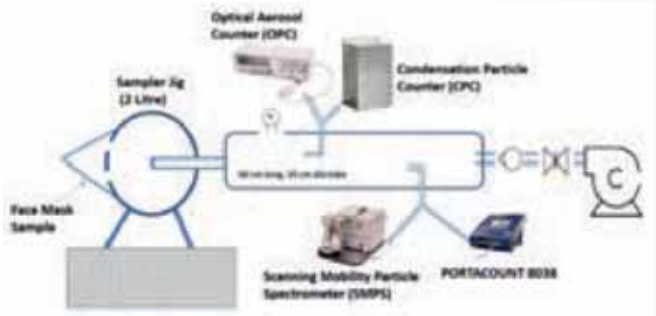
breathing tube were developed using replaceable HEPA filter with airflow of 115 - 210 lpm. Fully charged 3.7V and 26Ah Li ion batteries enable 8 hours of uninterrupted operation @ 210 lpm (with fresh HEPA filter). Batteries take about 4 hours to charge. Respirator unit and facemask weigh 1.4 and 0.5 kg respectively.

Motor drive controller embedded application was built on a 32 bit safety class microcontroller based on Arm Cortex R5F processor. Controller card has capability for field oriented control algorithm in addition to V/F control. Isolated voltage, current and temperature sensors enable continuous monitoring of VFD operation and protection. Power stack uses a compact sandwich bus bar to minimise power losses. Controller board with fully assembled power stack is integrated and tested at 11 kW. DSP firmware code was developed to implement the V/F algorithm on the Hercules DSP. Switching was tested at 20kHz.



10kW variable frequency drive (VFD)

A Procedure to assess face masks was developed to test their performance during the design phase itself. Intrinsic sampler, as the name suggests, characterises effectiveness of filter medium. Full mask sampler, comprising aerosol generator, mixing chamber, aerosol sampler, etc., evaluates the efficacy of full mask in 'face fix' and 'sealed' configurations. The



Full mask Sampler for assessment of particle capture efficiency of whole mask

procedure was validated by certified N-95 masks and were used to assess the performance of masks under different sterilization procedures.

F-CVD process was deployed for simultaneous coating of alumina on inner and outer surfaces of SS and MS pipes of diameter ranging from 13- 38 mm. The coatings were gravimetrically analyzed and characterized by SEM-EDS. Uniform coating thickness of 20 m was achieved.



Alumina coating on SS 304 tubular substrate



Intelligent X-Ray, Gamma, Neutron and Gamma Neutron Monitors

Beam Loss and Radiation Monitoring System was developed commissioned at Low Energy High Intensity Proton Accelerator Facility (LEHIPA). The system monitors the beam loss and ensures safety of personnel during normal and emergency situations. It has 32 intelligent radiation monitors for Gamma, X-ray, Neutron flux and dose monitors with ranges suitable for different radiation zones of the accelerator. The system is networked from sensors to operator panel with ethernet connectivity.

UT based NDT workbench with 4-channel ultrasonic imaging system (UIS) was developed for flaw detection, sizing and characterisation of mechanical components. The automated 4-channel UIS can acquire A-scan 1-D data and B-scan & C-scan cross-sectional images to visualise the internal details of the mechanical components being tested. 2-axes mechanical scanner was interfaced to the system for imaging the components in contact as well as in water immersion modes of inspection. The system was used to detect flaws in SS, aluminium, welded regions of mechanical components and has demonstrated detection of 2mm Flat-Bottom-Hole (FBH) in 190mm diameter SS cylinder.



NDT Workbench Installed at CDM

Ultrasound Technology (UT) was used to estimate gas-liquid-solid phase fractions in the pipes of the helical digester of a modular biogas plant (10 kg kitchen waste/ day) based on Nisargruna technology. The technique involved scanning a contact type 2.25 MHz UT sensor along the pipes and the reflected signals were analyzed to determine fraction of gas, liquid and solids present in the digester pipes. The state of solid could also be determined. The UT measurements provided very useful insights into variation of three-phase composition in the opaque pipes of the helical digester.

A prototype electronic mine for CME, Pune was developed to serve as replacement for dummy mine to assist army personnel training in demining operations. The unit comprises of battery operated compact pressure sensing setup which can be buried in the ground for detecting footfalls above 8 kg-f. The pressure sensor below the mine will trigger a wireless alarm whenever a trainee steps on the mine without having neutralized it. Field trials were carried out at CME, Pune and its working was demonstrated to CME army officers.

The Electromagnetic manufacturing machine joins or forms thin metallic objects by cold impact process ensuring high joint integrity and repeatable process performance. The technology was transferred to a private industry. This machine is capable of coupling variety of coils for welding, crimping and forming of dissimilar metals such as SS-Cu, SS-Al and Cu-Al. It can perform tubular compression and expansion of joints (tube-tube, tube to rod) as well as flat sheets of thicknesses varying from 0.5 mm to 2 mm.



Compact Electromagnetic Manufacturing Machine

Electronics & Instrumentation

A safe and secure PLC (NUCON-1000) was developed to mitigate the issues related to cyber security, technological denials, obsolescence and independent verification by commercial PLCs (Programmable Logic Controllers). A distributed control system integrated test facility consisting of 32 Node and 9 Node (catering to total 8000 I/Os) NUCON-1000 PLCs interfaced with SCADA servers was setup at ECIL, Hyderabad. Validation of I&C requirements of a large Distributed Control System (DCS) for INRP project was



Control Room of NUCON PLC Test Facility

carried out at the test facility. Based on the functional requirements of the DCS, a detailed checklist for evaluation of Secure PLC was prepared. For validation of every functional, performance, redundancy, switchover, safety and security requirement of I&C, large number of test cases were prepared and documented in Integrated Test Plan (ITP) document. PLC software was developed to test all the test cases in ITP and hosted on the CPUs of control nodes. Validation exercise established the suitability of Secure PLC for I & C applications of INRP project.

ANU-NISHTA for Cyber Security of C&I Systems developed by Reactor Control Division was enhanced to facilitate execution of only "White listed" applications on windows. Software modules for White listing of Windows applications, device drivers and integration with ANU-NISHTA hardware module have already been developed. A GUI configurator for specifying applications, such as executables, scripts, drivers and DLLs, to be White listed based on file name, regular expression or SHA-1 digest has also been developed. The White listing database is encrypted using ANU-NISHTA hardware module. All the relevant documents including software specifications, design and user manual have been prepared.

Prototype four-train Reactor Protection System based on DMSP (Diverse Modular Safety Platform) was set up in BARC. Application program for the four trains of RPS was developed and implemented using the SPERTS framework and integrated with CPU firmware. Design & test documents like Software Requirement Specification, Software Detailed Design and System Validation Plan are prepared. IO simulator and Operator Information System (OIS) have been designed and



Four Train Prototype Reactor Protection System



Digital Mobile Radio for Wireless Communication at Security Posts of CISF and Anushaktinagar Security

implemented. Integrated four trains of Reactor Protection System along with IO simulator and OIS is tested as per system validation plan.

Digital Mobile Radio (DMR) for wireless communication at security posts in BARC and Anushaktinagar were commissioned. The project involved RF simulation and survey to provide a reliable network with redundant and diverse repeaters including coverage overlap. As a part of this, communication towers, repeater station, network management centre and 20 base stations of DMR Network for CISF and Anushaktinagar security have been installed. A 6dB Ground plane antenna with 12 m Antenna Mast and LMR cable have also been installed and tested with the DMR Network. Integrated systems such as handsets, static sets and vehicle mounted sets were handed over to CISF for BARC perimeter protection.

Personnel Thermal Screening System based on uncooled thermal camera was installed at BARC North Gate Entry portal to assist in rapid screening of employees entering BARC in compliance of COVID-19 guidelines. Similar system was installed at DAE headquarters at OYC.

A prototype face recognition based surveillance system was developed for recognizing persons from surveillance videos captured in semi-indoor environment. System features include face detection, tracking, enrolment, recognition, face quality assessment, evidence integration over successive frames and event logging, all provided in real time. The system was tested in lab which indicated 86.96% TPIR on 1627 video sequences.

Electric Fence Energizer for Perimeter Intrusion Detection System (PIDS) to not only detect unauthorized attempts of intrusion at a protected facility but also to deter the intruder by giving a very sharp but non-fatal electric shock. The energizer connected to electric fence generates 8-9 kV, 120 μs pulses at 0.66 or 0.33 Hz repetition rate and energizes upto 250 m length of fence. The energiser qualifies for electric shock safety requirement as per 'IEC 60335-2-76 – International Electro Technical Commission- 2002'.



Energiser for Perimeter Intrusion Detection System (PIDS)

Low noise standalone analog MCA benchtop module was developed for high resolution (1.85 keV @1332.5 KeV of ^{60}Co) Gamma ray spectroscopy using HPGe detector. It has Gaussian shaping amplifier, pole zero adjustment and base line restorer, 8K MCA, built-in isotope library and energy calibration with ethernet interface to Anuspect Software.



Integrated benchtop module with HV, LV, Shaper and MCA and Anuspect

Portable Radio-isotope Identifier (PRID) – a hand-held instrument measures the characteristic gamma emission spectra of materials in the energy



Portable Radio-Isotope Identifier (PRID)

range 60keV - 3 MeV and identifies isotopic composition of radioactive sources using inbuilt isotope library. PRID is suitable for detecting radioactive materials in nuclear & security establishments and ports and can also measure dose rate in the range of 10R/h to 1R/h.

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.

RAPPCOF facility continued the tasks related with the safe supply of Co-60 for various uses, right from receiving the adjuster rods from various Indian PHWR power reactors (a by-product of neutron regulation), processing of the activity, fabrication of sealed sources, to supply of Co-60 sources (irradiator sources & teletherapy sources), are all carried out. The production of Co-60 sources ar RAPPCOF increased four times in last 10 years.

At RAPPKOFF, Kota, total activity of Co-60 which was processed during the year was about 2.2 MCi during the financial year 2020-21. This includes 125 Gamma Irradiator Sources and 12 Co-60 Teletherapy Sources (CTS). It is expected to process ~2.0 Mci upto March 2021.

RAPPCOF transported 3.5 MCi to various Multi-Purpose Gamma irradiators and Radiotherapy Hospitals in the country and abroad till December 2020 in the current financial year, which includes the export orders of 500 kCi to M/s. REVISS, UK. 250 kCi to M/s. ANSELL LANKA-SRI LANKA and 342 kCi to M/s. VINAGMAMMA, VIETNAM. Apart from this 1.0 MCi activity has been transported in the first quarter of 2020 and expecting approximately 1.5 MCi in the first quarter of 2021. RAPPCOF planning to export 1.25 MCi to UK, Malesia and Sri Lanka and 600 kCi of Co-60 to Indian customers as per the existing demands in first quarter of 2021.

RAPPCOF received 06 Adjuster rods from RAPS-4 in the Financial Year 2020-21 upto December 2020 and transported 04 Adjuster rods from KAPS,



Discharging operation of highly radioactive Cobalt-60 Adjuster rods received from RAPS Unit #4 in RAPPCOF Storage pool



High intensity Cobalt-60 Sealed sources (Cobalt-60 Teletherapy Sources (CTS), W-91 and BC-188 irradiator sources) fabricated at RAPPCOF



Highly intensity Cobalt-60 irradiator source ready to despatch to M/s. VINAGMAMMA, VIETNAM



Shri. Saeed Anwer Tariq, OIC, RAPPCOF flagged off the M/s Reviss, UK export order at RAPPCOF on May 22, 2020

Gujarat and 08 Adjuster rods from RAPS Unit-6 and expecting 12 Adjuster/Regulating rods from NAPS, UP in the month of January.

RAPPCOF trained staff to carry out source operation for 12 Multi-purpose Gamma Irradiator Plants in the country uptil December 2020.

AGRICULTURE

Crop Improvement

Radiation induced mutagenesis along with recombination breeding was used to develop new crop varieties. Two crop varieties namely, Trombay Linseed TL99 and Mustard TMB204 have been released and notified for commercial cultivation by Ministry of Agriculture & Farmers Welfare, Government of India. The Linseed variety TL99 is released for Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam and Nagaland. It matures in 129 days and gives 1274 kg/ha yield with the oil percentage at 37% and 497 kg/ha oil yield. TL99 has a unique fatty acid composition with low linolenic acid at 2



Field view and seeds of Trombay Linseed Variety, TL99



Field view and yellow seed of Trombay mustard variety, TBM 204



Field view of Turmeric tissue culture derived plants

to 5 % and can be used as edible oil. It is moderately resistant to powdery mildew, Alternaria blight, and wilt and resistant to rust disease. This is the first linseed variety released in the country for edible oil purpose. The mustard variety TBM204, a yellow seeded mutant with a yield of 1336 kg/ha, was released in West Bengal. For popularization and supply of quality seeds to farmers, breeder seed multiplication was taken up in Trombay varieties, rice (15 quintals) and pulses (60 quintals). A total of 332 quintals of breeder seed of Trombay groundnut varieties were produced and distributed to 22 seed agencies like National Seed Corporations, State Seed Corporations, seed companies and farmers. In biotechnological approach for crop improvement, a rapid, reproducible and sustainable micro-propagation technology was developed for pineapple and turmeric. This offers a continuous source of numerous uniform sized and disease-free plantlets in a relatively short time and space and is useful for in vitro mutagenesis for generating

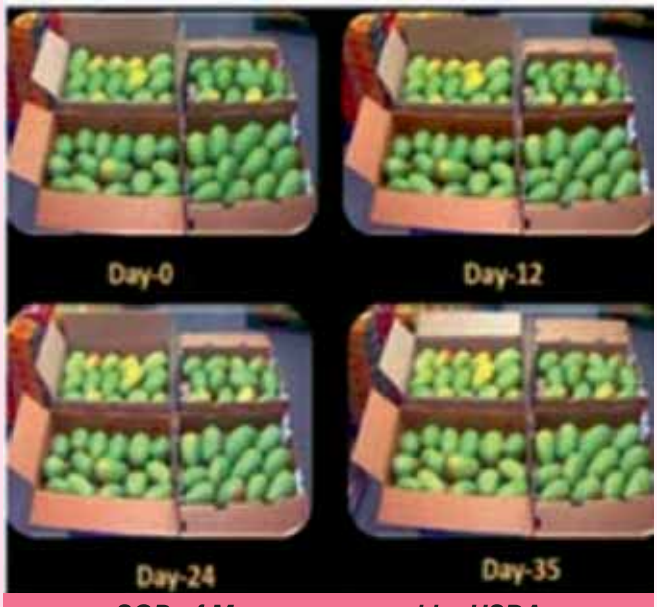
variability. In banana, transgenic lines harbouring PVND7-Sm1 showing resistance to fusarium wilt race1 was developed. Whole genome of black gram cultivar PU31 and Trichoderma virens wild type have been sequenced. BioKit for qualitative detection of group of Organophosphate (OP) and Organocarbamate (OC) pesticides in food commodities such as vegetables and fruits has been developed.

FOOD PROCESSING

GRAS (Generally Recognized As Safe) preservatives used in treating mango to extend its shelf life to enable sea-route shipment was approved by the US Department of Agriculture (USDA).

Technology for Shelf life extension of Kinnow involves cleaning, surface hygienization, coating with GRAS preservatives, air drying, polishing and storage in ventilated Plastic Boxes with proper Hygiene (PBVH). This commercially viable technology extends shelf life of Kinnow mandarin up to 45 days at 8±2ºC storage and relative humidity >85%. The control fruits lost 17% weight, while the treated and packaged fruits lost only 2.7% on 45 days of storage.

The spice-herbal infusion BhabhaAnti-Viral Infusion-23 (BhAVI-23) comprising of 23 selected spices and herbs was conceptualized and formulated. The infusion displayed prominent anti-viral activity as evident from inhibition of the HIV1-RT as well as through reduction in the infectivity of P1 bacteriophage as well as in-vitro anti-diabetic potential against haemoglobingly cation. Major bioactives were identified as eugenol, methyleugenol, 2-caren-10-al, cinnamaldehyde, 4-(1-methylethyl)-Benzaldehyde and eucalyptol.



SOP of Mango approved by USDA



Shelf life of Kinnow extended up to 45 days



Dehydrated Java plum (Jamun) strips with ensured safety,preserved aroma, and Extended storage life

The role of phenolic acids in enhancing Fe^{+2} mediated hydrolysis of glucosinolates in irradiated

cauliflower was demonstrated. A significant increase (15%) in cysteine content of cauliflower after radiation treatment suggests enhanced sulfur flux under radiation stress to compensate for decreased sulfur availability.

About 46 compounds were detected in the dehydrated Jamun stick developed to address perishability and limited seasonal availability of the fresh fruit.

Radiation Procession Services

Radiation Processing Plant (RPP), Vashi

Radiation Processing Plant, Vashi has provided gamma radiation processing services for Spices, Ayurvedic raw material, healthcare products and pet feed etc. to customers from all over the country. Thirty-eight new customers were registered during the current year. This has resulted in improved product availability throughout the year. Source strength of the plant was increased up to 712 kCi from 612 kCi, which resulted in reduction of waiting period for the customers.

During the current financial year, 2019-20, 4540 MT of spices, Ayurvedic raw material, healthcare products and other products were processed against the annual target of 4500 MT.

RPP facility was re-certified for ISO 22000:2005. Surveillance audits for ISO 9001:2015 (Quality Management System) was also carried out by certifying agency and found in full compliance with the Standard's requirement. Gamma Radiation Processing Services are provided for hygienization of spices, ayurvedic raw materials, pet feed and packaging materials.

The activities of the Dosimetry Services, Vashi Complex included the Plant commissioning dosimetry for M/s Jamnadas, M/s Hi-media, M/s Akshar Gamma, M/s A.P. Medtech for sterilization of medical products and for Class VI and Class III food products, were completed during the reported period. Recommissioning dosimetry was carried out for two radiation processing plants. Dose rate certification was provided to three Cs-based blood irradiators and supplied to Apollo Hospital, Ahmedabad, National Institute of Immunology, Delhi and Rajiv Gandhi Cancer Institute, Delhi, is completed. Production & supply of 1.5 Lakhs Ceric-Cerous Sulphate Dosimeters were done for various gamma irradiators in the country for the measurement of absorbed dose.

New MoU for Radiation Processing Plants in Private Sector

MoU was signed with M/s Lion Foods Pvt. Ltd., for setting up a Gamma Radiation Processing Plant for disinfestation, shelf life extension of food products and sterilization applications of healthcare products, at Madhupur, Taluka: Talala, Distt: Gir Somnath, Gujarat. MoU was signed with M/s Suzaina Foods for setting up a Gamma Radiation Processing Plant for disinfestations, shelf life extension of food products and sterilization applications of healthcare products, at Chikhli, Navsari, Gujrat (Virtual MoU signed due to COVID-19). MoU was signed with M/s Sukshma Gamma Pvt. Ltd., Vijaywada, for setting up a Gamma Radiation Processing Plant for disinfestations, shelf life extension of food products and sterilization applications of healthcare products, at Model Industrial Park, Mallavalli Distt. AP (Virtual MoU signed due to COVID-19).



MoU was signed with M/s Lion Foods Pvt. Ltd., at Gir Somnath, 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. Positron Emitting Tomography (PET) is a powerful imaging agent through which quantitative information on the distribution of positron-emitter labelled radiopharmaceuticals (PET radiopharmaceuticals) in the body can be realized. ^{18}F-FDG is currently the most widely PET radiopharmaceutical in clinical oncology in addition to its clinical applications in cardiology and neurology. The application of PET in clinical oncology is increasing since many molecular targets relevant to cancer can be labelled with positron emitter radiopharmaceuticals and also these products needs to be produced in strict GMP compliance.

Around 28 batches of TCM-1 (COLTECH) and 1 batch of TCG (GELTECH) consisting of 519 numbers of ^{99}Mo/^{99m}Tc generators were processed and supplied to NM centres across the country. About 33 batches of TCM-2 (Mo-99 as sodium molybdate solution for solvent extraction generators) consisting of 116 consignments were supplied. In total, 196.7 Ci of Mo-99 activity for TCM-1 and TCG and 28.35 Ci of Mo-99 activity for TCM-2 was supplied.

BRIT continued to supply cold kits towards preparation of radiopharmaceuticals at hospital radiopharmacy. A major part of the supply comprised 19 cold kits for Tc-99m labelling (TCK Kits) towards preparation of Tc-99m radiopharmaceuticals for the functional imaging of various organs. Re-188 and Lu-177 based cold kits were also supplied for preparation of Re-188 and Lu-177 therapeutic radiopharmaceuticals.

Iodine-131 radiopharmaceuticals continued to be the most used therapeutic radiopharmaceuticals. 131I-NaI was supplied in the form of oral solution and capsules for treatment of thyroid cancers and other thyroid related disorders. 131I-mIBG was also produced and supplied for treatment of neuroendocrine tumours. During the period under report, more than 500 Ci of I-131 based products were supplied to NM centres all over India.

BRIT resumed the supply of 25 mCi and 50 mCi of I-131 capsules, while 100 mCi capsules were introduced for supply due to the advantages associated with capsules in comparison to oral solution (minimum chance of contamination, ease of usage, more accurate dose delivery, less radiation dose to the buccal cavity of patient etc.).

Lu-177 radiopharmaceuticals (^{177}Lu-DOTATATE and ^{177}Lu-PSMA) comprised the bulk of the other therapeutic products supplied by BRIT. In spite of the lockdown conditions leading to limited demands for all products, demand for these Lu-177 radiopharmaceuticals saw an increasing trend.

Towards enhancing the production capacity for Lu -177 radiopharmaceuticals, a new production facility was installed under the 12th Plan Project, "Advanced Facilities for Radiopharmaceuticals Production (AFRP)" during this period. Cold commissioning, trial cold runs for pharmaceutical validation followed by regular production of ^{177}Lu-PSMA could be successfully carried out.

A GMP-compliant ^{131}I-mIBG (Diagnostic) production facility (procured from ITD, Germany) which was installed in 2019-20 under the 12th Plan Project, "Advanced Facilities for Radiopharmaceuticals Production (AFRP)" was routinely used for the production and supply of ^{131}I-mIBG (diagnostic) doses during this year.

Ru-106 plaque brachytherapy is an effective and vision-sparing treatment modality for ocular cancers. Waste Management Group, BARC has developed Ru-106 notch plaque sources for ocular cancer therapy which were given regulatory approval recently. BRIT initiated the marketing and supply of six brachytherapy sources during 2020-21.

Supply of ready-to-use ^{68}Ga-PSMA for PET-based diagnosis of prostate cancers to PET centres around Mumbai was continued this year also.

Cold kit for the facile preparation of ^{68}Ga-PSMA (Prostate specific membrane antigen) for PET based diagnosis of prostate cancer was introduced during this period and made available to the nuclear medicine practitioners.



Cold kits for the preparation of ^{68}Ga-PSMA

Production procedure for preparation of Sterile Evacuated Vials required for the generator/cyclotron-based radiopharmaceuticals was developed and is now available for nuclear medicine practitioners. Currently these Sterile Evacuated Vials are being used at Radiation Medicine Centre, Mumbai and Medical Cyclotron Facility, BRIT Regional Centre, Kolkata.

The Medical Cyclotron Facility (MCF), Parel, continued the production and supply of PET radiopharmaceuticals, mainly ^{18}F-FDG and ^{18}F-Sodium Fluoride and to a lesser extent the newly launched [F-18]-Fluro Ethyl–L-Tyrosine (FET). Regular and uninterrupted supply of about 164 consignments of PET radiopharmaceuticals such as ^{18}F- FDG, ^{18}F-NaF, and ^{18}F-FET to various hospitals in and around Mumbai accounting for nearly 64 Ci of radioactivity during the year 2020-21. More than 15000 patients benefitted with PET investigations in the reported year. Cu-64 was produced by bombarding attenuated proton beam of 12 MeV at 10 μA for 90 minutes on enriched 30 μm thick Ni-64 target. Radiochemical separation and purification employing ion exchange column chromatography (IE-CCM - AG® 1-X8, 100-200 mesh, chloride form) has been carried out to obtain $^{64}CuCl_2$ in clinical grade form. In vivo PET CT analysis using human prostate cancer cell line (LNCap) Xenograft model in Nude Mice, was carried out. High-uptake and long-term retention of radioactivity were found in the tumor (10.04 ±1.08% ID/g) which corroborates with scintigraphy studies. 25 mCi of Ga-68 was produced via irradiation of enriched Zn-68 in the liquid target irradiation system.

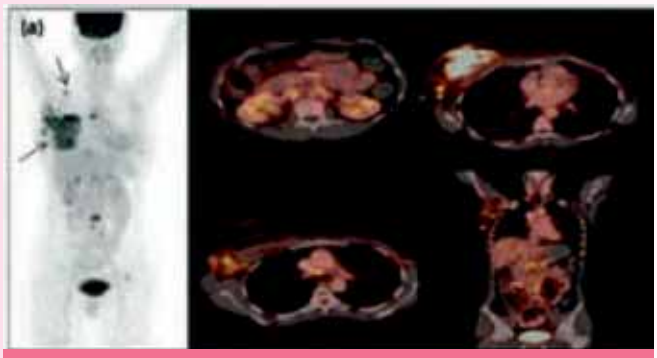
A 30 MeV, 350 μA Medical cyclotron facility has been installed and commissioned with 5 beam lines – 3 for medical isotope production from liquid and solid targets and 2 beam lines for material science research and ADSS target study. There are 9 hot cells (2 for PET, 7 for SPECT) for radioisotopes production in clean room area. VECC facilitates BRIT to produce FDG radiopharmaceuticals and deliver on regular basis to various hospitals. Also, other radioisotopes like, Ga^{67} and Ga68 have been produced by BRIT on trial basis from solid target of Zn^{68}. Besides producing radioisotopes for medical uses, the cyclotron is used for various research and developmental applications. A few topics to name are Radiation damage studies; Production of ^{68}Ge for preparation of ^{68}Ge/^{68}Ga generator, ^{64}Cu, ^{22}Na for Positron Annihilation Studies and ^{57}Co sources, which is used in calibration of isotope



30 MeV Medical Cyclotron at Chakgaria campus of VECC Kolkata

dose calibrators, gamma cameras and Mossbauer sources which will be done in future for which separate clearance will be taken; Wear and tear studies and Target window study for Pb-Bi target assembly.

Radiopharmaceutical Committee of DAE (DAE-RPC) clearance was obtained for the manufacture and supply of No-carrier-added $^{64}CuCl_2$ as a PET radiotracer for cancer imaging; Freeze-dried HYNIC-RGD kit for the formulation of ^{99m}Tc-HYNIC-RGD dimer for SPECT imaging of cancer and ^{90}Y alumino silicate microspheres for radionuclide therapy of liver cancer. Proposals for two new radiopharmaceuticals such as freeze-dried DOTA-TATE kits for the formulation of ^{177}Lu-DOTA-TATE (an agent for radionuclide therapy of neuroendocrine cancers) and 'Ready-to-use' formulation of patient doses of ^{177}Lu-Trastuzumab for radioimmunotherapy of metastatic breast cancer were submitted to DAE-RPC for approval.



FDG PET-CT scans of a cancer patient suffering from metastatic breast cancer

During the year, a total 494 units of irradiations were carried out in Dhruva reactor for various applications in healthcare, industry, agriculture and research. This includes 122 cans of MoO_3, 216 cans of TeO_2, 42 cans of Ir, 32 cans of Sm_2O_3, 34 cans of $LuCl_3$, 2 cans of red Phosphorus and 3 containers of Xenon. Apart from these, 28 cans of miscellaneous irradiations and 15 cans of service irradiations were also carried out in Dhruva reactor. Additionally, 10 units of irradiation were carried out in APSARA-U for producing radioisotopes. During the year radiochemicals such as $Na_2{}^{99M}oO_4$, $Na^{131}I$, $^{177}LuCl_3$, $153SmCl_3$ and $Na^{125}I$ were supplied in the form of radiochemical formulations. Among these, around 400 Ci of $^{177}LuCl_3$ was directly supplied to the leading nuclear medicine centres across the country as radiopharmaceutical precursor. More than 1000 cancer patients were treated with therapeutic radiopharmaceuticals such as, ^{177}Lu-DOTA-TATE and ^{177}Lu-PSMA-617 formulated using $^{177}LuCl_3$. 43,000 Ci of ^{192}Ir activity was also produced during the year and supplied to BRIT for radiography and industrial applications.

Intrinsically radio-labelled $^{177}Lu_2O_3$-HSA (human serum albumin) hybrid nano-composite was synthesized following a novel bio-inspired synthesis route. The nano-composite formulation demonstrated favourable pharmacokinetics and tumour regression in animal model. ^{177}Lu-labeled nitroimidazole decorated gold nanoparticles (DOTA-Au-NIM) prepared for targeting tumour hypoxia showed excellent results in-vitro. An electrochemical separation technique was developed and successfully demonstrated for the separation of $^{132/135}$La theranostic pair from proton irradiated natural $BaCO_3$ target.

Studies were carried out to evaluate the potential of Ubiquicidin derived peptides as infection imaging agents and elucidate mechanism of interaction with bacterial membranes. Human Serum Albumin (HSA) nano-colloid, required for the preparation of lyophilized HSA nano-colloid kits (99mTc-HSA nano-colloid used for sentinel lymph node imaging for diagnosing cancers) was synthesized and delivered to BRIT for supplying as freeze-dried kits to the nuclear medicine centres.

The success of any radiotherapy for cancer treatment depends on the use of comprehensive Quality Assurance (QA) program throughout the chain of the treatment process. Pre-treatment verification of dose delivered to the cancer patient is one of the important parts of this chain and an image based dosimetry QA system for advanced radiotherapy was developed as an import substitute. The system carries out a quantitative and comparative analysis of two data sets. The first is a dose map obtained from radiotherapy Treatment Planning System (TPS) and the second is the image of the radiation beam portals acquired during pre-treatment verification delivery, which is subsequently converted into dose map using suitable built-in calibration process, and is further processed and stored in DICOM RT format. User interactive features have been provided to modify the input for quantitative and qualitative analysis. The added features include Physics

QA module for the evaluation of radiation field size, radiation beam uniformity, radiation beam symmetry and radiation beam penumbra. This dosimetry QA system will be useful for clinical medical physicists in evaluating advanced treatment plans to achieve higher level of accuracy and consistency in treatment delivery.

Extensive expression of Prostate Specific Membrane Antigen (PSMA) is common in all prostate cancers (PCa), which make it a potential target in cancer diagnosis and therapy. Unlike other tissues like kidney, small intestine, or brain, expression of PSMA in malicious tissues is ~1000-fold higher. PSMA-617, a peptide based Lu labelled ligand is used in radiotherapy of prostate cancer. However, this ligand is not readily available in India. PSMA is a structurally complicated molecule and its synthesis is very challenging. Using novel synthesis strategies such as triphosgene chemistry and coupling chemistry, BARC has now synthesized upto 5 mg of material at a cost ten times lower than the market price. This ligand has been labelled with Lu-177 at BRIT, Vashi, with a radio chemical purity of 99.5%. RPC approval is obtained to use it as therapeutic agent to treat prostate cancer. Two batches of 2 mg each of the NOTA-bisphosphonic acid ligand with > 97% purity was also synthesized for treatment of bone metastasis.

Positron Emission Tomography (PET) uses 18F labelled bio-molecules in early detection of cancer. Newer PET radiopharmaceuticals are being developed for targeted imaging of different cancers and for radiotherapy planning taking into account their clinical efficacy, patient tolerance and safety. Clinical trials on animals are carried out at Radiation Medicine Centre (RMC) by injecting them with 18F Fluoroethyl- 2-Nitroimidazole and Fluoroethylated Thymidine. 18F content in different organs was used to study their metabolic behaviour. The data is extrapolated for use in pharmaceutical dependent bio-kinetic models developed for humans, specifically for Gastro-intestinal (GI) tract, liver and urinary bladder.

Radiation technology equipment

Blood Irradiator

Four Blood Irradiators-2000 units with Cs-137 source (5525 Ci) have been supplied to hospitals in India during April 2020 to December 2020 and supply of 02 units of BI-2000 is expected upto March 2021.

Radiography Camera

Production and supply of 09 new indigenous radiography camera, model ROLI-2, and 12 Nos. of model ROLI-3 were done from April 2020 to December 2021. Expected supply upto March 2021 is 15 Nos. Inspection & servicing of 366 numbers of BRIT manufactured as well as imported ROLI cameras, were the highlights during the reported period. Expected servicing & inspection, upto March 2021 is 264 radiography cameras, both, imported as well as domestic.

Gamma Chamber 5000

Supply of two units of GC-5000 with Co-60 source is expected upto March 2021, while one unit of GC-5000 was decommissioned during the reported year 2020-21. Inspection & servicing was provided for eight units of GC-5000.

Radio Diagnostic & Treatment Services

RIA procedure for the estimation of C-reactive protein, an indicator of infection or chronic inflammatory disease such as rheumatoid arthritis, lupus, as well as risk of heart disease was developed in collaboration with Mangalore University. A prototype kit is ready for clinical evaluation.

Cell culture laboratory for in-vitro testing of new radiopharmaceuticals was maintained, various cell lines were sourced, propagated and made available whenever required.

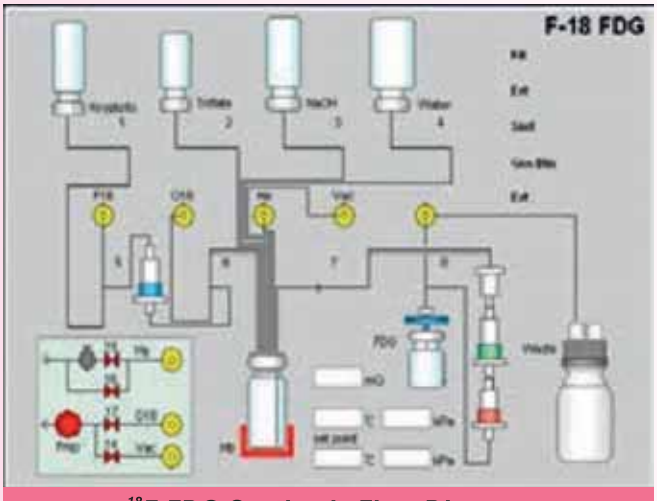
Magnetic cellulose particles required for the production of magnetic particle-based RIA and IRMA kits were produced for the in-house consumption and Radiation Medicine Centre, Parel, Mumbai.

Regional centres at Delhi, Dibrugarh & Kolkata, Hyderabad (also k/as Jonaki), Bengaluru, and Kota continued their respective services towards the supply of ready-to-use-radiopharmaceuticals to surrounding

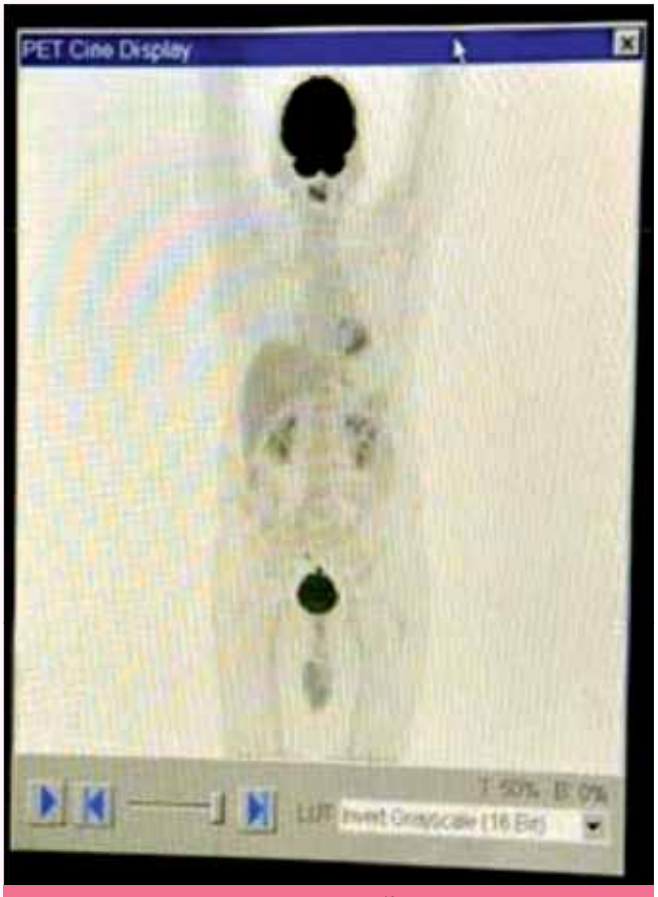
nuclear medicine hospitals, rendering RIA & IRMA diagnostic services for the benefit of patients in the entire North-Eastern region, PET Radioisotopes production in Cyclotron (VECC), preparation & supply of labelled compounds, radioanalytical certifications and processing of Co-60 sources for their various uses in Engineering Programme of BRIT. Around 3,000 consignments of in-vivo and in-vitro kits were supplied to RCR's for providing extended services to nearby hospitals, research centres, or institutions at and surrounding these cities.

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 4000 patients of the region avail the (RIA & IRMA tests as well as RPhs products supply) services from this centre.

During the year 2020-21, approximately 55 Nos. of Technetium cold kits for formulation of 99mTc-radiopharmaceuticals were supplied to various Nuclear Medicine Hospitals in Kolkata by the Regional Centre, Kolkata. Regular production and supply of 18F FDG to different hospitals from DAE Medical Cyclotron, CYCLONE- 30, Kolkata, started in June, 2020. The Centre continued to supply 18F FDG inspite of the lockdown period. Total 576 numbers of Invoice have been generated till December 2020 of the reported period 2020-21. Around 200 batches of 18F-FDG were routinely analysed and certified by Quality Control during this period. Regular Quality Assuarance was performed before the batch release of all the RPhs which were supplied through the Centre during the reported period. Production of new product, pharmaceutical



^{18}F-FDG Synthesis Flow Diagram



PET-CT scan of ^{18}F-FDG



PET-CT Scan of bone using ^{18}F-NaF injection made at RCR, Kolkata

grade Na[18F]F injection, bone imaging radiopharmaceutical using modified Integrated Fluidic Processor in IBA Synthera module. This new product has been launched in December,2020.

Regional Centre, BRIT, Bengaluru supplied 87 Ci of ready-to-use ^{99m}Tc-pertechnatate to nuclear medicine hospitals and 500 TCK cold kits were sold through retail outlet and door delivery for the preparation of ^{99}mTc-radiopharmaceuticals to nearby nuclear medicine centres. Gamma irradiation unit, BI-2000 with Cs-^{137} source is received at RCR, Bengaluru and is ready for its installation and commissioning. Radioanalytical Laboratory analyzed and certified 50 samples for the measurement of residual radioactivity in various commodities such as food items for human & animal consumption, medicine and miscellaneous items.

Regional Centre for Radiopharmaceuticals, Delhi continued the supply of clinical grade, ready to use diagnostic ^{99m}Tc-radiopharmaceuticals injections in compliance with GMP and RPC, ready-to-use radioactive therapeutic injections of ^{131}I-mIBG, ^{177}Lu, ^{153}Sm, COLTECH/GELTECH Generators and TCM-2 (^{99}Mo Generator kit for Solvent Extraction), for nuclear medicine centres in Delhi and NCR regions. During the period, 2020-21, Regional Centre, Delhi has been involved in production & supply of 10 Ci in 145 consignments, of clinical grade, ready-to-use Tc-99m radiopharmaceuticals injections. Quality Control of ready-to-use Tc-99m & its labelled RPhs from 106 batches were analyzed during the said period.

During the period, Regional Centre of BRIT, Hyderabad (Jonaki) supplied ready-to-use Tc-99m as Sodium Pertechnatate (2.935 Ci) to local Nuclear Medicine Centres. It has supplied 406 Nos. of TCK Cold kits (produced at BRIT, Vashi Complex). It has initiated the setting up of Radiopharmaceuticals laboratory for the preparation and supply of ready-to-use Tc-99m and Ga-68 formulations to these local Nuclear Medicine Centres and Radioanalytical facility for providing radioanalytical services to the users. Also, during the Year 2020-21, RC, BRIT, Hyderabad continued the synthesis and supply 32P labelled nucleotides (57.75 mCi) and molecular biology reagents such as Taq DNA Polymerase, PCR master mix and enzymes for research in frontier areas of Molecular Biology, Biotechnology, Biomedical and Drug Discovery research of the country.

Labelled Compounds and Diagnostic Kits

Labelled Compounds Programme of BRIT is involved in the synthesis & supply of a variety of 14C, 3H and 35S-labelled products and various types of Tritium-Filled Self-Luminous sources. During 2020-21, Labelled Compounds Programme has supplied 16400 Tritium Filled Self-luminous (TFS) sources of various sizes and shapes to defence establishments and used for illumination of various types of gadgets and instruments.

A proposal is submitted for setting up of tritium gas facility at CIRUS reactor building, BARC, Trombay, and the associated work has been initiated. Once this facility is ready for operation, the tritium gas handling operation related to Tritium filled light sources and tritium labelled compounds production activity will be shifted to CIRUS building.

Custom synthesis of variety of labelled compounds for the supply of a variety of 14C (Preparation of Sodium acetate 1,2- C-14 & Standardization of synthetic route for the preparation of acrylic acid – 1-C-14, was completed), 3H and 35S-labelled products, was done during the reported period. Custom synthesis of C-14 labelled Methylamine hydrochloride was synthesized & supplied to IIT Mumbai.

Labelled Compounds Laboratory also continued the production and supply of 14C-Urea Capsules which is used for diagnosis of Helicobacter Pylori infection which causes stomach ulcers.

DDW is a readily available by product of heavy water plant based on hydrogen sulphide-water bi-thermal exchange process. Some in-vitro & in-vivo studies demonstrated that use of DDW in cancer therapy can significantly decrease the growth rate of malignant cells. In response to the awareness drives initiated by HWB, many enquiries have been received for supply of DDW of various concentrations showing huge potential of application in this field. HWB has

executed supply of 9000 kg of 125 ppm DDW to M/s GoodRich Magma, Bangalore. Second request received from the same user for supply of 96,000 kg of 125 ppm of DDW is under execution in a phased manner. About 150 ltr. of 125 ppm DDW has been supplied to M/s Balaji Innovation Group, Vadodara. Supply of 10 KL of 125 ppm DDW to M/s Star Impex is under progress.

Radio Analysis

Radioanalytical Laboratory (RAL) carried out the assay for the following measurement and certification services:

Man-made (artificial) radioactivity levels in food items for human & animal consumption, which facilitated the export of food items to various countries where the radioactivity test certificate is a mandatory requirement.

Naturally occurring radioisotopes (NORMS) in environmental samples, such as coal, fly ash, soil, rock phosphate, phosphogypsum etc. Testing and certification of NORMS in coal and fly ash helped many thermal power plants in the country to obtain MoEF clearance for their operation.

Gross alpha, gross beta content in water samples. Testing of water samples received from BIS helped in BIS licensing of many packaged drinking water plants in the western region (especially, Maharashtra and Gujarat).

Cobalt-60 contamination level in steel samples helped in the export of steel products to different countries.



Simultaneous Alpha/Beta Counting System at RAL, Vashi Complex

During the year 2020-21, Radioanalytical Services at Vashi Complex carried out more than 2800 tests on export/domestic commodities and 530 tests on water samples (gross alpha, gross beta ^{226}Ra & ^{228}Ra).

The laboratory is accredited by NABL for certifying many of the parameters and empanelled by BIS for the testing of gross alpha and gross beta in water samples.

Radiation Sterilization Plant for Medical Products (ISOMED)

Gamma Radiation Processing Plant facility at ISOMED for terminal sterilization of the medical products is being revamped and is under renovation during the reported period 2020-21.

Safety System Upgradation and Refurbishment of ISOMED facility has been undertaken by BRIT with effect from November 2020. The project is poised to offer following deliverables within a span of 36 months.

Rectification of the perennial issue of source interference (in compliance to regulatory recommendation) due to which round the clock commercial operations of the facility for terminal sterilisation of healthcare products have been kept in abeyance (after 44 years of service to the nation).

Completely renovated and upgraded set of safety systems as per the latest safety regulations to ensure reliability of uninterrupted commercial operations for the healthcare industry in future.

Completely renovated facility building thus ensuring full compliance to cGMP licensing requirements as per the latest provisions of Drug and Cosmetics Act - 1940 of the Government of India.

Currently, the structural repairs work of the facility building is under progress. Also, as a parallel project activity, the task of removal and shifting of 72 nos. of Cobalt-60 sources is under progress. The removal of sources would pave the way for the installation of new set of systems related to Coablt-60 source assemblies in the underground source storage pit with the improved / modified design. The design for the new set of Horizontal Transportation Casks, custom

built to cater to the requirements of Category II type Land Based Stationary Gamma Irradiators is being undertaken.

New Projects

Setting up of Fission based 99Mo Production Facility

Major civil modification job comprising of construction of internal partitions, annex building, installation of DG set, installation of elevator, epoxy flooring & painting of wall in the active area, installing metal ceiling, fire rated fibro silicate board, etc. were undertaken by DCSEM has been completed and the same is handed over completely to BRIT. Three radiation shielding meant for Dissolution hot cell; Purification hot cell and Conditioning and packaging hot cell received from NRG, BARC, were installed in the respective hot cell by M/s. INVAP. M/s. INVAP conducted cold trials of the process thereby checking the efficacy of all in-cell/ external gadgets to be utilized for actual process. All process equipment's including vacuum tanks and process lines have been satisfactorily cold tested. FMP group concluded the drafting of the updated PSAR and the same was submitted it to AERB for review for obtaining layout approval of the FMP project. Further the PSAR has been defended in front of SARCAR committee (an expert advisory committee constituted by AERB for review and recommendations of approval process of such facilities). The evaluation processes are currently in advanced stage and FMP group is expecting the layout approval anytime soon. Imported sealed reference sources meant for calibration of radiation



Installation of Radiation Shielding Windows (RSW)



Cold commissioning of FMP initiated

instruments, process parameters, etc. has been received by FMP. Also, consumables including major chemicals, resins, etc. have been received. Motor vehicles procurement has been completed and deployed in the services.

Advanced Facilities for Radiopharmaceuticals Production

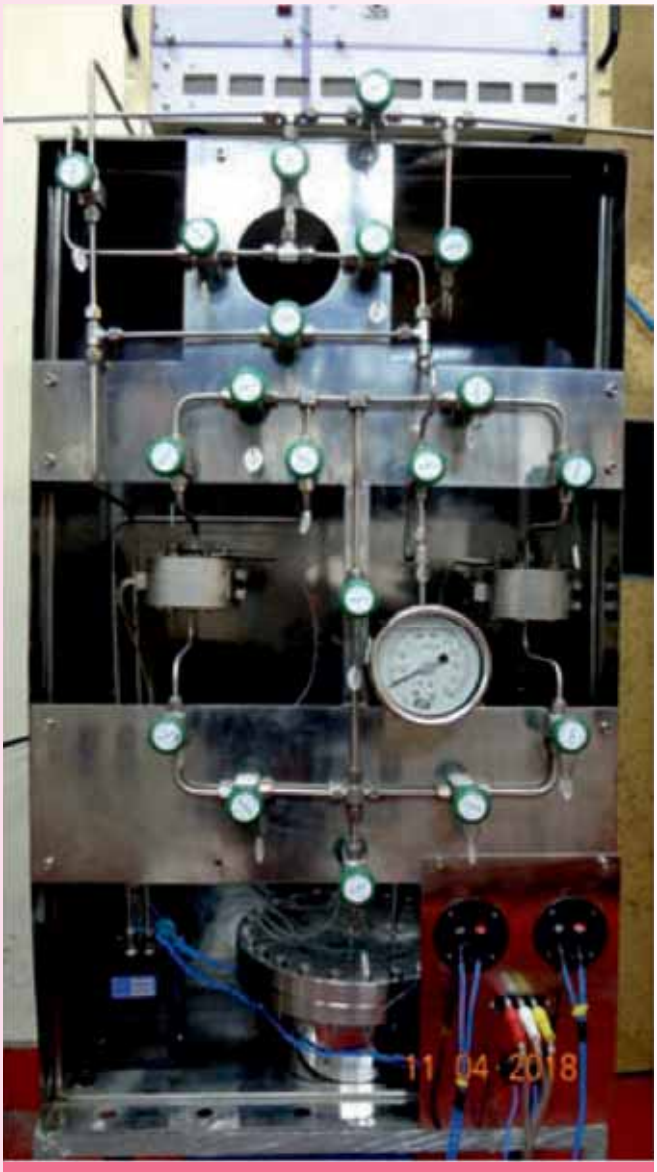
Commissioned new GMP compliant facility for the production of 131I mIBG injection doses. Facility for production of 177Lu based radiopharmaceuticals commissioned. Replacing asbestos false ceiling with SS panel type false ceiling completed. Improvised GMP standards. Flooring replaced with PVC flooring as per GMP standards. New exempt waste system (SS dump tank and SS delay tanks) commissioned in RPL & Old system discarded. GMP compliant cold storage, freeze drying machine commissioned to enhance production



SS panel type False ceiling installed in main lab of Radiopharmaceutical Production Laboratory



Hot cell facility for production of RPhs based on ^{177}Lu hot commissioned and put to use

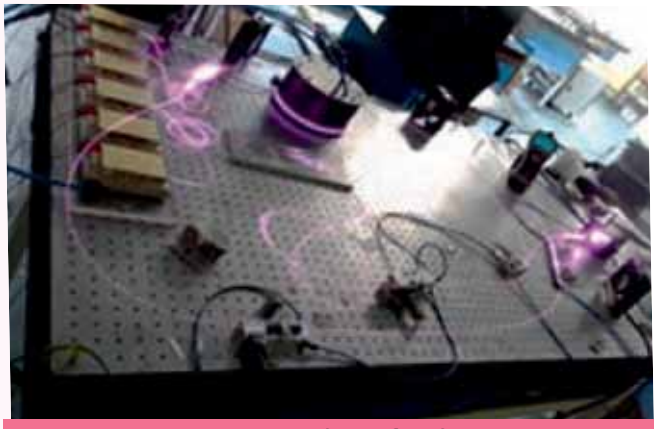


Tritium trapping/recovery unit at LCL/Vashi

capacity of TCK cold kits. RAL facility set-up in Project house, Anushakti Nagar, Mumbai. For improving radiological safety during production of TFS in LCL, advance SS manifold unit installed. For reducing release of tritium through LCL stack, advance tritium trapping system commissioned. Real time PCR machine commissioned at Regional Centre, Hyderabad, and put to use for the development of kits for detection and determination of virus load.

Biomedical Applications

Development of 100 W of an all-fiber Tm-doped CW fiber laser oscillator at eye-safe wavelength of 1940 nm has been carried out with single transverse mode output with an optical-to-optical conversion efficiency of 35%. In literature, there is no report on generation of high output power of 100 W class at 1940 nm directly from oscillator. Specific wavelength of 1940 nm is important since water has a maximum absorption peak at this wavelength and laser at this wavelength is potentially useful in medical applications. It is challenging to generate 1940 nm wavelength from Tm-doped fiber laser since Thulium-doped fiber has an emission peak at 2000 nm, which is far away from desired wavelength of 1940 nm and there is significant re-absorption loss at 1940 nm. In order to achieve lasing at 1940 nm, fiber length was critically optimized to have lower re-absorption losses and simultaneously having sufficient gain for lasing at 1940 nm. Since pumping wavelength is 793 nm and lasing wavelength is 1940 nm, quantum defect is 61%, which leads to higher heat load in Tm-doped fiber thus an efficient water cooled heat sink for Tm-doped fiber was designed and



100 W Tm-doped all-fiber CW fiber laser at eye-safe wavelength of 1940 nm

fabricated. The wavelength control and heat load removal from fiber along with self-pulsing were the major challenges faced and resolved in this development. Self-pulsing was removed by minimizing splice joint losses in the resonator. This laser has potential application in lithotripsy, surgery and plastic welding.

Various, medically important carrier free radioisotopes, are being produced in fast and thermal reactors across the globe. We aim for the production of carrier free $^{89}SrCl_2$ radiopharmaceuticals using $^{89}Y(nfast,p)^{89}Sr$ reaction and standardization of flow sheet for chemical processing to obtain pure ^{89}Sr source which meets prescribed International Quality Control norms.

^{89}Sr (β- emitter, T1/2 50d) is one of the USFDA approved radioisotopes and used for bone pain palliation in metastatic bone cancer due to its biological resemblance with Ca. Several irradiation campaigns for the production of ^{89}Sr was carried out by irradiating high density yttria pellets in various locations of FBTR, namely core centre, fourth and fifth ring, depending upon the need and availability of irradiation positions. Post irradiation, de-cladding of the stainless steel irradiation capsule and chemical processing steps were carried out to obtain the pure ^{89}Sr source from the irradiated yttria target. Chemical separation methods involving solvent extraction, extraction chromatography, supported liquid membrane and ion exchange technique were employed for the purification of ^{89}Sr from various activated impurities produced during the irradiation of yttria matrix and SS clad. The flowsheet was standardised and demonstrated both in analytical scale.

The latest batch of chemical processing was carried out by solvent extraction followed by anion separation, removal of dissolved organic traces of the extractants and all stringent quality control norms were followed as per International and Indian Pharmacopeia. Quality control measures such as appearance, pH, residual anion ion content, spectral identification, radioactive, non-radioactive impurities, and biological quality control studies such as sterility and bacterial endotoxin were carried out and found satisfactory for the required quality control criteria which was also found to be in good agreement with the Inter-laboratory comparison through Radiopharmaceuticals Division, BARC. Approval by Board of Radiation and Isotope Technology (BRIT) for the commercial production of ^{89}Sr is in progress.

Alternative Applications of Heavy Water

Based on the MoU signed between BRIT and Heavy Water Board, deuterated NMR solvents were dispensed and supplied to various customers. All the solvents that were supplied had >98% Deuterium abundance.

Deuterium and heavy water find significant applications in life sciences, pharmaceuticals and technology. India has potential to become a global leader in production and supply of D-labeled NMR solvents, APIs and drug entities which are presently being imported. HWB has successfully navigated through multiple synthesis routes over the last two decades for production of d-labeled compounds. Collaborative agreements have been signed with Indian pharmaceutical companies for regular supply of heavy water from HWB and producing deuterated NMR solvents. For synthesizing deuterated NMR solvents, processes have been developed at HWP, Baroda in laboratory scale. As part of MoU signed between BRIT& HWB, BRIT is marketing Chloroform-d, DMSO-d6, Acetone-d6, Acetonitrile-d3, Benzene-d6 and small quantities of Heavy Water to various reputed research institutes in the country.



Specialty materials produced by HWB

Draft MoUs and Work Orders have been prepared for collaborative sub projects with MS University Baroda (Synthesis and biological evaluation of deuterated analogs of some antineoplastic drugs); ACTREC (Evaluation of anticancer potential of DDW on experimental model systems and clinical trial patients of human breast cancer) and NCL, Pune (Technology development for production of Methanol-d4 using catalyst and synthesis of deuterated building blocks).

For the project on augmentation of production of deuterated compounds at HWP, Baroda, safety review is under progress and detailed engineering is being carried out.

Besides dispatching small quantities of Heavy Water for R&D purposes, approval has been taken for supply of 178 kg of Heavy Water to various users viz. M/s Sigma-Aldrich, M/s Laurus labs, M/s SSRD labs, M/s L.G. Industries, M/s Synzeal etc.

Cancer Diagnostics and Treatment Services

The Tata Memorial Centre (TMC), an autonomous institution under the administrative control of the Department of Atomic Energy, Government of India. TMC comprises of Tata Memorial Hospital (TMH), the Advance Centre for Training, Research and Education (ACTREC) and the Centre for Cancer Epidemiology (CCE) in addition to new and upcoming cancer centres at Sangrur, Visakhapatnam, Mohali, Varanasi and Guwahati.

Under the cloud of fear of the unknown and ignoring the life-threatening risks, the pan India staff of hospitals under Tata Memorial Centre (TMC) were at the forefront to treat the cancer patients. No cancer hospital or cancer centre was closed even for a single day during these trying times. This was despite the fact that many medical & non-medical staff were under quarantine due to COVID infection.

Cancer patients with COVID infection were also treated. Separate wards were created to isolate cancer patients with COVID infection from the non-COVID cancer patients. Adequate protective measures were in place and the staff in these wards were fully geared up in Personal Protective Equipment (PPE) kits.

During the lock-down period in the year 2020, the patient load was markedly reduced. Of all the cancer centres across India, only the cancer hospitals in Varanasi and Sangrur showed increase in the total number of new patient registration over the year 2019. The rest of the cancer hospitals saw a fall in patient registrations ranging from 20% to 45%.

At the Tata Memorial Hospital (TMH), the new patients' registration fell by 46%. As most hospitals in Mumbai were almost shut down, the referrals for investigations increased by 22%. In view of the lockdown, teleconsultation facilities were initiated and more than 900 patients availed of this facility. Over 6000 patients registered online. The hospital saw more than 1000 cancer patients with covid infection and there were 19 deaths related to the same. More than 600 staff members contracted covid infection and all recovered. More than two-thousand (2000) patients with COVID infection were treated in the hospital. On the occasion of the National Sadbhavna Day (20th August), TMH launched emotional support helpline service for cancer patients in Mumbai & Pune. It was named Can-Helper, a toll-free number, founded in association with Cipla Palliative Care & Training Centre and Municipal Corporation of Greater Mumbai and the Pune Municipal Corporation. From the data compiled till the year 2018, the most common cancer sites in males were of the mouth, blood (leukemia) and the lungs; in females, it was of the breast, uterine cervix and the gall bladder.

At the Advanced Centre for Treatment, Research & Education in Cancer (ACTREC), the new patient registration fell by 35%. More than 700 cancer patients and almost 400 staff members were infected with COVID virus. There were eleven (11) covid-related deaths among the cancer patients.

At the ACTREC, the programs of the Cancer Research Institute's (CRI) Principal Investigator led laboratories continued during 2020, with the on-going projects steadily progressing towards fulfilling their aims and goals. New projects were initiated in the area of basic and applied research on cancer. The year 2020 saw the introduction of the Human Leukocyte Antigen laboratory services.

The outpatient cancer services in the campus of the Sri Krishna Medical College in Muzaffarpur are scheduled to be commissioned soon. A Memorandum of Understanding (MoU) was signed between Tata Memorial Centre and the Government of Bihar for the mode of implementation of their Mukhyamantri Chikitsa Sahayata Kosh scheme to the beneficiaries.

The Homi Bhabha Cancer Hospital (HBCH) & the Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC) were the only hospitals in Purvanchal to treat cancer patients during the COVID pandemic. These were only the second cancer hospital in India to show increased number of cancer patients managed in these times. Their new patient registrations increased by 17% over the previous year. More than 200 cancer patients were infected with COVID virus and five (05) of them succumbed. Almost 150 staff members contracted COVID infection and there were no casualties. Director TMC, Dr. RA Badwe inaugurated the Patient Registration Counter and the St. Jude India Childcare Centre at MPMMCC in 2020. The first Linear Accelerator, the second in Varanasi was commissioned in MPMMCC. The Brachytherapy services were made available at MPMMC from July 2020. The Uttar Pradesh Chief Minister, Shri Yogi Adityanath praised the radiotherapy services offered by MPMMCC. Dental prosthetic services were introduced from the year 2020. The HBCH & MPMMCC obtained affiliation from Mahatma Gandhi Kashi Vidyapith, Varanasi to start paramedical and Post-Graduation medical courses.

The Homi Bhabha Cancer Hospital (HBCH) in Sangrur saw a 3% rise in number of new patient registrations. Only Eleven (11) cancer patients and twelve (12) staff member were infected with covid virus and all of them recovered from the virus infection. The Unified Payment Interface payment system was introduced under Digital India Scheme in Sangrur.

The Homi Bhabha Cancer Hospital & Research Centre (HBCHRC) in Mullanpur is due to be commissioned in June 2021.

At Visakhapatnam (Vizag), Andhra Pradesh, the Service Block and the hostel for nurses and doctors were inaugurated in June 2020. Newer diagnostic imaging modalities like MRI, SPECT-CT and PET-CT scans were introduced in the year 2020 that also saw the introduction of Brachytherapy. A Second Operating Theatre was commissioned at the Visakhapatnam Port Trust hospital. The annual new patient registrations saw a drop of 21% over the previous year. Twenty-six (26) cancer patients and forty-seven (47) staff members contracted COVID infection and they were all recovered.

The annual new patient's registration at the Dr. B. Borooah Cancer Institute (BBCI) fell by 26% in the year 2020. More than 200 cancer patients and almost 100 staff members were afflicted with COVID infection and eleven (11) cancer patients succumbed to the COVID infection. At BBCI, the first Stereostatic Radiosurgery in Northeast India was performed in October 2020. Digital Mammography and Dental Prosthetic services were started in the middle of the year. Other new services introduced included the Pain Clinic and Flow Cytometric Immunophenotyping. The Honorable Chief Minister of Assam, Shri Sarbananda Sonowal lauded the role of BBCI during this COVID pandemic. A fellowship in Pediatric Oncology was started from January 2020.

As and when required, help was provided to the Ministry of External Affairs for setting up of the 100-bed cancer hospital in Hulhumale, Maldives under the Line of Credit (LoC) extended to Maldives in the year 2019.

The National Cancer Grid (NCG) was the largest cancer network with more than 230 members. Since the beginning of the COVID-19 pandemic, NCG took the initiative to help all the members centres to provide periodic updates on various aspects of COVID-19, including the overview of SARS COV-2, judicious use of PPE, testing methods, treatment of COVID-19, sero-immunology, psycho-social issues, public health implications, the role of nurses, administrator's role, vaccines, research priorities, and patient's perspective. The National Health Authority has signed an MoU with the NCG to incorporate essential and optimal guidelines in the Pradhan Mantri Jan Arogya Yojana (PMJAY) scheme for cancer packages to facilitate preauthorization and claims. Enabling patients to become the owner of their health records was one of the objectives of NCG for the National Digital Health Mission. Supporting the conduct of multi-centric clinical research was also another mandate of the NCG. In the

year 2020, the NCG funded four (04) such studies. The NCG library launched a discovery tool – Akshara that provided access to browse and search at article level for 17000 indexed journals, videos, monographs, and presentations.

A Memorandum of Understanding (MoU) has been signed between Tata Memorial Centre (TMC) and the Vietnam National Cancer Hospital (VNCH) in Hanoi for student exchange programs, research & educations collaborations, and sharing of cancer management intelligence in the first week of January 2021.

Three (03) patents were filed from ACTREC in the year 2020. They include Antibodies Against Lipocalin-2 and Uses; Nanoparticles Incorporated Self-Gelling Composition as Drug Delivery System and Novel peptides targeted to cisplatin resistant ovarian cancer cells.

^{60}Co Teletherapy Sources for Cancer Hospitals

Nine ^{60}Co-teletherapy sources with total activity of about 97.8 kCi in the range of 132 and 184 RMM were supplied to various cancer hospitals in India during the reported year 2020-21.

WATER

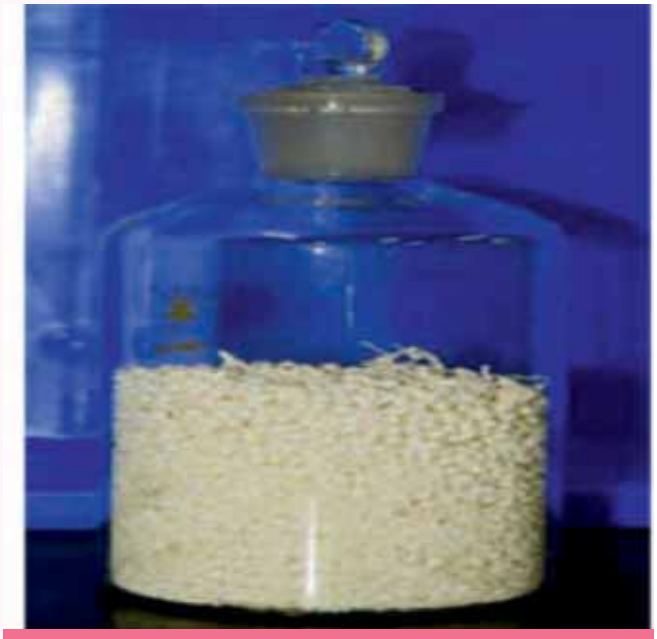
Water Purification, Desalination of water & Isotope Hydrology

A 1000 LPH capacity community-scale Arsenic Removal Plant with water ATM facility was inaugurated at Ichapur Village, Dist. North 24 Parganas, West Bengal on 6th July, 2020. This is a part of DAE's project on "Deploying Water Purification Technologies in 50 villages in India". Ground water in the North 24-Paraganas District of West Bengal is severely contaminated (as high as 500 ppb) by Arsenic, way beyond limits prescribed by WHO and BIS-10500. Through 8 hours of daily operation, the plant is providing Arsenic free water to about 400 families in 2 villages, at a daily consumption of 20 litres per family @ Rs. 5/-.



1000 LPH Arsenic Removal Plant Set up at Ichapur, West Bengal

Forward Osmosis (FO) membranes based on poly (sulfone-co-amide) polymer was developed by optimising the steps such as purification of monomers, synthesis of polymer, casting and gelling of membranes. The membranes were rolled in 2512 spiral module and tested under FO condition. The membranes offered an average water flux of 20 LMH and with back diffusion of salt of 0.5 – 0.7 % from draw solution to the feed (draw solution salt rejection 99.3 – 99.5%) at standard FO condition.



Poly (sulfone-co-amide) polymer

A process of degradation of dyes in contaminated waste water using microbubbles of ozone was developed. Apart from colour removal, removal of dissolved carbon to the extent of 75% could be attained within a short time of 5 min. Based on the successful lab-scale trials, a bench-scale facility (2 L capacity at 30 LPH) has been installed to continuously degrade dye contaminated waste water.



Poly (sulfone-co-amide) Forward Osmosis Membrane



Decolorisation of a mixed dye using microbubbles of ozone

A hybrid granular SBR technology was developed for effective wastewater treatment in a single treatment tank without requiring secondary clarifier (patent application filed). For demonstrating the process and to promote the technology, a 150 kl/day full scale hgSBR plant to treat sewage from 270 houses was commissioned in October 2020. The plant is being operated continuously with 6 cycles of 4 h each. This technology was transferred to four entrepreneurs for large scale implementation.



A full scale 150 KLD hgSBR plant commissioned fortreating sewage from 270 houses at DAE Township, Kalpakkam



Gaseous activity of geothermal springs (93°C) in Tapoban area

An isotope hydrological investigation was carried out in Tapoban-Badrinath geothermal area of Uttrakhand to understand the source and origin of thermal water, and estimate its residence time and reservoir temperature. The stable isotopes ($\Delta^{18}O$, $\Delta^{2}H$) data confirmed that the thermal water is of meteoric origin. The mixing phenomenon between thermal and shallow ground water is substantiated using tritium (^{3}H)



Collection of gas samples from geotherma springs in Badrinath area (91°C)

and chemical data. The estimated transit times of Tapoban and Badrinath thermal waters are in the range of 40-44 and 102 - 112 years respectively. Application of various models indicated temperature of the subsurface reservoir and the reservoir were about 140±5 ^{0}C.

INDUSTRIAL APPLICATIONS

Fabrication of ROTEX-I: an Industrial Radiography Device

BRIT, has indigenously developed Remotely Operated Tungsten shielded Exposure Device (ROTEX-I), an industrial radiography device using Ir-192 radio-isotope. The device has been designed as a portable type, Cat. II radiography device and having a maximum source capacity of 2.405 TBq (65 Ci) of Ir-192. The device uses tungsten as shielding material to make it compact & light weight. ROTEX-I has been designed to meet the requirements to qualify as a Type B (U) transportation package & as an industrial portable radiography device. The fabrication of the first operational prototype of the device is completed. The device is checked for its operation functionality & found satisfactory. The shielding integrity of the device is also checked by the radiometry test using 27 Ci of Ir-192 radio-isotope & the observed results were well within acceptable range.



Fabrication of ROTEX-I: an Industrial Radiography Device

Fabrication of Mo-99 Transportation Package

BRIT has designed a Molybdenum-99 radio-isotope transportation package. It has been designed for a maximum capacity of 44.4 TBq (1200 Ci) of Mo-99 radio-isotope. Tungsten has been used as shielding material in the package to make it comparatively light and compact. The package has been designed to qualify as a type B(U) transportation package for the transport & storage of special forms & other than special forms of radioactive. For the first time in India, the tungsten block of such big size (diameter of 210mm & 300mm long) weighing 160 kg has been developed in single piece lauding the 'Make in India' initiative. The fabrication has been completed for the first prototype of the transportation package. The radiometry test is also carried out to ascertain the shielding integrity of the package & the package successfully showed its adherence to the standards.



Fabrication of Mo-99 Transportation Package

Conceptual Design of Mobile Food Irradiator

Board of Radiation & Isotope Technology (India) has conceptualized Mobile Food Irradiator (MFI), a Category-II, batch type irradiator designed to irradiate low dose food products such as fresh fruits, vegetables, cereals, pulses and medium dose food products like fish & frozen meat etc. The very concept of Mobile Food Irradiator is based on the idea of making the irradiator itself capable to reach to the location of food produce. The irradiator will be mounted on a 40 feet trailer bed and can be moved to different places as per the irradiation schedule. The irradiator is designed for 100 kCi of Co-60 radioactive source which is expected to give a typical throughput of 12-13 tons/day for low dose food products. The Mobile Food Irradiator (MFI) has been conceived as an irradiator that can be extended to smaller districts at remote locations of India, so that it can benefit the farmers or distributor at the lower level of supply chain & storage. This can help the farmers or the local distributors to preserves the food for a longer period of time. In addition, farmer will also be empowered to be able to sell their food produce as per their convenience, jeopardizing the monopoly of the existing market & can also explore for exportation of foods that would have otherwise spoiled en-route.



Overview of Mobile Food Irradiator

Development of Cranking Unit

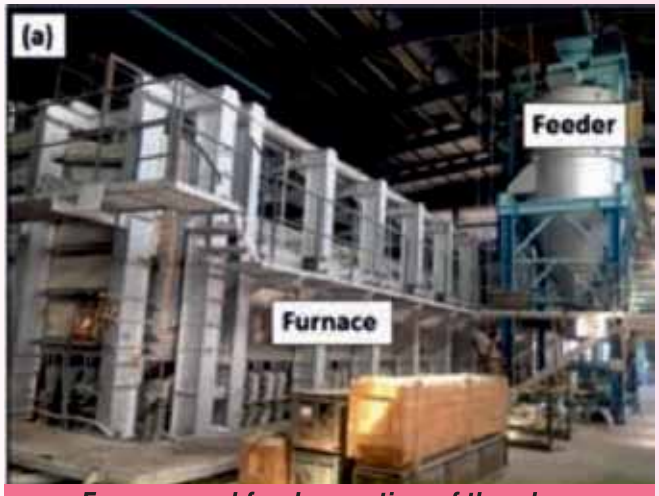
BRIT has developed a new comparatively efficient & light weight cranking unit for the safe remote operation of the indigenous industrial radiography device. The new cranking unit is around 4 kg lighter than the existing one. It has also been ensured that the unit can be operated in any orientation with near zero slippage. In the cranking unit, the Teleflex cable used to provide the necessary motion has also been developed in India with on-par quality as its imported counterparts possess. The developed tele-flex cable is made of 26



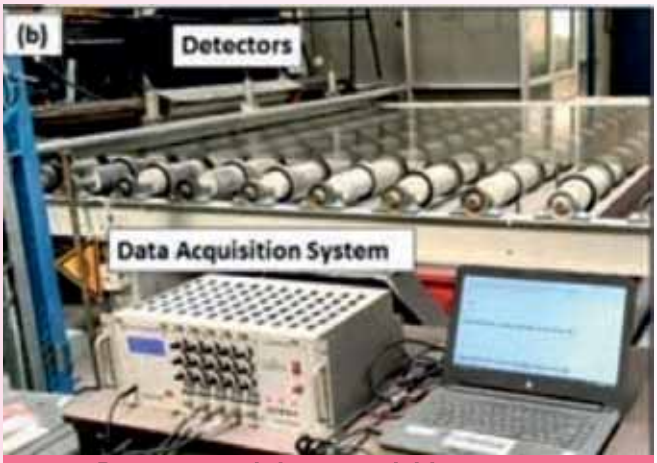
Development of Cranking Unit

strand spring steel wire winded together to achieve the necessary flexibility, corrosion resistant & strength. The protective sheath over the Teleflex has also been developed with 5 layer of protection using Teflon tube, stainless steel braiding (with 96 nos. of wire), PVC covering etc. The fabrication of the cranking unit prototype has been completed. The prototypes were subjected to the regulatory required qualifying tests & it was observed that the same were successfully meeting all the qualifying criterion required by the standard to use them for the remote operation of the radiography devices.

Radiotracer investigations were carried out in two different glass production plants of M/s Borosil Renewable Limited, Bharuch, Gujarat. The main objectives of the investigations were to investigate the flow dynamics of molten glass and evaluate the design of the two subsystems i.e. furnace and forehearth of the plants. Lanthanum-140 as lanthanum oxide was used as a radiotracer. The flow parameters such as mean residence time, degree of axial mixing, breakthrough time and mixing time were measured. Also, several flow



Furnace and feeder section of the glass production unit



Detector and data acquisition system used for online monitoring

abnormalities such as dead volume, parallel flow paths and poor mixing of the molten glass were identified. Based on the results of the investigations, design of both the plants were evaluated and modified. In addition to this, the results were also used to validate the computational fluid dynamics models and for further improvements in design of the glass furnaces and associated sub-systems. The radiotracer investigations helped the industry to optimize the process/operating parameters leading to significant revenue savings.

Radioactive Particle Tracking (RPT) experiments were conducted for single-phase and liquid-liquid two-phase flows in a lab-scale air pulsed sieve plate column to measure local velocities, and turbulence variables. Data generated in the RPT experiments are very useful for understanding local hydrodynamics in air pulsed sieve plate column. The data are also useful for validation of numerical models.



Setup for RPT experiments lab-scale air pulsed sieve plate column

Many industrial components, structures and assemblies are examined by radiometric measurements using penetrating radiation such as Gamma rays for thickness validation and defect localisation. Gamma radiometry is preferred where other diagnostic methods are excluded due to extreme mechanical, geometric or design factors. In particular, Gamma radiometry is used for detection of flaws in biological shield components and assemblies used in nuclear industry. Biological shield is made of mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a safe level. These flaws may be sub-surface in nature and hence may not be visible to human eyes. The flaws can be in the form of voids, cracks, inclusion of undesired materials or even due to design faults. Presence of flaws may severely affect the efficiency of the shield component to attenuate radiation and will result in higher transmitted radiation. Gamma radiometry using sealed Cobalt-60 source for evaluating shielding integrity of a Product Positioning and Handling Cask and Lead shielded casks were carried out at Kota for departmental projects. These tests are often necessary before putting such manufactured components and assemblies into actual use.

Radioisotope Sources supplied by BRIT

Industrial Irradiator Sources

Total 62 nos. of W-91 irradiator sources & 187 nos. of BC-188 Irradiator sources with total activity of around 3508 kCi were supplied in fourteen consignments to various processing plants within the country.

Radiography Sources

A total of 45 consignments of Ir-192 & Co-60 radiography sources with total activity 1492 kCi were supplied from April 2020 to December 2021. About 577 sealed consignments of various radioactive sources were fabricated by BARC and supplied through BRIT.

I-125 Brachytherapy Seeds and P-32 Skin Patches

About 112 125I brachytherapy seeds and fifteen 32P skin patches were supplied to hospitals for treatment of eye, prostate and skin cancers.

Isotope Application Services

Gamma scanning of Slug Catcher Downcomer and Condensate Header

Isotope Application Services (IAS) group of BRIT was approached for gamma scanning of downcomers and headers to verify the suspected choking and internal conditions at gas terminal, ONGC Hazira plant.

As the slug catchers have remained in operation since commissioning and scheduled pigging was carried out in both 36" and 42" Trunk lines periodically, probability of deposition of black material inside the slug catcher fingers was high owing to the receipt of black material during pigging operation. The presence of black material had been manifested during the pigging operation inside the pig catcher as well as in the CFU trains where the Condensate is being processed. The other solid impurities present in the well fluid, howsoever small, might also add to the black material depositions over the time. Due to the possibility of solid depositions in the slug catcher fingers as well as in the 4" & 8" condensate down comers (SC-I&II and SC-III) which has the potential of disrupting the normal operations in case of sub-optimal gas-condensate separation due to partial or complete choking of 4" & 8" downcomer lines with these depositions.

Frequent condensate draining from MS filters were being done. Also, instances of carryover of condensate along with the gas have frequently been encountered during operations in the GSU trains. Poor separation of gas and condensate in some of the slug catcher fingers may be the cause for this condensate carry over. The choked/partially choked downcomers will allow the liquid to build up in the slug catcher fingers and may be responsible for this poor separation. In the event of any choked 4" or 8" downcomer, the liquid condensate will not get emptied out from the finger during draining and owing to its huge quantity will pose a greater safety risk during opening of the 48" end flange without indication of its presence. In view of this, gamma scanning was required urgently.

Prompt action was taken by IAS group as per the urgency of the job. 10 μCi and 20 μCi of Co-60 radioactive source was selected as per the diameter of downcomers and header. Source transport NOC was obtained from AERB. All the formalities related to Covid-19 guidelines including testing of the entire team was completed. The job was planned thoroughly and the transportation of the men and materials to the site were arranged.

PIG tracker was used to monitor the radiation data measurement. Radiation survey of the area was carried out by RadEye survey meter. Scanning of the top joints of downcomer, downcomer pipe and condensate collector header was carried out at slug catcher area I, II and III respectively. Total 54 nos. of downcomers (total length approx. 110 m) and 120 m of collector header was scanned. Data was recorded at x, y & z orientation as required according to diameter of the pipes. In spite of harsh environmental conditions at the field, the scanning work was completed successfully and norms of social distancing, wearing mask etc were also followed throughout the job.



Gamma scanning of condensate collector header being carried out at slug catcher II

CHAPTER

5



MACE telescope at Hanle, Ladakh

BASIC AND APPLIED RESEARCH



A bird's eye view of the High Heat Flux Tet Facility in Operation

The Department of Atomic Energy has contributed significantly towards strengthening of basic research in India. The Department pursues basic research in its R&D centres that ranges from Mathematics to Computers, Physics to Astronomy and Biology to Cancers. It also provides grants-in-aid to nine institutes of national eminence. Following were the major activities and achievements of DAE in basic research, during the period of report.

MATHEMATICS & COMPUTATIONAL SCIENCES

The main themes of research of the mathematics group at the Harish-Chandra Research Institute (HRI) are in the areas of Finite Group Theory, Algebraic Geometry, Differential Geometry, Harmonic Analysis, Lie Algebras and Number Theory. Following are the contributions made to some of these areas for 2020-2021:

Finite groups are sets with a finite number of elements that are endowed with a binary operation, usually called multiplication, which is required to satisfy the conditions of associativity, having an identity element and invertibility. A finite group, the number of whose elements is the power of a prime number p is called a p-group. An element of a group that can be written as $a.b.a^{-1}.b^{-1}$ for some elements a and b of the group is called a commutator. Here . denotes the binary operation in the group and a^{-1}; b^{-1} denote the inverses with respect to this operation of the elements a and b. The commutator subgroup of a group is the smallest group contained in this group and containing all of its commutators.

A long-standing problem in finite group theory is to classify all finite groups in which every element of the commutator subgroup is a commutator. A recent result in the subject tells us that if the commutator subgroup of a finite p-group, p a prime number 5, is minimally generated by 3 elements, then every element of the commutator subgroup is a commutator. This statement, however, is not always true when the commutator subgroups is minimally generated by more than 3 elements. A work of Prof. Manoj Kumar and his student Rahul Kaushik takes up the case when the commutator subgroup of a finite p-group is of order p4 and exponent p. A complete classification of such finite p-groups in which not all elements of the commutator subgroup are commutators is provided in this work, which is available on the mathematics archive as ArXiv:2005.13929.

A central theme of modern Algebraic Geometry is the study of moduli spaces. These are spaces that parametrise intersting families of geometrical objects. In a joint work, which is on the mathematics archive as ArXiv:2005.01084, Prof. Umesh Dubey and his collaborator Prof. Sanjay Amrutiya of IIT Gandhinagar studied some questions on the functorial construction of moduli of parabolic sheaves using their notion of moduli of filtered representations following A. King, which was the subject of an earlier joint paper that was recently accepted in the well-known journal Bulletin des Sciences Mathematiques. This study allowed them, in particular, to settle a question of V. Balaji in a large number of cases. As a consequence, they also deduce the projectivity of certain moduli spaces. Further, they obtained liftings of functorial moduli construction at the level of moduli stacks and deduced some properties for the moduli stack of stable objects.

In the theory of harmonic manifolds in differential geometry the central question is the Lichnerowicz conjecture that any simply connected harmonic manifold is either at or a rank one symmetric space. Lichnerowicz proved this conjecture for harmonic manifolds of dimension 4. It follows from earlier joint work of Prof. H. Shah that an asymptotically harmonic manifold of dimension 3 is at or a rank one symmetric space, thus proving the aforementioned conjecture in dimension 3. This work proved that t asymptotically harmonic and Einstein manifolds of dimension 4 are either at or are rank one symmetric spaces. Thus, a the Lichnerowicz type conjecture is proved for asymptotically harmonic manifolds of dimension 4. This work also recovers the Lichnerowicz conjecture for harmonic manifolds of dimension 4 by an alternate method. The strong merit of the proof given here is that a Singer-Thorpe basis is constructed for an asymptotically harmonic and Einstein manifold M of dimension 4, in which M is a symmetric space. On the other hand, the proof of Besse for harmonic manifolds of dimension 4 used Singer-Thorpe basis to prove its symmetry. This work also strengthens a result of Heber

that an asymptotically harmonic homogeneous and Einstein manifolds are either at or rank one symmetric space of non-compact type in dimension 4.

A Hilbert space of H of distributions on R^n, the real vector space of n-dimensions, is said to be translation invariant if every translate by an element x of Rn of any distribution f in H is also in H and has the same norm as f. The modulation invariance of H is defined similarly in terms of the notion of modulation of elements of H by the elements of R^n. In the article ArXiv:No.2004.02430V1, Prof. P.K. Ratnakumar and his collaborators Prof. Joachim Toft, Dr. Ramesh Manna and Dr. Anupam Ghumbher show that any Hilbert space H of distributions on Rn which is both translation and modulation invariant is necessarily the same as $L^2(R^n)$, the space of square integrable functions on R^n.

Given a square root $\sqrt{d}$ of an integer d, the set of numbers of the form $a + b\sqrt{d}$, where a and b are any rational numbers, forms a field. When d is a non-square integer, this field is called a quadratic field and is denoted by $Q(\sqrt{d})$. Associated to every quadratic field $Q(\sqrt{d})$ is a finite group called its class group and the number of elements of this group is called the class number of this quadratic field. The study of the class number of quadratic fields is an important topic in number theory. A recent work of Prof. Kalyan Chakraborty and his collaborators Dr. Azizul Hoque and Mr. Mohit Mishra, published as https://doi.org/10.1007/s40316-020-00139-1, contributes to this study by giving certain efficiently calculable conditions that allow them to specify the structure of class groups of order 4 in a certain family of quadratic fields $Q(\sqrt{p})$ with $d > 0$.

Algebraic numbers are an extension of the notion of rational numbers. They are complex numbers that are the roots of single variable polynomials with rational number coefficients. For example, the elements of the quadratic fields mentioned above are algebraic numbers. A famous theorem of K. Roth tells us that an irrational algebraic number does not admit very sharp approximation by rational numbers. Roth's theorem is a fundamental result in number theory that has been intensively researched over half a century. In 2004, Corvaja and Zannier, in solving some problems of Mahler and Mendes.

France, gave a certain generalization of this theorem. A recent work of Prof. R. Thangadurai and Dr. Veekesh Kumar, available as arXiv:2001.00386, obtained a multidimensional extension of the theorem of Corvaja and Zannier.

Following works were carried out in TIFR in Mathematical and Computer Sciences: establishing the existence of phase transition of a model is one of the most fundamental problems in the rigorous, mathematical treatment of Statistical physics. In this work, a novel technique was developed in the particular context of phase transition for independent percolation model on general quasitransitive graphs (in particular, Cayley graphs). The technique developed in the work also provided a new paradigm for proving existence of phase transition for various other models of interest. In a joint effort between IISc and TIFR, a city-scale agent-based simulator was developed to study the impact of various interventions on the spread of the Covid-19 epidemic. The tool was used to arrive at projections for the city of Mumbai and Bangalore (amongst others) as well as recommendations on the time frame and the strategy for the cities to open up. The projections for the infection rates made in the report are by and large turning out to be accurate for the city.

The Institute of Mathematical Sciences (IMSc) continued the research activities in Algebra, Algebraic Number Theory, Differential Geometry, Koszul duality and the alternating Schur algebra, Modular forms, Higson-Roe sequence for transformation groupoids (Non-Commutative Geometry), Novikov's Theorem in Higher Dimensions, Representation Theory, Application of topology to complex networks etc. During this period, there were 185 research papers in national and international publications. The Institute organized or co-sponsored several Conferences and workshops. The Institute members were involved in joint projects with colleagues from other national and international institutes.

PHYSICS

TIRCAM2 is proposed to be used on one of the side ports of the 3.6-m Devasthal Optical Telescope (DOT) for regular science observations. It was successfully tested on one of the side ports of the largest

Indian telescope, DOT, in collaboration with ARIES, Nainital. The first light from this port was seen on May 4, 2020. This achievement is significant since the efficiency of the telescope will drastically increase with two instruments being available for near simultaneous observations during any particular night. It is noteworthy to mention that TIRCAM2 is the only instrument of its kind in India which is sensitive up to 3.8 micron and is ideal for the imaging of astrophysical sources at wavelengths longer than 2 micron. A team of scientists from NCRA, working with colleagues from the Raman Research Institute, Bengaluru, have produced a landmark new result using the upgraded GMRT. They have been able to detect the signal from neutral hydrogen from some of the furthest galaxies in the Universe -- a signal that comes to us from 8 billion years ago. This detection has allowed the team to estimate the neutral hydrogen content in galaxies at the earliest epoch to date, in the life of the Universe.

In a study published in EPJ D, researchers in India and Argentina, led by researchers at the TIFR, have successfully determined the characteristics of electron emission when high-velocity ions collide with adenine - one of the four key nucleobases of DNA. Since high-energy ions can break strands of DNA as they collide with them, the team's findings could improve our understanding of how radiation damage increases the risk of cancer developing within cells. Magnetic field with the edge, this study overturns a dominant six-decade old notion that the giant magnetic field in a high intensity laser produced plasma evolves from the nanometre scale. Instead, the field actually originates at macroscopic scales defined by the boundaries of the electron beam that is propagating in the plasma. This could alter our understanding of magnetic fields in astrophysics and laser fusion and may help in designing next generation high energy particle sources for imaging and therapies.

MACE (Major Atmospheric Cherenkov Experiment) telescope was installed at Hanle, Ladakh to explore gamma-ray sky in the energy range above 20 GeV. Trial runs of the telescope were conducted for about 45 hours including Crab Nebula observations. Monte Carlo simulations to characterize the expected performance of the telescope are being carried out. Estimates of minimum flux sensitivity were revised for



MACE telescope at Hanle, Ladakh

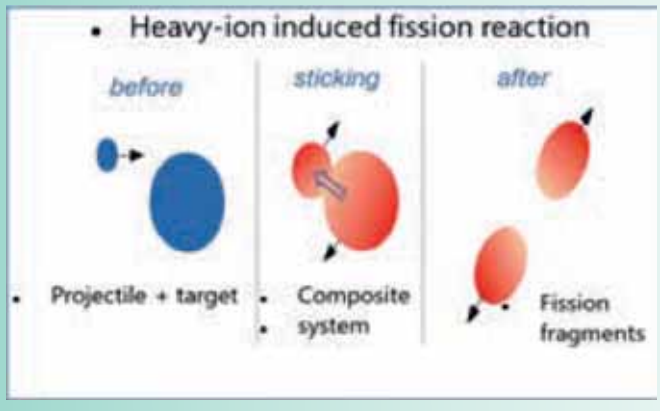
the telescope whereby extensive air showers were allowed to have azimuthal orientation in the range 0 –360° to incorporate the effect of the geo-magnetic influence on the shower images. A module to unfold the observed spectrum into true energies was developed. A utility was developed to simulate the real source observation and to estimate minimum time to detect various gamma-ray sources.

The importance of the ground-state structure of ^{7}Be as a cluster of A and ^{3}He has been highlighted by measuring significant cross sections for breakup of radioactive ^{7}Be nuclei produced in a transfer reaction into A and ^{3}He cluster fragments via its resonant states in the continuum. The experimental breakup cross sections compare well with the results of the coupled-channel calculations. Hexadecapole deformation of ^{24}Mg nucleus was measured using quasi-elastic scattering.

A competing role of shell effects and entrance channel dynamics in fission fragment mass distributions of ^{191}Au, a nucleus in the newly identified island of mass asymmetric fission in the sub-lead region was investigated. Measurements were performed down to excitation energy of 20 MeV above the fission barrier via two different entrance channels, viz. ^{16}O+ ^{175}Lu and ^{37}Cl+ ^{154}Sm reactions. Apart from the signature of the shell effects in both the cases, clear experimental evidence of quasi-fission was observed in the mass distributions of the Cl induced reaction. This crucial evidence along with a systematic analysis of the available experimental data has revealed that the dynamics in the entrance channel has significant influence on most of the reactions used

earlier to explore the persistence of recently discovered mass asymmetry in β -delayed fission at low energy in this mass region, ignoring which might lead to ambiguity in interpreting the heavy-ion data.

The neutron energy spectra in coincidence with both the correlated fission fragments in $^{32}S + ^{184}W$ reaction forming the compound nucleus ^{216}Th at an excitation energy of 71.31 MeV have been measured at various angles with respect to one of the fission fragments. Pre- and Post-scission neutron multiplicities of 2.68 ±0.48 and 3.3 ±0.20 respectively have been extracted by analyzing angular correlation of the neutron energy spectra. The excess pre-scission neutron multiplicity in comparison to statistical model JOANNE2 code predictions have been converted into total fission delay. A comparative study of fission delay for the $^{16}O + ^{208}Pb$ reaction forming the compound nucleus ^{224}Th at similar excitation energy as in ^{32}S + 184W have been analyzed considering deformation dependent level densities, particle binding energies and transmission coefficients.



Nuclei with proton and neutron numbers between the magic numbers 20 and 28 form an interesting island in the nuclide chart. To explore the underlying physics, the ^{49}V and ^{51}Cr nuclei were investigated using the Indian National Gamma Array (INGA) facility at TIFR. Further, an experiment using fusion evaporation reaction was carried out employing multi-clover, multi-Lanthanum Bromide gamma detector array at TIFR to explore nuclear triaxiality and related exotic phenomena, such as, wobbling rotation, nuclear chirality, etc., in the candidate nuclei ^{189},^{190}Pt.

Measurements of prompt fission neutrons and gamma ray spectra have been carried out in the fast neutron induced fission of 232Th at a neutron energy of 2.6 MeV at FOTIA, BARC. While the measured prompt fission neutron spectrum and the extracted Maxwellian temperature (1.22 ± 0.03 MeV) agree reasonably well with the predictions of the GEF model, the average gamma ray energy from the gamma spectrum is lower by ~17% from the model predictions.

The trace formulae discovered establish fundamental connections between the density of energy levels of nuclei and the underlying classical periodic orbits. Several successful applications of this have been made to explain experimental results from alpha-radioactivity of even-even nuclei, pairing phase transition in tin isotopes, and temperature- and isospin-dependence of the level density parameter in mass region of 110. A detailed examination of spectral statistics of the well-known super deformed ^{152}Dy has established the connection of shapes at different excitations and universality classes from random matrix theory. The celebrated work by Philip Anderson on localization in disordered quantum systems has been generalized to relativistic quantum mechanics, discovering a new spin-flip transition among other results. A concerted effort has been initiated to build quantum computing technology which is scalable.

The Indian Scintillator Matrix for Reactor Anti-Neutrinos – ISMRAN, is a large area plastic scintillator array for antineutrino measurements and search for a new type of neutrino and its oscillation to other types. These measurements have potential applications for reactor monitoring using anti-neutrino detection in an over-ground plastic scintillator matrix. A 9 x 10 matrix of 1m long scintillator bars wrapped with Gd foils having 1ton weight was assembled at BARC to detect anti-neutrinos from Dhruva Reactor. The detector has been



The Indian Scintillator Matrix for Reactor Anit-Neutrinos-ISMRAN assembled at BARC

used for measurements with Am-Be radioactive source for finding the correlated pair of events of promptly emitted gamma and delayed neutron from its capture in the detector. The experimentally measured sum of energy from the capture of neutron from the Am-Be source on Gd with ISMRAN (9 x10) matches well with the simulations.

Exotic quantum phases in a spin-½ metal-organic kagome frustrated magnet $[Cu_3(CO_3)_2(bpe)_3]\cdot_2ClO_4\}n$ (bpe = 1,2-bis(4-pyridyl)ethane) have recently been detected using the neutron diffraction, neutron depolarization, and the specific heat measurements. These highly entangled quantum phases could have application in the development of future quantum computers and other transformative quantum technologies.

Shale, a type of sedimentary rock, is a new source of gas and oil. Resolving the pore attributes of gas bearing shale formations is a key to precise estimation of the gas-storing capacity of a reservoir. Small and wide angle scattering beamline (BL-18) at Indus-2 and ultra small-angle neutron scattering were used to quantify pore matrix roughening in Indian shale rocks.

The condensed matter theory group at IOP remained actively involved in pursuing research with the main focus on understanding the organization of bacterial chromosome, active matter, fluctuation theorem, topological aspects of quantum condensed matter systems, quantum transport in Dirac/Weyl materials, quantum magnetism, and the interplay of strong correlation and topology in artificial lattice systems.

In experimental condensed matter physics, major activities included studies on accelerator-based materials science, surface and interface physics, advanced functional materials, and nanosystems. The Ion Beam Laboratory houses the NEC 3 MV tandem Pelletron Accelerator, one of the major facilities used by researchers from all over the country. The accelerator provides ion beams of energies typically 1-15 MeV starting from protons and alphas to heavy ions. Different users (both internal and external) and research scholars across the country are using this facility for their research. Other important research activities include studies on solar energy photovoltaics, self-organized pattern formation on semiconductor surfaces, and their nanoscale functionalization by growing metallic nanostructures and magnetic thin films on patterned substrates to study anisotropic plasmonic and magnetic properties, and tunable metal oxide-based resistive switching devices for neuromorphic applications using energetic ion beams, quantum matter heterostrtutres, strongly correlated electron system, quantum transport in spin-orbit coupled systems, interfacial exchange bias phenomena, Raman spectroscopy, and the physics of 2D chalcogenide based materials and devices.

At HRI, research in condensed matter systems and materials have focused on strongly correlated systems, topological materials and catalysts for energy applications. HRI have been using a scheme based on the Langevin equation to probe both the phases and the dynamics of correlated electron systems. The method generalises to some nonequilibrium situations too. Till now it has allowed access to phonon and spin dynamics in magnetic materials, and the voltage induced breakdown of a Mott insulator.

HRI have worked on topological quantum matter, focussing on higher order topological insulators, on Majorana modes and more recently parafermions, on edge states in the quantum Hall system and gated and driven bilayer graphene, and on surface states of Weyl semimetals. HRI have also made some progress on understanding the nature of topological phase transitions and how they can be classified in terms of known ideas from quantum critical phenomena.

HRI have developed new insights into electronic structure of layered ternary transition metal tri-chalcogenide compounds. We have studied some of these materials as catalysts for hydrogen evolution reaction and have identified that some specific edge sites act as catalytic centers. We have also developed a theoretical understanding of why Co decorated nitrogen-doped graphitic carbon acts as efficient bifunctional catalyst for oxygen evolution and oxygen reduction reactions.

At HRI, the High Energy research is primarily on beyond standard model physics searches at present

and future accelerator experiments, neutrino physics, dark matter as well as Astrophysics experiments such as the Square Kilometre Array (SKA1). The contributions have come on new phenomenological studies of Beyond the Standard Model (BSM) of particle physics that involve extended scalar sectors, dark matter and supersymmetry. New ways of unravelling such scenarios at experiments using machine learning methods have been proposed. Search strategies for new particles such as charged Higgs bosons and their interactions at collider experiments has been proposed. Contributions have been made to a TDR on physics studies at a future lepton-hadron collider. Efforts were continued to address the open issue of dark matter of our Universe in the contexts of theoretical model-building and studying gamma-ray signals and radio data signals from outer space. Members of the Neutrino group are a part of new experiments planned to study neutrino properties such as the INO and DUNE collaborations and physics studies at these experiments are one of the major efforts that are continuously being carried out. In addition, impact of new physics such as signatures of dark matter and neutrinoless beta decay, muon g-2 anomaly and supernova neutrinos have been also looked at.

Quantum information and computation is an area at the interface of different subjects in physics, computer science, mathematics, and engineering. The Quantum Information and Computation (QIC) group works on a broad range of topics in this area. Among the topics that the group works in, includes quantum entanglement theory, quantum thermodynamics, many- and few-body quantum devices, quantum communication, quantum computation, quantum cryptography, etc. In the last academic year, the group has worked on several topics, and have written more than 30 papers since January 2020. We have introduced the notion of reverse quantum speed limit for arbitrary quantum evolutions, which answers a fundamental question: "how slow a quantum system can evolve in time? In another work, we identified hierarchies of localizable entanglement due to spatial distribution of local noise in multiparty quantum systems. Operation characteristics in steady state versus the same in transient regimes of quantum thermal transistors have been analyzed.

String theory is a theoretical framework which can provide us with a unified theory of all forces of nature. The string theory group at HRI has explored various aspects of the theory in the last one year. Studies have been carried out in two-dimensional string theory to gain understanding of non-perturbative aspects of the theory. Various aspects of the low energy effective action of the theory have been explored by making use of modular graphs. Relations between triangle groups, automorphic forms and non-linear differential equations have been unraveled. Finally, the statistics of the scale of supersymmetry breaking in string compactifications has been examined.

The equation of state of neutron stars has been studied with emphasis on the possible quark hadron phase transition in the core. The models of nuclear multifragmentation were improved using inputs from microscopic models (RMF) as well as Nuclear Statistical Equilibrium models were developed for supernova matter. The study of nuclear equation of state was done from isospin imbalance ratio of quasiprojectile and preequilibrium nucleons in the framework of transport model (BUU). A novel theoretical model has been proposed for the fast calculation of fission-fragment yields based on the concept of nuclear shell stabilization. The proposed framework provides an efficient alternative to microscopic approaches based on the evolution of the system in a space of collective coordinates. It can be used to carry out global calculations of fission-fragment distributions across the r-process region. In addition, a four-dimensional Langevin dynamical model is developed to study heavy-ion induced fusion reactions. The model has been benchmarked and systematic study has been performed. In addition, theoretical study of Giant Dipole Resonance (GDR) width has been performed and compared with the data obtained at the VECC Cyclotron facility. The universality relationships between various multipole moments for magnetized white dwarfs have been studied in order to exclude equation of state dependent observational inferences.

Effects of anomalous magnetic moment of quarks on the thermodynamic properties, dilepton emission and mesonic excitations of hot and dense magnetized quark matter have been investigated.

The spread of COVID19 through droplets ejected by infected individuals during sneezing and coughing has been considered as a matter of key concern. For a quantitative understanding the spread of virus the evolution of droplets in space and time under varying external conditions of temperature, humidity and wind flow by using laws of statistical and fluid mechanics has been investigated. The quantitative results obtained here will be useful to devise strategies for preventing the spread of other types of droplets containing microorganisms.

The research and developmental activities carried out in the field of experimental nuclear physics included research on Wobbling in atomic nuclei, Jacobi shape transition in hot and rotating nuclei, Nuclear level density away from the β-stability line, Decay rate under compression, experiment to characterize the beams from K130 and K500 cyclotrons besides various developmental activities for physics research.

SINP has joined the India-US joint collaboration program in Laser Interferometer Gravitational-wave Observatory (LIGO). Indian scientists have long been contributing to LIGO and now the GoI has approved a project where Indian scientists will be able to install a India based Laser Interferometer in collaboration with US scientists. SINP has joined hands in this effort.

Using properties of black horizon it was shown that area of a black hole horizon must be discrete. The spectrum is integer or half-integer spaced. Number of states of the area is in agreement with the Bekenstein-Hawking area law with an exponentially decaying correction.

Integer Quantum Hall (IQH) edges are simply described by non-interacting electron transport. SINP has demonstrated that interactions split an integer mode into three modes of conductance $e^2/3h$ with fractional charge. Fully equilibration or decoupling of the fractional modes results in expected or new fractional conductance plateaus. The observed fractional edge modes with high equilibration lengths of 777 micro-meter might be used as the basis states for quantum information processing.

Investigations of the metallic perovskite $GdRh3C_{1-x}B_x$ ($0.00 \leq x \leq 1.00$) show that all compositions undergo magnetic ordering at low temperatures, but the nature of the ordered state is significantly different in the carbon and the boron-rich compositions, where the former shows signatures of an amplitude-modulated (AM) magnetic structure and the latter exhibits evidence of an equal-moment (EM) incommensurate antiferromagnetic ordering.

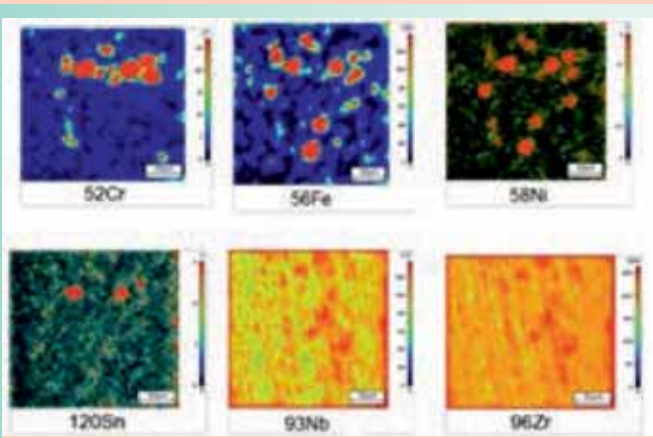
The 5-year integrated Master of Science (M.Sc.) program in Physics at NISER offered courses from core areas of physics such as Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics and Mathematical Physics. In addition, elective courses based on upcoming areas in physical sciences were also offered for final and pre-final year students. For the Ph.D. students, the course included were from the core-areas of physics such as Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics, particle physics and condensed-matter physics.

CHEMISTRY

Theoretical studies were carried out to gain fundamental insight into early events in radiation damage in steel. Irradiation generates point defects, which interact with various solute elements present naturally in steel or as an additive, resulting in aggregation of different elements. Using density functional theory, it is inferred that the interaction of vacancies with the Cu atoms is attractive, and the Cu-Cu interaction becomes more attractive in presence of nearby vacancies, thereby promoting Cu clustering in irradiated steel.

Theoretical and computational studies were also carried out to design materials or processes for CO_2 sequestration, inert gas adsorption, photovoltaic and photo-catalytic applications, ionic liquids for separation of Li ions from a mixture of alkali metals in aqueous solutions and design of suitable ligands for the separation of Zr and Hf. Machine learning techniques have been applied to understand dynamical transitions in viral capsids, intricacies of fullerene solvation and phase behaviour of ionic solutions.

The surface and depth profile of elements such as Ni, Fe, Cr, Zr, Sn and Nb in Zr-Nb(2.5%) were studied using O+ion in secondary ion mass spectrometer.



Formation of SPPs on different surfaces

Surface distribution analysis indicated possible formation of secondary phase particles of $Zr(FeCr)_2$ and Zr2(FeNi) of size ranging from 1 – 20 m with inhomogeneous surface distribution for Ni, Fe and Cr. The elements Zr, Sn and Nb showed homogeneous surface distribution. The depth profile of the elements showed a homogeneous depth distribution.

A method using platinum gauge electrode was developed to separate Pu (to the extent of 90%) from analytical waste containing U and large excess of Fe and Cr. The method involving selective deposition of Pu from bulk solution followed by filtration and heat treatment gives pure PuO_2.

An aqueous stable Uranyl(V) compound stabilized by di-picolinic acid (DPA) was synthesized by electrochemical process using platinum electrode at -0.9 V in aqueous medium under anaerobic environment. Cyclic voltammogram shows a pair of oxidation and reduction waves at E^0 = -0.592 V corresponding to [U(VI)/U(V)] redox couple.DFT calculation shows strong complexing ability of DPA stabilizing the unstable oxidation state U(V) in aqueous medium.

Tungsten is the most favoured plasma facing material in nuclear fusion. The mechanistic pathways of diffusion of H, D and T in bcc W employing Density Functional Theory (DFT) using PBE and PBE-D3 functional and harmonic transition state theory are reported. The activation diffusion barrier was determined using nudge elastic band techniques. The Zero Point Energy (ZPE) was incorporated by phonon calculations to include isotope effects. The surface adsorption of H, D and T is predicted to be exothermic, whereas surface to sub-surface and bulk absorption is endothermic but the vacancy induced absorption in bulk W was predicted to be exothermic. H, D and T atoms were observed to be diffused, preferably between nearest tetrahedral sites. The calculated diffusion coefficients, rate constants, permeability constants and solubility are found to be higher for H compared to its heavier isotopes D and T, which is in agreement with the experimental results.

BARC has undertaken a unique programme for the production of CRM reference materials for DAE and non-DAE institutes as well as for Indian industrial & social sectors. Reference materials were prepared for evaluating the concentration of trace elements of Al, Ca, Cr, Cu, Mg, Mn, Zn and Ni in soil. Preparation of certified bauxite and dolomite reference materials is at an advanced stage. Specialized and high impact analytical services were provided to different research institutes and industries across the country, including analysis of water samples, number of high purity chemicals used in semiconductor industry, sulphuric acid used in submarine batteries and ferrocene used as burn rate modifiers of propellants. More than 3,000 samples with about 10,000 determinations, were analysed. A notable contribution in this direction is the analysis of helium in air bubble samples from thermal springs of Bakreshwar (West Bengal) and Tantol (Jharkhand). Helium in the air bubbles collected from the thermal springs was in the range of 0.31 - 0.65%, considerably higher than that in ambient air (5 ppm). BARC has also made significant contribution in treating the chemical and electronic waste. This year thousands of litres of liquid organic chemicals & used machine oils were incinerated. Validation of NABL accreditation for ISO/IEC17025:2017 for year 2020-21 was completed.

Various synthetic organo-selenium compounds were investigated for antioxidant, radio-protection, anti-cancer and anti-viral properties. In-vivo studies confirmed anticancer activity of DSePA (Diselenodipropionic acid) against leukaemia and lung cancers and a provisional US patent is filed (US App. No. 17/003420 dated 26-Aug-2020). Oral formulation of DSePA is being developed in collaboration with ACTREC. The deuterated analogue of DSePA was synthesized and evaluated for biological efficacy as radio-protector or anticancer agent in cellular models.

Sorbents have been developed to selectively extract various metals, such as Ga from Bayer's liquor and Cs from radioactive waste. The functionalized resin beads were supplied to HWB for testing in a pre-pilot scale column operation for Ga extraction. Fluorescence based sensors were developed for b-Lactoglobulin, common milk allergen, amyloid fibrils, protamine, thrombin and perrhenate anion (a non-radioactive surrogate of hazardous pertechnetate anion). Mechanistic studies on iodine–paint interaction, formation of organic iodides from painted surfaces under nuclear accident conditions and their impact on iodine volatility, etc., have been carried out. The tropospheric lifetimes of various Volatile Organic Compounds (VOCs), with respect to important tropospheric oxidants, are being measured to understand their atmospheric impact. Role of aerosols in impacting weather and climate is investigated, using a surface and interface selective Vibrational Sum-Frequency Generation (VSFG) spectroscopy.

Membrane - electrode assemblies of 314 cm^2 active area were fabricated with Pt-based electro-catalysts for aqueous electrolysis in Hybrid Sulfur process for splitting water. The structural, physical and chemical integrity of foam based iron oxide catalyst was established by evaluation of fresh and spent catalyst foams after 110 h of use in sulphuric acid decomposer. Both foam based catalysts and membrane electrode



Spent foam catalyst after 110 h of use in sulphuric acid decomposer



Membrane - electrode assembly developed of - 314 cm^2

assemblies were deployed in closed cycle Hybrid-Sulfur cycle for hydrogen generation. R&D on individual steps of Cu-Cl thermochemical cyclecontinued towards establishing the feasibility of indigenous spray reactor for $CuCl_2$ hydrolysis and its mechanistic understanding through kinetic data generation. Phase pure Cu_2OCl_2 was synthesized. A 29 cm^2activemembrane electrode assembly was developed for CuCl/HCl electrolysis step.

A new method based on Mn coupled dissolved ozone process was developed for decontamination of stainless steel surfaces. The process is based on reconversion of MnO_2 to permanganate, which is formed as a by-product during the chromium oxide (present in SS) dissolution in permanganate based formulation. Mediated electrochemical oxidation for Chromium based oxides dissolution was also developed and tested for TAPS decontamination. Alkylimidazolium ionic liquids with different alkyl side chain lengths were evaluated for prospective anti-biofouling formulations.

Exploring phase transitions under varying thermodynamic conditions, especially high pressures, is an important area of research from applied as well as basic research point of view. Using a Diamond Anvil Cell (DAC) it is possible to mimic earth interior environments in laboratory and carry out in-situ studies on technologically and geo-physically relevant materials. These extreme environments may involve complex stress states giving rise to structural changes at atomic level and subsequently phase transitions. In-situ

investigations of this nature help in understating various mechanisms of a deep earthquake, plastic straining and its effect on phase transitions. First in-situ quantitative study of kinetics of plastic strain induced phase transitions on any material have been carried out on ultra-pure Zr. Results open a new opportunity for quantitative study of strain-induced phase transitions and reactions with applications to material synthesis and processing, mechanochemistry and geophysics.

Dithiocarbamate functionalized CNT is immobilized in Sodium Alginate (SA) micro spherical beads by crosslinking with calcium ions. Aqueous solution SA and f-CNT was dropped into $CaCl_2$ solution using multi-channel peristaltic pump and the prepared hydrogel beads were dried and used as adsorbent bed in laboratory column separation of 250 ppm Hg^{2+} feed solution. The adsorbed mercury ion was then desorbed with 1M HNO_3 solution and the bed was regenerated. The studies showed that f-CNT-alginate beads can be applied in continuous column mode to use the superior capacity of f-CNTs for removal of Hg^{2+} ions from mercury containing waste water.



The column set up for Hg^{2+} removal

A rapid spectrophotometric method was developed for detection of total iron [Fe(II) + Fe(III)] at sub-ppb level in the secondary coolant waters of PHWR. A new glow discharge mass spectrometry method to determine impurities in high purity Hf was developed. The method enables the determination of about 70 elemental impurities. A method using graphene oxide was developed for the determination of Be by graphite furnace atomic absorption spectrometry. It was applied to the effluents of Be plant and water samples with satisfactory results. 6Li/7Li isotopic ratio in spodumene mineral from AMDER was determined by glow discharge mass spectrometry.

Highly cross-linked Polyglycidyl Methacrylate (PGMA) gel has been developed using UV polymerization adsorbs Uranium from aqueous media. The gel brings down U to less than 20 ppb from a feed of 1500-2000 ppb. It has a high adsorption capacity (150-180 mg U/g of gel) and high recovery (desorption is about 97%) with capability for multiple cycles (at least 50 cycles). This gel is useful for decontamination of ground water in areas affected by high Uranium and Arsenic contamination.

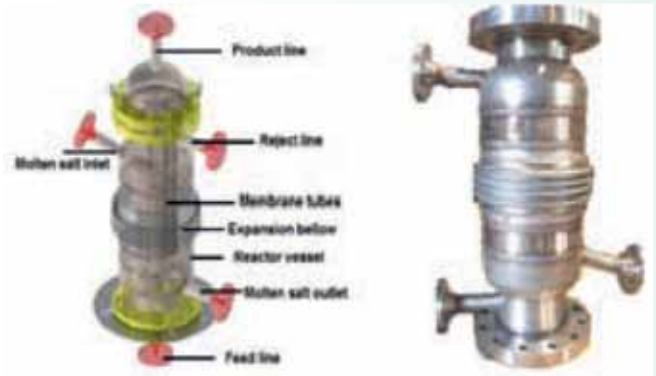
Highly filled polymer-composite formulation containing poly (ethylene-co-vinyl acetate) and magnesium lactate was developed through a solvent free route by melt compounding and extrusion. A large number of dosimeters were tested to assure batch to batch variability. The dosimetric response was checked on three ESR (Electron Spin Resonance) instruments independently. The dosimeter was found to have reproducibility in terms of relative standard deviation <10% under routine working conditions. The reproducible response was observed in the wide dose range 80 Gy to 4000 Gy. There was no significant effect of humidity (13-94%), temperature (20-40oC) and dose rate (0.85-3.1 kGy/hr) on the response in this dose range. The fading of the signal was negligible during 10 days of storage. The response of the dosimeter was checked against alanine and Fricke, under real plant conditions. The regression co-efficient of ~0.99 was found in both the cases. A typical dosimeter is of 50 mg weight and diameter 3.5 mm thus making it suitable for



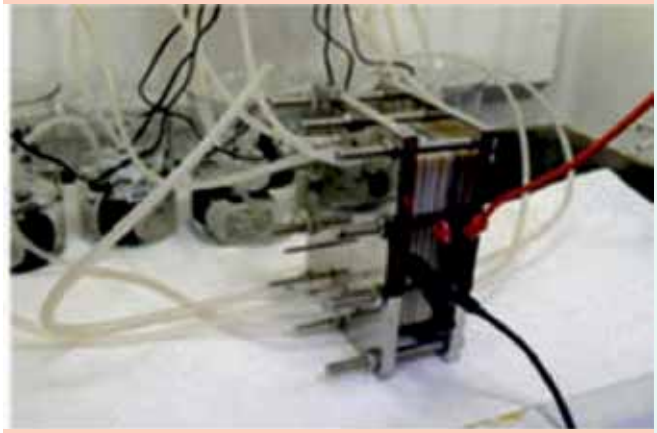
Developed Dosimeter

dosimetry of complex 3-D objects. The sheet form of the developed dosimeter is suitable for single piece dose-mapping.

HI decomposition reaction, which is the hydrogen producing step of IS thermo-chemical process, is equilibrium limited (22% conversion at 450 □C) and involves highly corrosive & high temperature (450 □C) environment. In order to enhance the HI to hydrogen conversion beyond 90%, with solar/nuclear energy as heat source, a novel multi-tube membrane reactor was designed with provision for molten salt heating (550 □C) that can withstand upto 15 bar pressure. The design was carried out as per ASME standards. Based on the final design, a prototype 6-tube membrane reactor was fabricated to accommodate six 50 cm long and 10 mm OD composite metal membrane tubes for production of 150 NLPH hydrogen up to 5 bar pressure. It is a first-of-its-kind jacketed multi-tube membrane reactor incorporating expansion bellow in order to allow thermal expansion and contraction during operation. Features like leak-tightness of reactor, protection of membrane from mechanical damage, efficient feed distribution system, effective catalyst loading into the vessel and flow facilitation of molten salt have been incorporated in the membrane reactor assembly.



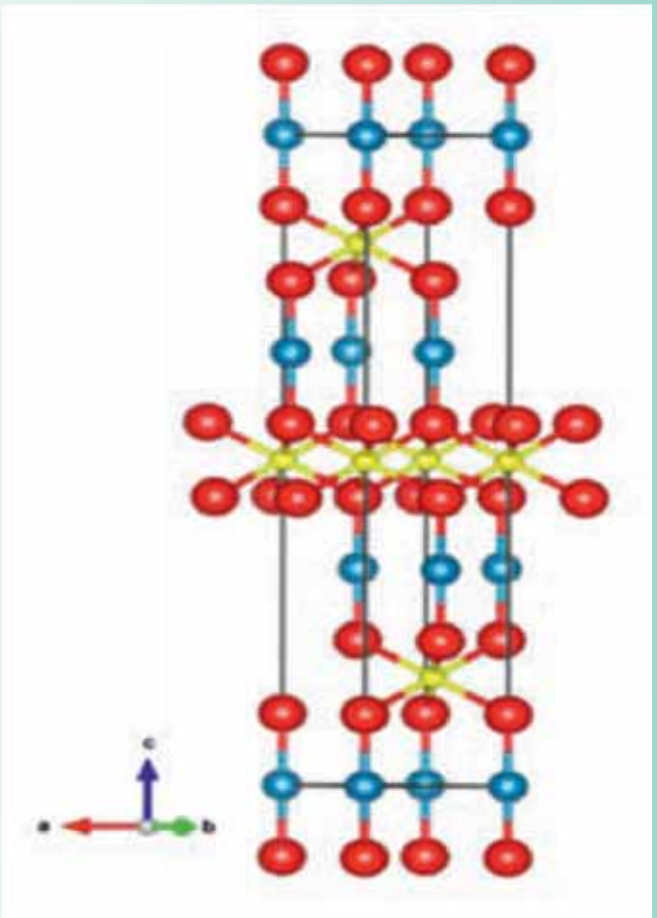
Schematic & Photograph of Six Tube Membrane Reactor with provision for Molten Salt Heating



Bipolar Electrodialyser

Bipolar membranes consist of cation and anion exchange membranes laminated over each other. They can split water into H^+ and OH^- ions under electrical field gradient. Bipolar membranes were developed using SPEEK-PEG and anion exchange membranes. A 400 cm^2 bipolar electro-dialysis cell is developed, which can produce acid and base to 1.7 M concentration.

$AgInO_2$, an n-type transparent oxide has been reported to form under high temperatures and pressures with residual silver impurity. In this context, we reported the formation of phase pure $AgInO_2$ by hydrothermal method using nitrates of silver and indium as starting precursors for the first time by conceiving the factorial design approach to identify optimum conditions for the synthesis.



Crystal structure of $AgInO_2$ (blue, yellow & red balls indicate Ag, In & O respectively)

The X-ray diffraction (XRD) of the product prepared with the hydrothermal conditions of 180 C, 4 M KOH and 24 h of dwell time is matching with the rhombohedral R3m(166) system of $AgInO_2$ with an increase in relative intensity of (006) to (012) facets (i.e., I(006)/I(012) = 0.40, ICDD # 96-150-9398) to 3.26 indicating texturing. The Rietveld refined unit cell parameters of AgInO2 are found to be a = 3.27668(10) Å and c =18.8838(7) Å with the unit cell volume of 175.585(14) $Å^3$. The quantitative estimation indicates the presence of no secondary phases.

The factorial analysis performed by considering two levels of each factor and splitting the experimental runs into two blocks. Considering response as the fractional intensities of the highly oriented peaks of $AgInO_2$, Ag and In_2O3, calculated from the XRD patterns of the respective samples, two design matrices of two levels each were constructed. In the first block of experiments, the dwell time shows least significance. Even though temperature raise from 150 to 180 C is favourable, its interaction with the concentration of KOH has opposite effect. Calculated effects for the second block of experiments indicate that increase in temperature from 180 to 210 C results in the composite mixture instead of pure phase. In this case, the high negative value of temperature effect (-17) dominates the positive contribution from the interaction terms. Overall, the pure phase formation conditions derived from X-ray diffraction intensities suggest 180 C and 4 M KOH as the best conditions with no dependence on dwell time in the range 24 to 60 h.

Field Emission Scanning Electron Microscopy (FE-SEM) disclosed the hexagonal-shaped platelike morphology with an average width of 300 nm and thickness of 70 nm. Energy Dispersive X-ray analysis confirmed the atomic ratio of Ag to In as 0.98 with no evidence of potassium. The Transmission Electron Microscopy (TEM) of $AgInO_2$ grain is a well-defined facet with a hexagonal plate-like shape. The Scattered Area Electron Diffraction pattern (SAED) reveals the (001) dominance that is in concurrence with XRD. The percentage fraction of the surface area of the dominantly exposed (001) facets to the total is unusually higher (52 %) than the theoretical estimate of 2 % for isotropic specimen.

X-ray photoelectron spectroscopy survey spectrum of $AgInO_2$ nanoplates indicated the presence of only Ag, In, C and O. The high resolution scans indicate the presence of Ag and In in +1 and +3 oxidation states respectively along with three oxygen signatures correspond to that of lattice O^{2-}, adsorbed Ox- and hydroxyl groups.$AgInO_2$ is thermally stable up to 595 °C in air and exhibited a specific surface area of about 48.5 $m^2 g^{-1}$ with an optical band gap of 2.20 eV and an activation energy of 0.24 eV/f.u for electrical conduction.

The stabilization of $Ag(OH)_2^-$in strong basic medium, mutual solubility of $Ag(OH)_2^-$ and $In(OH)_3$ in KNO_3 solution and processing at temperatures between 150C (4.8 atm) and 210 C (18 atm) under hydrothermal conditions are the order of visualization to optimize preparative conditions like temperature, pH and dwell time to realize phase pure $AgInO_2$. The compound was tested for sensing hydrogen from 1 to 10000 ppm of H_2in air and it exhibits high degree of selectivity (over NH3, NOx, LPG and HCHO) and repeatability.

In conclusion, hexagonal nanoplates of phase pure $AgInO_2$ was successfully prepared by hydrothermal route for the first time by considering a factorial design approach and it is believed that these experimental investigations will stimulate the synthesis of various delafossite compounds for different applications by factorial design approach.

At TIFR, the researchers have developed the magnesiothermic defect engineering protocol to design a new catalyst system where metal nanoparticle active sites replaced with defects as catalytically active sites. This is the first metal-free-ligand-free catalyst for CO_2 conversion. The defects in nanosilica convert CO_2 to methane with excellent productivity and selectivity.

The School of Chemical Sciences at NISER continued to impart high quality undergraduate and postgraduate level of knowledge to students coupled with cutting-edge research activity by the faculty and the students of the school. In addition to traditional organic, inorganic, physical and theoretical chemistry areas, the school also embarked on teaching and research activity in the interface areas of Biology, Material Sciences and Medicine. The School of Chemistry offered one of the best integrated M.Sc. and PhD programs.

BIOLOGY

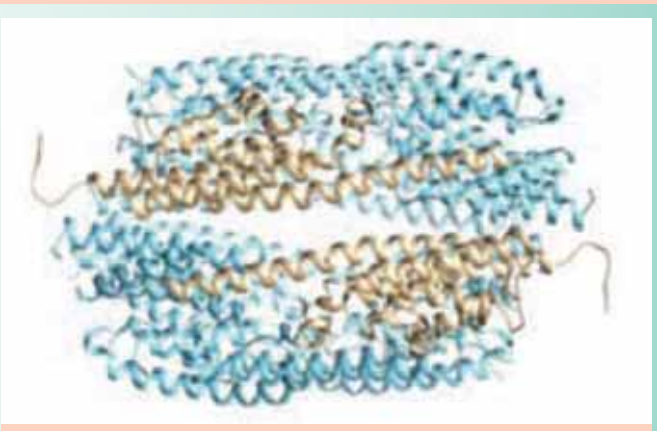
In order to identify novel therapeutics for COVID19, in silico docking and in vitro and in vivo experiments were carried out. Several ingredients of Ayurvedic Kadha, repurposed drugs and chlorophyllin were found to bind and inhibit critical proteins of SARS-CoV-2 virus. The in-silico work also suggested that 16 FDA approved drugs and a few natural compounds could potentially inhibit key enzymes of the virus. In vitro work has been initiated for biochemical and structural characterization of some of these viral proteins.

The recombinant SARS-CoV-2 main protease (Mpro) has been expressed and purified to homogeneity and crystallized for structural investigations. The complexes of Mpro with potential inhibitors are being prepared for structural studies. The gene for another SARS-CoV-2 protein, the papain-like protease (PLpro) has been cloned and expressed. The purification and biochemical characterization of the protein are currently underway.

Chlorophyllin, a known radio-modifying agent, was found to inhibit multiplication of SARS-CoV-2 virus in vitro. In a Phase I clinical trial on healthy subjects, use of Chlorophyllin enhanced lymphocyte counts and reduced the abundance of circulating hematopoietic stem cells in human blood. Chlorophyllin has been approved by Drug Controller General of India for conducting Phase II clinical trials on COVID19 patients.



Crystals of Recombinant SARS-CoV-2 MPro



Heteromeric complex of Translin (blue) and Trax (sandy brown) protein

Crystal structures of heteromeric complex of Translin and Trax proteins have been determined to high resolution (1.8 □) using X-ray diffraction data from INDUS-2 synchrotron. The structure shows the complex is composed of six protomers of Translin and two protomers of Trax.

Mitocurcumin, a mitochondrial targeted derivative of curcumin, was found to exhibit bactericidal effects at micro-molar concentration. Mitocurcumin was proposed to be a new class of antibiotic - effective against gram positive as well as gram negative bacteria. There was no evidence of resistance against mitocurcumin in a multi-generation study on bacteria and the molecule was found to be active against multidrug-resistant strains like MRSA.

Health profiling of over 5580 newborns were completed for congenital malformations, still births, Downs syndrome, twins and low birth weight in hospitals located in normal and high-level natural radiation areas (NLNRA&HLNRA) of Kerala coast. Risk of coronary heart disease among new-borns from HLNRA in the dose group 1.51-3.0 mGy/y was significantly lower compared to NLNRA dose group ≤ 1.50 mGy/y.

DNA double strand breaks (DSB) using premature chromosome condensation assay revealed higher initial repair ratio in HLNRA individuals compared to NLNRA individuals, indicating the influence of chronic low dose natural radiation on initial DNA DSB repair.

DNA repair gene polymorphisms showed no significant association at XRCC1 (Arg399Gln), XRCC3

(Thr241Met) and PRKDC (XRCC7 G/T) among NLNRA and HLNRA individuals, though polymorphism at NEIL1 (G/T) and LIG1 (A/C) indicated differential patterns between NLNRA and HLNRA as well as across different dose groups in HLNRA.

Radio-adaptive response study showed significant correlation of base excision repair gene polymorphism [hOGG1 (Ser326Cys), XRCC1 (Arg399Gln) and LIGASE1(A/C)] with DNA damage and mRNA expression in human peripheral blood mononuclear cells among the adaptive donors indicating the role of BER gene polymorphisms in identifying donors with radio-sensitivity.

Differentially expressed proteins obtained using Liquid Chromatography-Mass Spectrometry of samples from high background radiation areas of Kerala were used to construct protein-protein networks using a Python-based pipeline developed in NCBS, Bengaluru. The signal transduction protein YWHAZ (14-3-3ζ), cytoskeletal protein ACTB, signalling protein PRKACA and the molecular chaperone HSPA8 emerged as the top 'hub' proteins. The results confirmed the integral role of these proteins in regulation of cellular homeostasis in HLNRA individuals.

The iTRAQ proteomics data generated from the HLNRA population was deposited to the ProteomeXchange Consortium via the Proteomics Identification Database PRIDE (https://www.ebi.ac.uk/pride/archive/) repository. The PRIDE repository verified mass spectrometry data are available via ProteomeXchange with identifier PXD022380.

The enzyme 3-chymotrypsin-like cysteine protease (3CLpro) is a key agent in viral life cycle as it controls the coronavirus replication. 3CLpro could be a potential drug target as established in the case of SARS-CoV and MERS-CoV. We explored the potential of fused flavonoids as anti-CLpro inhibitors. Fused flavonoids are unexplored due to their low natural occurrence. We designed a strategy to synthesize 5a,10a-dihydro-11H-benzofuro[3,2-b]chromene skeleton and it's four novel derivatives. Our structural bioinformatics study clearly showed excellent potential of the compounds in conformity of experimentally validated inhibitor N3. Moreover, in-silico ADMET study displays excellent drugability and extremely low level of toxicity of the synthesized molecules. The synthesized molecules would not only be a potential set of inhibitors of CLpro but also further the cause of developing novel natural flavonoid based anti-COVID therapeutic spectra.

Piper betel leaf is known for its immense medicinal value. The leaf extract, fractions and purified compounds have anti-diabetic, anti-inflammatory/immune-modulatory, anti-ulcer, hepato-protective, anti-infective properties. Allylpyrocatechol (APC), an active principle in piper betel leaves has excellent anti-hypertensive and cardio protective property. Our investigation also indicated the cardio-protective property of AIP. Efficacy of APC to control hypertension and cardio-vascular disease in rats was tested by giving AIP orally from 15th day to 28th day. Oral gavage of AIP (10 mg/kg) showed excellent anti-hypertensive activity in rats. It modulated physiological, structural, electrical and biochemical parameters of the cardio vascular system for better functioning. Further, APC was found to be non-toxic up to 100 mg/kg.

The matrix of biomembrane is fundamentally a lipid bilayer, which is highly dynamic in nature with a rich phase behaviour. Neutron scattering has been used to investigate the interactions of different antimicrobials (ionic liquids, peptides), cholesterol and drugs with the lipid membranes. The measurements show that antimicrobial peptides selectively act on the model bacterial membrane, which has implications for infection imaging probe and novel antibiotics. In spite of their well-known side effects, the Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) are one of the most commonly prescribed medications. We have shown that NSAIDs modulate the lateral, internal and bending motions of the membrane, which play a vital role in their therapeutic actions and side effects. These results indicated that addition of cholesterol restricts the membrane dynamics which affects the entrapping as well as release profile of the drugs.

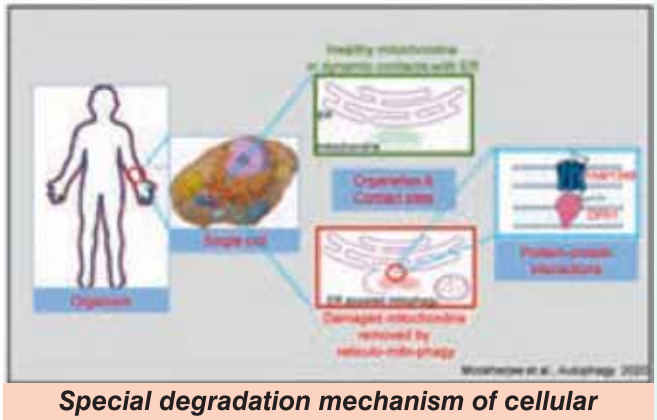
At TIFR, in a recent study, researchers tested the idea via switching on the signaling pathway that leads to overactivation of excitatory neurons within the forebrain, using genetically engineered mice. The experiments showed that prolonged activation of excitatory neurons

in the first two weeks after birth resulted in anxious and despair-like behaviors as the animals aged. This animal study reinforces just how critical the first few weeks of life are for optimal brain development. At the TIFR's National Centre for Biological Sciences, Bengaluru, the investigators reported the discovery of iron-sensing riboswitches (named Sensei). Present across bacterial phyla, these RNAs reside in the 5□ untranslated regions or within coding regions of messenger RNAs (mRNAs) encoding iron-related proteins. These riboswitches bind the reduced form of iron with high specificity. The investigators defined the sequence and structural space of iron-sensing RNAs and open avenues for the design of RNA-based biosensors.

At SINP, the wide-ranging and interdisciplinary research activities in biology encompass the relationship between the structure and function of biomolecules at the molecular level, as well as in the cellular context, and their perturbation in response to various factors leading to plethora of diseases. A major emphasis of the activities is to elucidate the underlying mechanisms of various disorders including infectious diseases, neurodegeneration, laminopathies, diabetes and cancers, in order to identify novel therapeutic targets and vistas through multi-dimensional and cross-platform approaches.

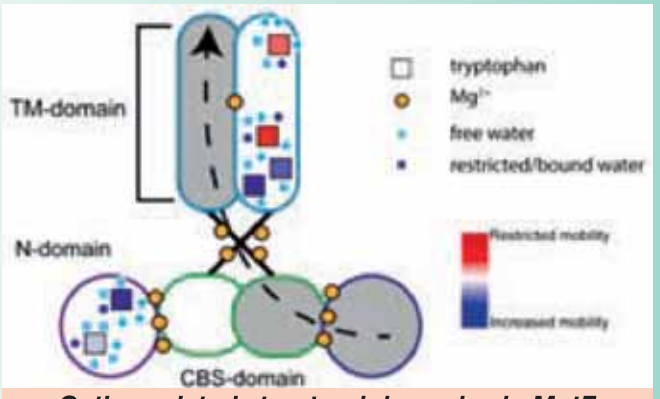
Following were some of the key research activities in biology at SINP during the year:

• Under special degradation mechanism of cellular compartments in neurodegenerative diseases in which it was shown that the abnormal internal cellular arrangements in neurodegenerative diseases need specialised recycling of cellular organelles. Novel degradation mechanisms of cellular compartments occur in neurodegenerative diseases. Stress induces in the generation of “naked” mitoplasts (mitochondria devoid of the outer membrane). This causes close contact of exposed inner mitochondrial membrane with endoplasmic reticulum (ER). ER, then, assists in mitophagy (mitochondrial degradation) which is mediated by FAM134B (present on ER) and OPA1 (present on inner mitochondrial membrane).



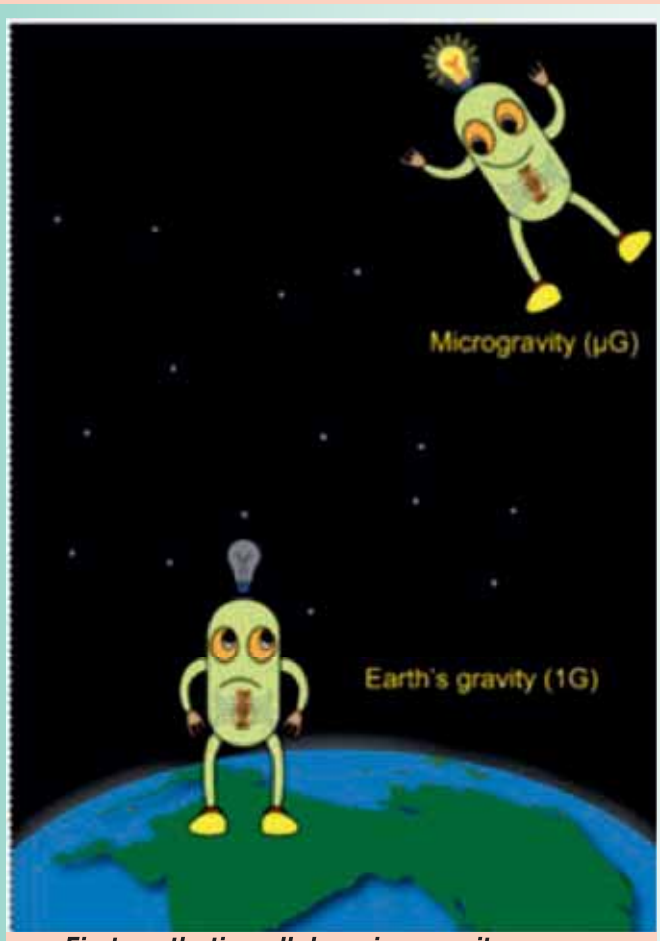
Special degradation mechanism of cellular compartments in neurodegenerative diseases

• Under Gating-related structural dynamics in MgtE magnesium channel in membranes the Magnesium transport mechanism is poorly understood despite the fact that changes in Mg^{2+} levels are implicated in various diseases including head and neck cancer. Structural dynamics of the magnesium channel is significantly altered when the channel shuttles between closed and open states. The structural integrity of the Mg^{2+}-sensing N-domain is preserved during gating.



Gating-related structural dynamics in MgtE magnesium channel in membranes

• Under Synthetic Biology, the first synthetic cellular microgravity sensor in bacteria E-coli was created using engineered gene circuits. The bacteria responded to microgravity by changing the expression of a fluorescence protein. Since the design of engineered genetic microgravity sensing device is universal, it can be connected with any cellular processes. The control of the cell division process using microgravity has been successfully demonstrated. The work showed for the first time how to integrate microgravity as a physical signal with biochemical processes.



First synthetic cellular microgravity sensor in bacteria E-coli was created using engineered gene circuits

The School of Biological Sciences (SBS) at NISER remained involved in mixing and imparting traditional wisdom with modern technology by developing a research programs along with a vibrant teaching curriculum. SBS continued to promote scholarly and innovative thinking to conduct cutting edge research in diverse areas ranging from molecular to organismic biology. To facilitate the process, the school continued to offer 5-year integrated M.Sc program, Ph. D program and Post-Doctoral program to motivate and train students. To further strengthen the SBS research program, an Integrated Ph.D program initiative is under progress.

CANCER

India is plagued by an estimated one million disparate cases of cancer every year with 60 – 70% mortality. Cancer actually refers to a constellation of different types of diseases based on location besides cellular and molecular heterogeneity. Along with signalling pathways, it is important to explore the other cellular machineries for alternative strategies to fight against cancer. In this regard, our research activities at SINP on cancer focus via an integrated approach on the alterations in cellular architecture and metabolic reprogramming, in tandem with tumor-microenvironment interactions, which might determine the fate of cancer cells.

It has been established that over-expression of the epigenetic reader ZMYND8 perturbs acquired chemo-resistance and in turn chemo-sensitizes invasive breast cancer cells. The epigenetic reader ZMYND8 has been proposed as a candidate chemo-sensitizer for better therapeutic outcome in chemo-resistant breast carcinoma.

Research is ongoing for designing suitable (size~50-60 nm) nontoxic and crystal defect induced anisotropic nanoparticles for zone specific surface enhanced Raman spectroscopic detection of Oral Cancer and adenoma like pathological parathyroid glands in ex-vivo and in-vivo environment in collaboration with Tata Medical Center, Kolkata.

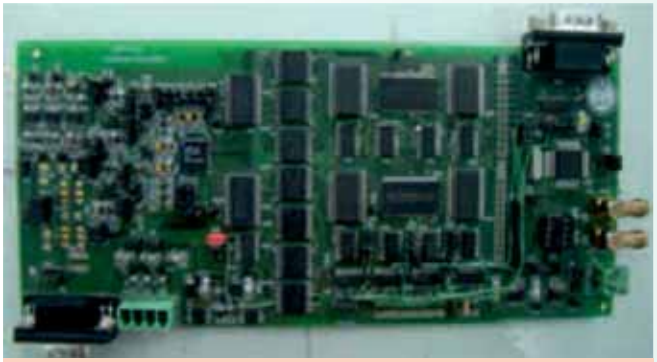
SYNCHROTRON & THEIR UTILISATION

At RRCAT, Indus-1 and Indus-2 synchrotron radiation sources were operated for the synchrotron radiation (SR) user community. During the nationwide lockdown period, the Indus facility was kept under shutdown. After restart of the facility complying with COVID-19 related precautions and guidelines, the beam availability for SR users in Indus-1 and Indus-2 was 2921 hours and 1879 hours respectively till December 2020. The projected beam availability from April, 2020 to March, 2021 is expected to be ~ 4400 hrs for Indus-1 and 3300 hrs for Indus-2. The number of user experiments at Indus-1 and Indus-2 beamlines from April to December 2020 is 245 and by March 2021 this number is expected to cross 350.

The Indus-1 and Indus-2 synchrotron radiation sources are operating in round-the-clock mode for more than a decade. In order to ensure smooth and reliable operation of Indus machines, there has been

continuous effort for the upgradation of various sub-systems by way of developing and deploying improved technologies mostly based on indigenous efforts. Following development activities have been carried out with an aim of their deployment in the machine in future.

A prototype serial communication analyzer has been developed to detect the communication errors at protocol and signal level. This will aid in speedy diagnosis of communication errors and thus will improve the uptime of Indus control system.



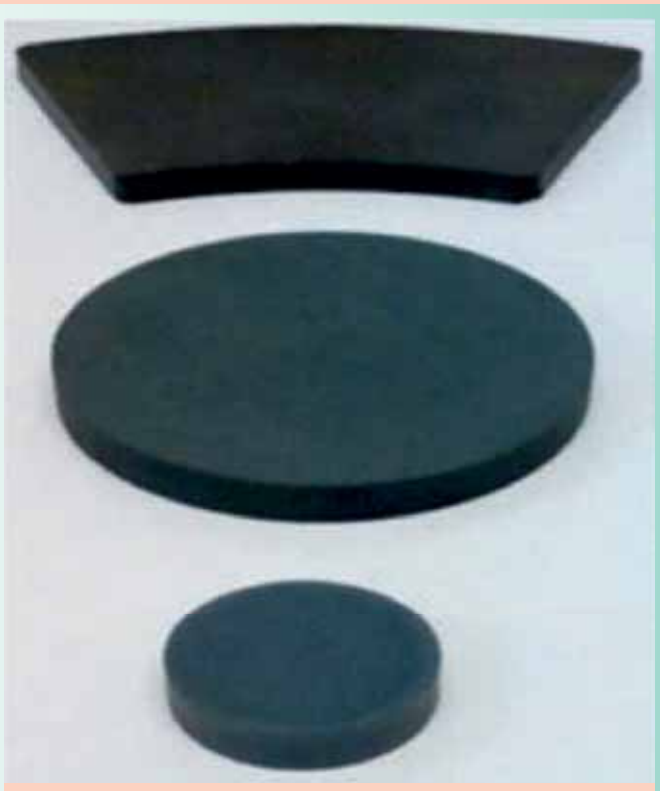
High-speed data-acquisition board



Command-response telegram electrical voltages captured

A high-speed data acquisition and processing platform, with input bandwidth up to 630 MHz and sampling speed upto 130 Msps, is developed for particle accelerator control & instrumentation applications.

Indium doped Calcium Vanadium Garnets (ICVG) have been designed, developed and fabricated as import substitute for construction of ferrite disk resonator for 60 kW - 505.8 MHz CW circulators for Indus 2. Temperature dependent magnetization measurements show better temperature stability of magnetization than the imported garnets. Microwave-magnetic characterization show narrow FMR line-width suitable for being used in high power circulator applications.



The garnet disc components

As an alternative to klystron based RF power system, an IOT based RF Power system along with HV DC power supply, high power circulator was installed, commissioned and deployed in Indus-2 for energizing Indus-2 RF cavity at the operating frequency of 505.8 MHZ



IOT amplifier as set-up in Indus-2 along with their constituent sub-system

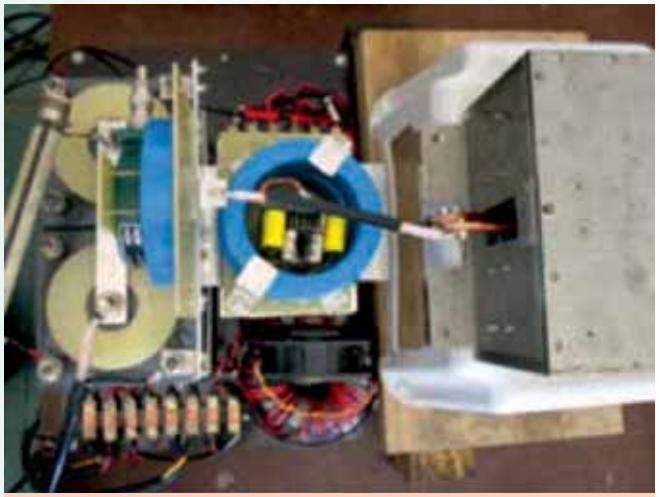


IOT RF output connected to 6-1/8" coaxial rigid line system

Pinger kickers are advanced diagnostic tool to study the linear and nonlinear dynamics of the beam. Towards the preparatory activities to install horizontal pinger magnet in Indus-2, the optimization and testing of pulsed power supply has been carried out with actual load i.e. pinger magnet and coated vacuum chamber in lab.



Developed power supply



Pulse forming network and magnet

2700 mm long Aluminium alloy 6063-T6 UHV chamber with internal aperture of 81 mm x 17 mm, with non-evaporable getter (Ti-Zr-V) coating inside, for undulator device in Indus-2, was designed, developed and tested for its ultra-high vacuum performance.

In-flange type compact Fast Current Transformer (FCT), having rise time of 235 ns and lower cut-off frequency (-3 dB) of 30 Hz, has been developed for the monitoring of pulsed beam current (up to 800 mA , pulse duration of 10 μs and repeating at up to 300 Hz) of the 10 MeV electron linac.

An electron beam radiation processing facility named ARPF (Agricultural Radiation Processing Facility), based on indigenously developed 10 MeV, 5 kW electron linacs, has been set up at Indore. The facility was operated for carrying out a large number of irradiation experiments on various research samples including seeds for mutation breeding, grains for post-harvest treatment and irradiation for gem industry. FDA licence for radiation processing of Risk Class-A medical devices has been obtained. This is the first 10 MeV electron beam facility in the country licenced by AERB and FDA for radiation processing of medical devices.

A solid state Marx modulator (50 kV, 2 A, 16 μs, 300 Hz) has been designed and developed indigenously for electron gun of 10 MeV electron linac. This transformer less modular design provides lower ripple, lower droop, adjustable pulse width and fast rise time. It has been tested on a resistive dummy load of 25 kΩ equivalent to electron gun.



Advanced 50 kV, 2A, solid state Marx based gun modulator



Exploded view of 50 kV, 2A, solid state Marx based gun modulator

The 9.5 MeV, 10 kW electron linac named Linac-3 has been designed to operate in two modes – electron mode (with an average beam energy of 9.5 MeV), and x-ray mode (with an average beam energy of 7.0 MeV). The new design incorporates a pre-buncher RF cavity before the linac structure and an energy filtering system after the linac structure, which limits the maximum electron energy to an acceptable value as per the regulatory requirement. Commissioning experiments for high average power operation are soon going to commence and design validation will be done based on this.

Indus-1 and Indus-2 are national facilities with 14 beamlines in Indus-2 and 6 beamlines in Indus-1. In view of the constraints due to COVID-19 pandemic, there have been 245 user experiments carried out in the period April 2020 to December 2020, with about 150 research publications. Some of the important published user experiments include, development of microfluidic chip using x-ray lithography, detector calibration for the solar x-ray monitor on board India's Chandrayaan-2 mission and determination of chemical impurities in some homeopathic medicines which were of interest to ministry of AYUSH. There has also been a significant increase in the number of users from the pharmaceutical industries.

The SINP beamline at Indus-2, RRCAT is already commissioned, however, AERB clearance is still waited for its proper use by the common users. Here we report grazing incidence X-ray diffraction study of a 200 Å thick WS2 film deposited on Si substrate to show its performance. The measured XRD pattern (shown in the figure) shows a diffraction peak located at $2\Theta = 14.37°$ with FWHM = 0.37°, for the Ar-annealed WS2 film, which corresponds to the (002) crystal planes of hexagonal WS2, confirming the layer stacking along the c-direction.

CYCLOTRONS & THEIR UTILISATION

Successful Beam Acceleration from K500 Superconducting Cyclotron in first harmonic mode

Beam extraction from K500 Superconducting Cyclotron could not be done earlier due to unacceptably

large first harmonic imperfection in the magnetic field (50 G). The necessary corrections in the magnetic field were done and verified from field measurements. Thereafter N2+ beam (4.5 MeV/A) was accelerated, extracted and transported to user's scattering chamber for characterization. This was done in second harmonic mode of operation which has less stringent requirements in terms of RF power and extraction voltages and has been reported last year. This year the main effort was to accelerate and extract beam in the first harmonic operation which will provide us much higher beam energies that is currently available from the operating accelerators in our country. Acceleration in first harmonic mode requires higher Dee voltages for which a series of modifications were carried out during the past one year. Several changes in the RF cavity were done to reduce arcing and peak surface field. The geometry of the central region was analysed by applying voltages on Dee-1, 2 and 3 respectively. Operation and initial first Harmonic beam trial have been planned at 14 MHz. Accordingly, the cavities and RF amplifiers were tuned at 14MHz. RF conditioning was done for a few days in pulsed mode and once the arcing inside the cavities got reduced, CW powers were fed to the cavities. The RF powers were increased gradually to the required levels and DEE voltages were measured using Dee voltage meter and also calibrated from X-ray end point energy measurements. Amplitude and phase loops were introduced thereafter for close loop amplitude and phase control. After achieving required Dee voltages for first harmonic operation, beam trial started with Nitrogen 4+ beam. The main challenge here was to arrive at an optimised setting of the RF voltages and trim coils so that the beam gets accelerated up to the extraction radius without significant loss and beam centering was achieved throughout the acceleration process. After several days of beam trials, this could be achieved and around 250 nA Nitrogen beam could be transported up to the extraction radius of 660 mm. This beam trial for extraction from the cyclotron using two electrostatic deflectors and nine magnetic channels and optimization of the parameters of these elements are being done.

Room Temperature Cyclotron (RTC) Utilisation

The room temperature cyclotron (RTC) has been operating round the clock and delivering light and heavy ion beams for various experimental research programs. The internal Penning Ion Gauge Ion Source (PIGIS) producing light ions, is presently being used for the experiments. External Electron Cyclotron Resonance Ion Source (ECRIS) was also used for the heavy ion beam development activities and experiments as well. It was planned to develop sulphur 10+ beam in cyclotron and for this initially oxygen 5+ beam was accelerated because both the beams have very close charge to mass ratio (q/m) and difficult to separate by the analysing magnet located at the axial injection line. Accelerating close q/m beams in cyclotron is vital as it obtains useful operational parameters to develop new beams. The parameters thus obtained were utilised for internal beam development of sulphur 10+. In the process sulphur 10+ beam has successfully been accelerated and extracted from K130 room temperature cyclotron for the first time. Presently K130 cyclotron is capable of delivering sulphur beam for experimental purpose. Following ion beams have been utilised for the experimental purpose.

PLASMA & FUSION TECHNOLOGIES

Portable Hand Held Plasma Sterilizer

A portable hand held plasma sterilizer, indigenously developed by IPR, consists of a plasma unit with multiple jets (100 numbers) along with power supply (230 V, 50 Hz). The portable sterilizer has been developed for disinfection of surfaces contaminated by microbes like bacteria and viruses. The device uses air at atmospheric pressure as the operating gas. The plasma generated from this device has a maximum temperature of 30oC, making it particularly useful for sterilizing heat-sensitive materials. Preliminary test results on disinfection of bacteria (C. albicans, P. auruginosa and E.coli) revealed that a 180 second treatment led to near complete wipe out of all the bacterial colonies. The sterilizer was also tested on SARS-CoV2 and it was found that 79% viral reduction was obtained after treating for 300 seconds. The results are promising and indicate that this device can be used in hospitals and has a potential to sterilize surfaces that cannot be moved like bedside tables, bed mattresses, privacy curtains, slings for patient lifting, table tops,

wooden furniture in patient's room, wall blinds and medical equipments. Further testing and development are in progress.



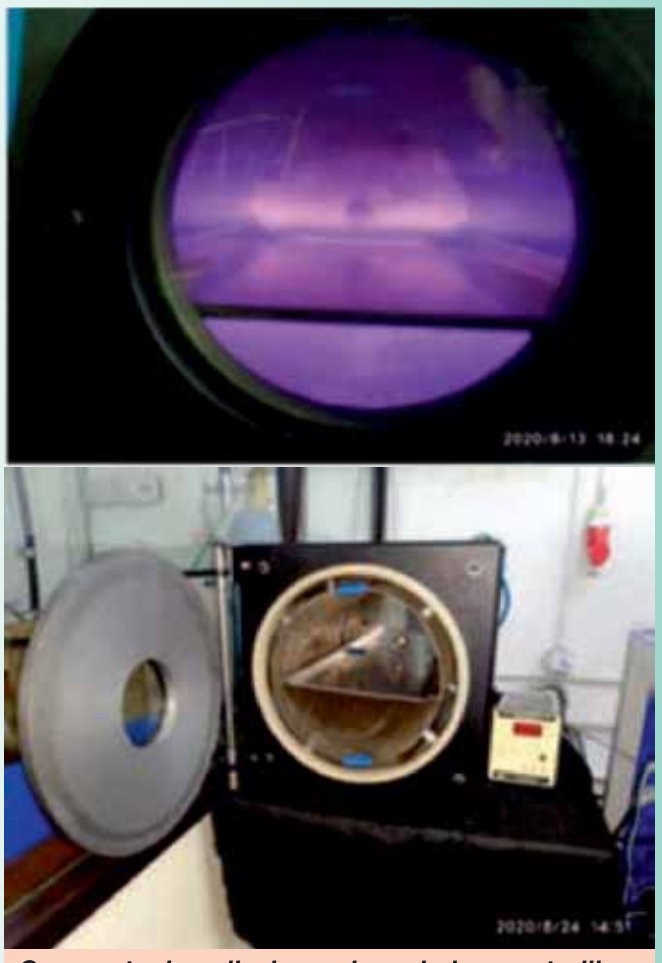
Testing of mask using this portable plasma sterilizer



Portable hand sterilizer

Glow discharge-based Plasma Sterilizer

An earlier version of such a system has been tested at B.V. Patel Pharmaceutical Education and Research Development (PERD) Centre, Ahmedabad, and found to work against different kinds of bacteria. That system was too large to use inside a BSL-3 facility, which is essential for testing against dangerous viruses like COVID-19. A compact version has now been developed and will shortly be sent for testing.



Compact, glow-discharge based plasma sterilizer

Delivery of First indigenously-developed Cryopump to Space Applications Centre, ISRO

IPR and SAC-ISRO Ahmedabad signed an MOU in 2017, covering the indigenous development & delivery of three cryopumps by IPR to SAC. The first prototype cryopump of 400 mm opening, with cryo cooling provided by a cylindrical bath at its center with cryopanels attached to it, has been delivered to SAC. This provides a pumping speed of 5000 litres/s for Air/Nitrogen and a pumping capacity of 6000 mbar-



CVPS -400 mm –opening Liquid nitrogen based cryopump



Nano Anti-microbial coatings

l/sec. The Cryogenic Vacuum Producing System (CVPS) was tested at IPR and is now installed on a Cryo-Vac chamber at SAC Ahmedabad and is working as per specifications. This is a 100% Made in India Product, including Cryo-adhesive, Sorbents, coating, panels etc. The facility for making such panels is under one roof at IPR, along with in-house characterization and pumping performance evaluation. The gases that can be pumped with liquid Nitrogen coolant include Nitrogen, Argon, Water vapor & hydrocarbons, while pumping of Helium, Hydrogen, Xenon and other gases can be done using liquid helium.

Nano Anti-microbial coatings

Nano-silver coatings on fabric as well as yarn, which offer anti-microbial properties, are normally expensive. Plasma-based nano-copper oxide (CuO) coating can also offer anti-microbial properties. Using a device called a magnetron, 100 nm thick layers of CuO have been made on polypropylene Fabric. Presently these coatings are being examined for their anti-microbial properties. Such coatings can be useful for making face masks, personal protective equipment, etc.

Plasma Activated Water (PAW) work for milk industry

Water does not normally contain any reactive radicals. Hence, for disinfection of milk cans, detergents are commonly used to produce radicals with water. Later, to remove the extra detergent from the cans, a lot of water has to be used. Plasma Activated Water (PAW) is produced by exposing distilled water to atmospheric plasma, leading to formation of radicals like NO_2^- ions, H_2O_2, gaseous O_3, NO_3^- ions, dissolved O_3 etc. A study has been done to determine the suitability of PAW in disinfection of milk cans. Microbial reduction is found to be 71% for 10 seconds exposure for cans made of different materials like glass, low density polyethylene, polypropylene, stainless steel and aluminium. More detailed studies are in progress.

Study on fungicidal properties of PAW on lemons

Lemons stored in cold storages beyond 2-3 months, depending upon the storage conditions, are often found to decay due to fungal growth. Since Plasma Activated Water (PAW) has active radicals, it can be used as a fungicide. For a feasibility study, fungi from stored lemons were isolated and wetted with PAW for about 15 minutes. It was found that there is a 100% fungus reduction. Further studies are in progress to optimize the procedure and develop a system that can be used for industry.

Antifouling Properties on Silicone Catheter Surface by Plasma Treatment

Catheter Related Infections (CRIs) are one of the most common Hospital-Acquired Infections (HAI),

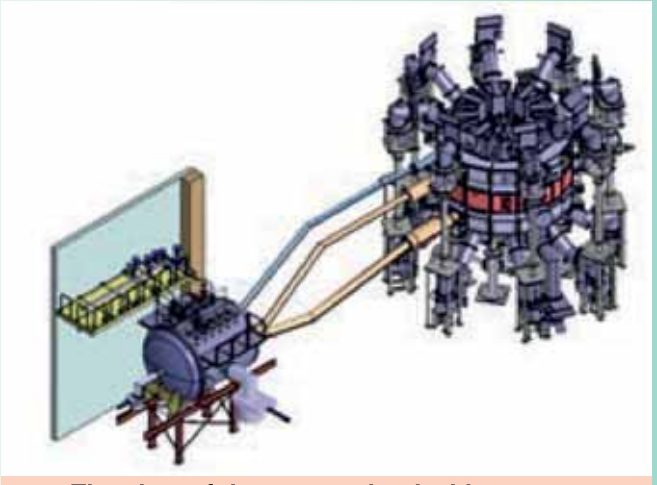
caused by microbial colonization known as 'biofilm'. This can lead to increasing morbidity and mortality of patients. Researchers around the world are working on development of promising strategies based on material science and surface engineering to address these limitations. IPR's study, based on an anti-fouling approach, involves modification in surface properties such that bacterial cells are not able to adhere and grow further. Preliminary results reveal that a plasma-treated catheter surface has considerably altered surface chemistry and morphology. Microbiological test results have shown significantly less (90%) bacterial adhesion on plasma treated silicone catheter surface as compared to the bare surface.

Aditya-Upgrade Tokamak Operation

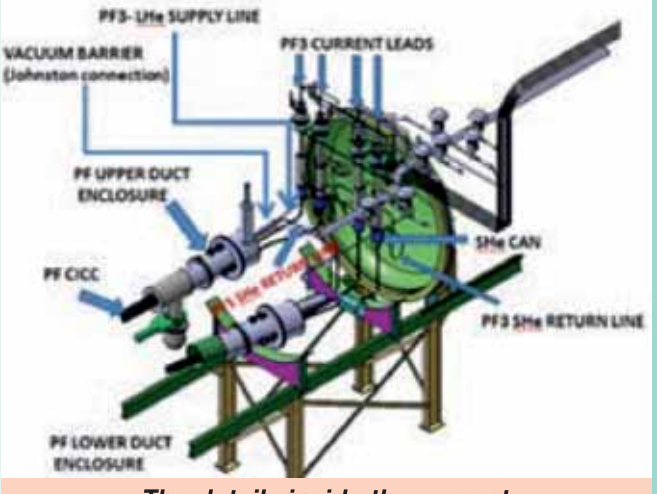
Recent experimental campaigns have demonstrated high-current, long-duration plasma discharges. While a peak current of 212 kA has been obtained (85% of the design value), long (300-350 millisecond) repeatable discharges with current values over 200 kA have also been obtained. The maximum duration of 385 ms (28% higher than the design value) has been obtained recently. These achievements became possible because of sustained efforts put in to improve wall conditioning by performing activities such as Novel (pulsed) H_2 GDC for long hours; Periodic discharges + ECR plasma cleaning; Vessel Baking at 135°C and Lithiumization. Using an in-house developed FGPA based PID controller in closed loop with a loop time of 1 millisecond, real-time control of the horizontal position was demonstrated. For the first time, a Deuterium gas puff has been injected into the Aditya-Upgrade plasma which has resulted in observation of plasma detachment and cold pulse propagation. These detachment studies will be helpful for the understanding of heat load mitigation and plasma transport. Also, for the first time, plasma shaping has been attempted by energizing the newly-installed divertor coils, demonstrating the formation of a strike point on the lower side. The position of the strike point matches that predicted by the indigenously-developed plasma equilibrium code IPREQ.

Steady-State Superconducting (SST-1) Tokamak Operation

Operation of the superconducting Poloidal Field (PF) coils is necessary for demonstrating the full operational flexibility of shaped plasma in SST-1. One of the PF coil pairs (PF-3 upper and lower coils) have been energized on SST-1 for the first time. It has been charged up to 600 A/turn at a ramp rate of 1 kA/s for a flat-top duration of 7 sec. This became possible through a series of steps. Firstly, the PF coil power high-current power supplies were commissioned for the first time. Secondly, these power supplies were connected to the coils through the Current Feeder System (CFS). CFS, located 12 m away from SST-1, is connected through a vacuum duct carrying Cable-in-Conduit Conductor (CICC) of both the Toroidal field and PF coils up to the current leads. The Vacuum Breaks (VB) present in the CFS are critical during Ohmic operation as they also protect the coils from the induced voltage generated between the



The view of the current lead with vacuum break which is between the power supply and the superconducting poloidal field coils.



The details inside the current lead / vacuum chamber

terminal ends of current leads. The operational requirement for PF3 coils is 1 kA/turn, and the system has so far been tested up to 600 A/turn. Work is currently underway to upgrade the ceramic-based VB to suitably-designed Glass-Fibre Reinforced Polymer (GFRP) based VB. Such VBs have been developed in-house and are currently being tested in SST-1 like operational conditions. Once these tests are successfully completed, these VBs would replace the imported ceramic-based VBs, a contribution to Atmanirbhar Bharat.

Hot helium leak test for high temperature components

In fusion machines, several precision-fabricated components, such as the plasma grids in Neutral Beam Injectors, are cooled using hot water at high temperature & pressure (150°C & 25 bar). These must be subjected to qualification tests to establish the manufacturing process before use in the actual device. To our knowledge, for the first time, the plasma grid of the extractor and accelerator system of the neutral beam injector has been subjected to such a qualification test. The grid involves a 1.5 mm thick copper layer electrodeposited on Copper base plate with milled channels to allow flow of water. The tests have been performed inside a temperature-controlled furnace and a global leak rate of $< 10^{-9}$ mbar l/s has been demonstrated. The process stands established for application in testing leak rates for components at their operational temperatures.



Plasma grid segments inserted in a vacuum hot furnace in preparation for the hot helium leak test

High Heat Flux Test Facility

The High Heat Flux Testing Facility (HHFTF) that was earlier operated in leased premises has now been disassembled, transported to IPR and then again made operational. The HHFTF uses a 200 kW/45kV electron beam for performing high heat-flux testing of fusion machine components, e.g. divertor plates, antenna screens, etc. It can raster the e-beam on components with a pre-defined beam pattern. Steady-state as well as pulsed heat loads can be produced. Apart from the testing chamber, HHFTF includes a high-pressure high-temperature water circulation system (HPHT-WCS) for cooling the test components. Over the next 2 years, HHFTF will also be coupled to a high-pressure, high-temperature Helium cooling loop (EHCL) which is now in the process of being set up. That will allow testing of components cooled by either water or helium gas.



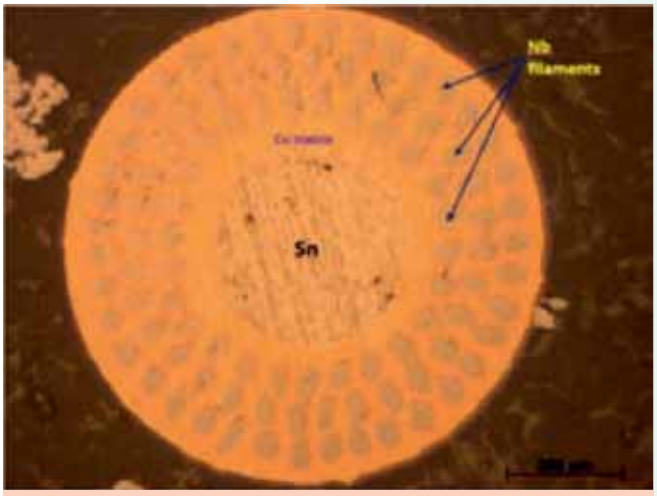
A bird's eye view of the High Heat Flux Tet Facility in Operation

Long Pulse operation of the Positive hydrogen Ion Source in the SST-NBI Test stand

A Test Stand for the Positive Neutral Beam Injector (NBI) system has been established to fully characterize all sub-systems before integration with SST-1. In this stand, the beam travels from the neutralizer and is terminated on a calorimeter. In the recent test campaign, the temporal traces recorded by electrical diagnostics showed consistent long pulses up to 3 sec for ion beam current up to 14 Amp with energy 27 keV. A bending magnet to divert the ionic components of the beam has also been characterized successfully – this is necessary for measuring the neutralization efficiency of the beam. Work is in progress to further increase the current to 30 A, which requires operation of cryo-condensation pumps and NBI cryoplant.

Development of Multi-filamentary Nb3Sn Superconducting Wire for National Fusion Programme

Nb3Sn multi-filamentary superconducting wires are mainly manufactured in two ways a) Bronze process and b) Internal Tin process. BARC chose the latter route because of superior stoichiometry control of Nb3Sn phase. In this process, Nb and Sn filaments are embedded in Cu matrix, and the composite is co-processed through a series of metal working steps followed by reaction heat treatment during which Nb_3Sn superconducting phase is formed. Through extensive research and development effort, 2 km long single length multi-filamentary Cu-Nb-Sn composite wires, each of 0.8 mm dia. containing 97 Nb filaments and one Sn filament, were fabricated in BARC. Presently, there are two variants of this wire in terms of the chemistry of internal tin: a) Sn alloyed with 1% Cu and b) Sn doped with 0.3% Ti. Superior filament configuration without failure has been achieved in both the variants. Development related to reaction heat treatment of multi-filamentary wires is in progress.



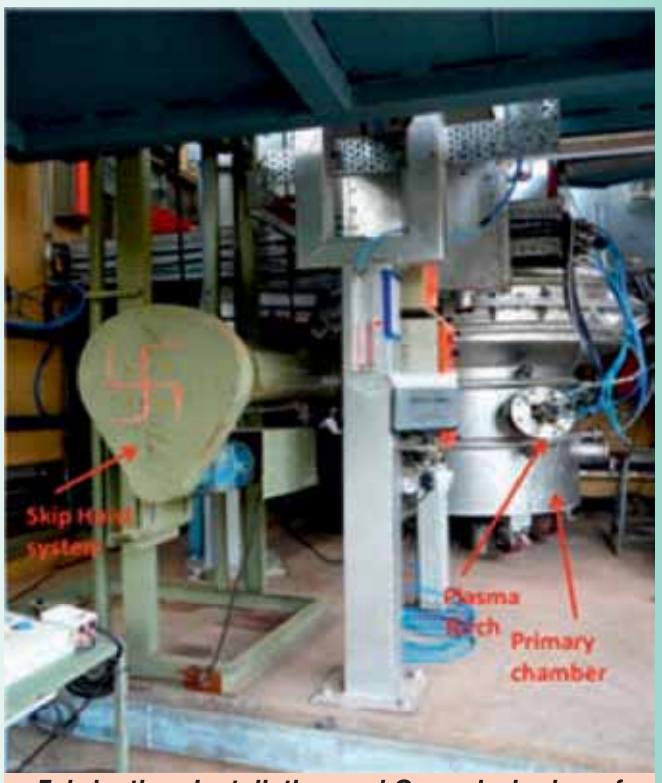
Cross section of multi-filamentary Cu-Nb-Sn composite wire



Multifilamentary wire with. Copper from the leading part of the wire was leached out to reveal the "brush", consisting of 97 Nb filaments of 40 microns each and a 100 micron Sn filament

Fabrication, Installation and Commissioning of Triple Torch Air Plasma Gasifier

In presence of high temperature thermal field of plasma and insufficient oxygen, carbonaceous material gets converted into CO and H_2. The process is called plasma gasification. A triple torch air plasma gasifier was fabricated and commissioned in BARC for safe incineration of non-explosive non-biodegradable solid wastes including chlorinated plastic at a rate of 1 ton per day. The process is environment friendly without release of any harmful gases such as SO_x, NO_x, dioxin, and furan and other pollutants like fine carbon particulates and poisonous carbon monoxide.



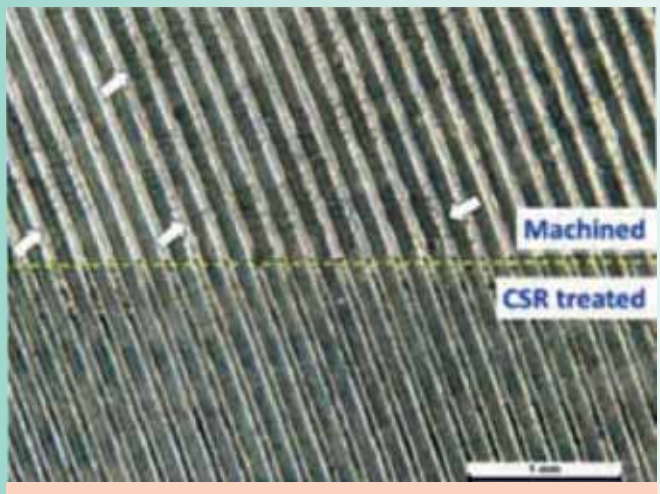
Fabrication, Installation and Commissioning of Triple Torch Air Plasma Gasifier

MATERIAL SCIENCE

Manufacture of Zr- and Ti- alloy components requires extrusion at elevated temperatures. In order to

prevent excessive oxidation, copper jacketing is used for manufacture of Zr-alloy products. A modified (Na, K) based polyphosphate glass is being developed as hot extrusion lubricant in the temperature range 800-1000 °C. Al_2O_3, CaO and CuO were added to the polyphosphate glass containing $NaPO_3$ + KH_2PO_4 to increase its melting temperature and achieve desired viscosity. Based on different experiments, modified (Na, K) polyphosphate glass could be a suitable glass lubricant for high temperature extrusion.

Stress Corrosion Cracking (SCC) of austenitic stainless steel (SS) is an important life limiting factor of nuclear components and affects safety of operation in any industry, including SS and nickel-based alloy components in LWRs. Common finishing operations such as machining, grinding, turning, etc., introduce surface metallurgical and morphological changes, which significantly affect SCC initiation. Conventional techniques of SCC mitigation, such as shot peening, results in an increase in surface roughness and high residual strain, factors which are known to aide SCC. A controlled surface rolling (CSR) technique, developed to burnish SS surfaces, is a low plasticity technique. CSR uses a small diameter roller of 20 mm width, which rolls 3-10 mm thick plates by automatic traverse in the x-direction under load control mode (pneumatically applied, maximum 1000 kgf). CSR technique aims at reducing surface roughness of machined SS and introduces compressive stresses to greater depths with low level of surface strain. In the following figure cracks

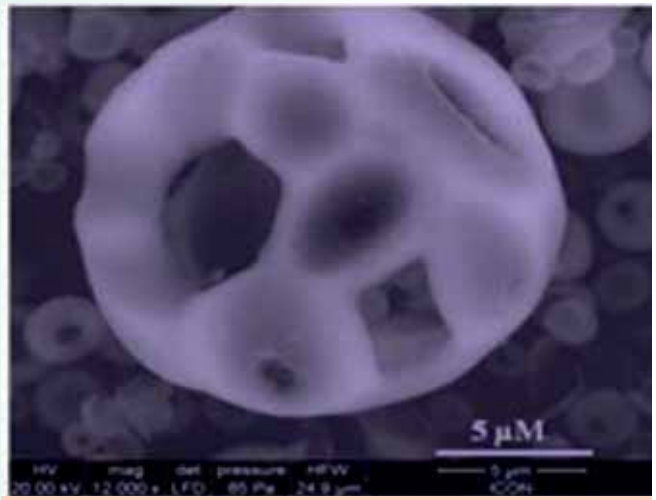


Surface of SS304L coupon showing both as machined surface and the controlled surface rolling treated surface after exposure to boiling magnesium chloride

are initiated all over the machined region after G36 test while SCC initiation was supressed in the CSR treated machined surface.

BARC has developed a new series of age hardenable Ni-Cr-Mo alloys that are stronger alternatives to many commercial Ni-alloys, like Inconel 686, Hastelloy C-276, containing 16-22 % Cr and 13-16 % Mo, for applications like heat exchangers, reaction vessels, scrubbers, etc. The alloys are age-hardened by precipitation of a new Ni_3X type phase with Ni3(Cr,Mo,Ti,W) stoichiometry over a temperature range 650 – 700 °C. The new phase is stabilized by addition of W and Ti in Ni-Cr-Mo alloys. The Ni_3(Cr,Mo,W,Ti) phase is iso-structural to the Ni3Nb Γ″ phase that forms in many Nb bearing Ni-base superalloys like Inconel 625, Inconel 718, etc. Advantage of the Ni_3(Cr,Mo,Ti,W) phase is that it remains stable up to its dissolution temperature at about 850 °C, unlike the metastable Ni3Nb Γ″ phase, which transforms to a stable Ni_3Nb d-phase with a different crystal structure at temperatures above 650 °C. As a result, the yield strength of the alloy in age hardened condition increases over the un-aged alloy by a minimum of about 60%, preserving more than 40% ductility, and retains its useful strength up to about 750°C.

Sorbent materials such as humic acid coated Fe_3O_4 nano-particles, calcium alginate bio-composite, bio-hybrid of silica and microbial cells for mercury respirator were synthesized and tested for their capacity to adsorb elemental and ionic mercury from contaminated effluents. It was found that absorption



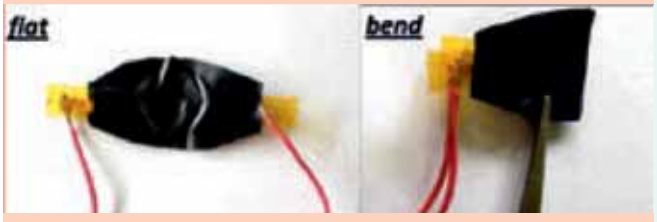
SEM micrograph of bio-hybrid of nano silica – S. cerevisiae cells

capacity of mercury for humic acid coated Fe_3O_4 nano-particles is 343.71 ㎍/gm, which is two times that of activated charcoal. A bio-hybrid of nano-silica and S.cerevisiae cells was synthesized with absorption capacity of 185.19 mg/g for mercury for purification of mercury contaminated liquid wastes.

Carbon Nanotube (CNT) wool was produced by condensing CNT aerogel in floating catalyst chemical vapour deposition. This is a special class of material where long CNTs are self-assembled together into a 3D structure. The role of sulphur to iron ratio was studied in detail to obtain CNT wool with different densities and chiralities. Filters prepared using the CNT wool were found to be effective in capturing nanoparticles including bacteriophages. A flexible capacitor prepared with CNT wool showed promising results and CNT wool doped with N using atmospheric pressure nitrogen plasma developed at BARC showed improved electrical conductivity needed in sensor applications.



CNT – Wool Filter



Flexible Capacitor Made uo of CNT Wool

Polycarbosilane (PCS), a precursor for making SiC fiber, was synthesised at kilogram scale from rearrangement reaction of polydimethylsilane (PDMS) at 500 °C and 10 MPa pressure in an autoclave. Different molecular weight fractions of PCS ranging from Mn = 200 to 2200 were separated by fractional distillation. PCS of melting point 140-145°C was extruded through a 10 hole-0.2 mm diameter spinneret in a lab scale melt spinning unit to obtain green (as-spun) fiber.



PDMS and different fractions of PCS

Post Fukushima, the focus is on design of Accident Tolerant Fuel (ATF) cladding to maintain fuel integrity for a considerably longer period of time during LOCA scenario. Several new concepts are being considered that could potentially provide substantially improved safety response to LOCA, while maintaining very good steady-state reactor operation characteristics. One of the near-term technologies that can be easily implemented as a drop in concept in the existing power reactors is MAX-phase ceramic coated Zircaloy fuel tubes, which shows significantly improved oxidation resistance. Ti_3AlC_2 MAX-phase ceramic coating was developed on Zircaloy-4 flat substrate and fuel tubes using high purity Ti_3AlC_2 MAX-phase powders synthesized from elemental Ti, Al and C powders through pressure-less sintering under inert atmosphere. MAX-phase ceramic coating was deposited on to Zircaloy-4 substrate using cold spray deposition. The process parameters for depositing 20-25 mm thickness MAX-phase coating on Zircaloy-4 substrate were optimized. The feasibility of industrially producing oxidation resistant coated Zircaloy-4 ATF cladding was demonstrated by fabricating a few full-length MAX-phase ceramic powder coated Zircaloy-4 fuel tubes through cold spray deposition technique.



Ti_3AlC_2 MAX-phase Ceramic Coated Oxidation Resistance Zircaloy-4 Accident Tolerant Fuel Tube

Low Alloy Nano-bainitie steel with a very high strength of 1 GPa and ductility as high as 20% was developed and produced in kilogram scale for application in fabrication of RPV. High strength, ease of fabrication, weldability and low cost are some of the desirable attributes in choice of a structural material. Owing to their low cost, ferrous alloys offer great

opportunity to tailor their mechanical properties and therefore an obvious choice as a structural material. Recently, due to bainitic transformation in low alloy steels, higher strengths upwards of 1 GPa, were achieved. The finer dispersion of bainitic plates (higher density of interfaces) of the order of few tens of nanometers, results in high strength and ductility which is important for engineering applications such as in rail, defence and automotive sectors.

The contemporary research focuses mainly on higher carbon (> 1 wt.% C) and lower heat treatment temperatures to achieve bainitic microstructure. However, higher carbon concentration in steel proves to be detrimental during welding due to formation of martensite. Therefore, a novel alloy composition is designed to alleviate the drawbacks of the contemporary bainitic steels by selecting a lower carbon concentration. Composition of the alloy with the desirable characteristics mentioned above and with a possibility for its use in making nuclear reactor pressure vessel is 0.25C-2.06 Mn-0.91Ni-1.39Si-0.25Mo-0.33Cr-0.025V (wt.%). In the initial stage, a 10 kg ingot of the above composition was produced at DMRL, Hyderabad.



Forged ingot of low alloy steel

Upsetting (50% deformation) of the as-cast ingot was carried out by forging at 1200°C after homogenization for 3 h. The 2-3 mm oxide layer on the surface of the forged ingot was removed by turning. All alloying elements including carbon exhibited a homogeneous distribution.

Low alloy steels are being indigenously developed for Indian PWR pressure vessels. Low Cycle Fatigue (LCF) tests were carried out on cylindrical specimens of 6.3 mm diameter and 25.5 mm length of 20MnMoNi55 RPV steel in post weld heat treated condition. A constant strain rate of 4×10^{-3} s^{-1} was maintained in all LCF tests and test frequencies were calculated accordingly. LCF tests were performed at the total strain ranges of ±0.25%, ±0.30%, ±0.40%, ±0.50%, ±0.6%, ±0.7% and ±0.9%. Irrespective of applied strain amplitudes, stress amplitude progressively reduces with number of cycles, indicating cyclic softening. The relationship between plastic strain amplitude and the number of reversals to failure 2Nf is described by the Coffin-Manson equation. The values of fatigue ductility coefficient and the fatigue ductility exponent for the present RPV steel obtained from the experiments were 0.73 and -0.55, respectively.

An external (in air) Particle Induced Gamma-ray Emission (PIGE) method using FOTIA was optimized for rapid and non-destructive determination of isotopic composition of boron ($^{10}B/^{11}B$ ratio) in natural and enriched B_4C samples. PIGE was used for detection of Boron in large size Zr alloys. A faster and sensitive method of Prompt Gamma-ray NAA (PGNAA) was also standardized to detect total boron and ^{10}B in Zr- alloys and neutron absorbers such as B_4C.

Gun insulator for SEM (Scanning Electron Microscope), being developed by BARC as a part of indigenous SEM development program, was fabricated by brazing alumina to various metals like SS, Kovar and Copper followed by TIG welding of two ceramic-metal



Different ceramic & metallic components required for fabrication gun insulator



In-house developed SEM gun insulator

sub-assemblies. Performance of the gun insulator was satisfactory with helium leak rate of 10^{-10} Torr.lit/sec.

A set up was fabricated to convert carbon fibres into composite SiC fibres (core- carbon with SiC periphery) in continuous mode operation. The process involves passing the carbon fibres through a region of elevated temperature. Nearly 500 meter long fibre was drawn with the composite fibre retaining the flexibility of the carbon fibre.



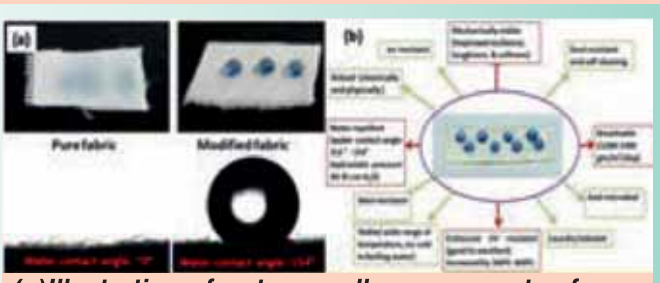
SiC Couted Carbon Fibre



Lead silicate base glass (without CeO_2) just after irradiation with different doses

Composition of Lead silicate glasses was optimised by adding B_2O_3, BaO and K_2O for use in radiation shielding. Doping the glass with CeO_2 (0.1wt.%) not only improved the transmission at lower wavelengths and made the glass harder but also lowered the radiation damage when compared to the base composition.

An electron beam assisted environment friendly procedure is developed for preparing water-repellent fabrics without compromising the breathability and mechanical properties. The procedure involves deposition of acrylate containing long-chain hydrocarbon on the microfibers followed by electron beam irradiation leading to covalent integration. This procedure generates submicron level roughness and lowers the surface energy of the microfibers and the pores of the fabric (breathability) are maintained with introduction of water repellence with various other multifunctional properties. Due to deposition of



(a)Illustration of water repellence property of pure and modified fabric (b)Multifunctional properties of modified cotton fabric

submicron scale pimples on the microfibers, the mechanical properties of the fabric are enhanced. No considerable change of water repellence was observed upon prolonged UV exposure and weather testing.

A simple, rapid, inexpensive and eco-friendly method for fabricating Super Hydro-Phobic (SHP) titanium surface using ethanolic solution of myristic acid and HCl was developed by simultaneous anodization and adsorption at IGCAR. The fast fabrication, excellent anti biofouling, chemical and mechanical stability of the developed SHP coating offers interesting applications, and also opens up new ways of creating stable super hydrophobic titanium surfaces with excellent self-cleaning characteristics. Also, a facile and industrially scalable electro spinning method was developed for super hydrophobic coating on 304L SS. Electro spinning method with optimum parameters enabled to develop a super hydrophobic coated steel surface with distinctive water bouncing effect thereby resulting in beneficial self-cleaning property, abrasion resistance, excellent chemical repellence.

An anomalous enhancement of corrosion resistance and antibacterial property of Commercially Pure Titanium (CP-Ti) surface in the presence of a uniform defect-free nanoscale (15nm) rutile titania film was discovered for the first time. The corrosion protection efficiency of nano-modified fly ash based cementitious coatings applied over reinforcement steel rebars was studied with five types of coatings. The accelerated studies indicated a significantly longer initiation time for cracking in nanomaterial incorporated coatings than the conventional cement polymer coating.

Silicone polymer-based nanocomposites containing β-Bi_2O_3 nanoparticles are successfully

prepared and characterized. The sample containing B-Bi_2O_3 and silica also exhibited the highest X-ray attenuation property, against X-rays of energies in the range of 30-66 keV.

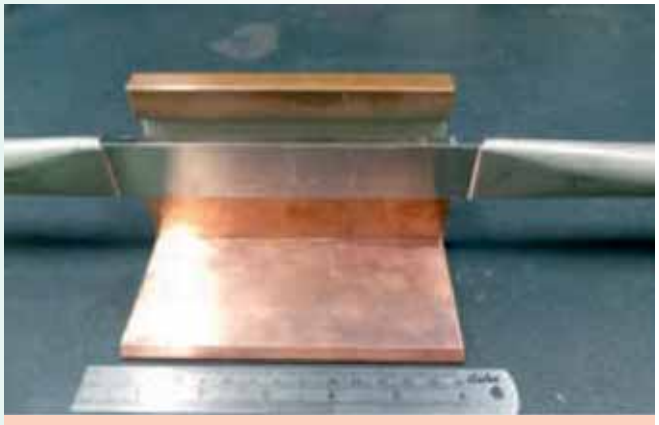
An enhanced thermal insulation of Fe_3O_4 nanoparticle by nano porous char layer formed during thermal decomposition of Fe_3O_4@carboxymethyl cellulose is demonstrated for the first time. In situ high temperature XRD results showed that the Fe_3O_4 core is stable up to 1000 °C due to the presence of a porous char shell. The presence of nanopores in the char layer of thickness 7 nm was evident in HRTEM images.

The first experimental evidence for soft glassy behavior in a sterically stabilized magnetic colloid (ferrofluid) when a uniform magnetic field is applied at a sufficiently high rate is demonstrated. Fast magnetic-field quenches favor structural arrest of field induced aggregates, owing to insufficient time to settle into lower energy states, thereby pushing the system to a frustrated metastable configuration like a repulsive glass.

The basic Focused Ion Beam - Scanning Electron Microscope (FIB-SEM) dual beam system, conventionally used for milling and imaging was transformed into a powerful tool for mask less single-step nanofabrication. Incorporation of a multichannel gas injection system transforms the FIB-SEM system as a single-step mask less lithography tool via deposition and etching at nanoscales. Further controlling the ion and electron beam by a high-speed and high-resolution pattern generator, enabled writing complex patterns at much faster rates and larger area patterns up to mm scale. Examples demonstrating single-step mask less deposition (bottom-up approach) and milling (top-down approach) abilities of the system is shown in Fig. 48. The advantage of this system is that it does not require an ultra-clean and smooth surface for writing. Any solid surface including non-conducting materials could be patterned. In addition to nanofabrication works with inorganic materials, FIB-SEM system is also used to investigate various biological materials including human cells in analyzing their structures via slicing and imaging so that structure could be understood three dimensionally.

A transient eddy current NDE (Non-Destructive Evaluation) system has been developed with the combination of fluxgate magnetometer and double “D” excitation coil. In conventional frequency domain NDE, the skin depth is the limiting factor due to the single frequency excitation. In contrast, in the transient eddy current NDE, the eddy currents are induced in the form of transients and decay with time. The decay of the eddy current is measured in time which consists of continuum of frequencies and hence the entire thickness of the conducting material could be investigated in a single shot. The defects located near the surface as well as in deeper layers of conducting materials can be measured simultaneously. The schematic view of the experimental setup and the changes of the secondary magnetic field recorded by the fluxgate with respect to positional coordinates for the defects located at different depths have been shown.

Towards the fabrication of direct current conduction pumps for sodium pumping in the auxiliary sodium circuit of Fast Breeder Reactors, an insulating structurally stable multi-layer composite ceramic coating, having high electrical resistance and thermal fatigue endurance withstanding >1000 thermal cycles (200-600 C), consisting of NiCrAlY bond coat, 30 wt% NiAl-70 wt% Al_2O_3 interlayer of intermediate thermal expansion coefficient and $55A_l2O_3$:$45Y_2O_3$ top layer, is made on oxygen free electronic copper bus bar using air plasma spray. The coatings cross section before and after 1000 thermal cycles revealed stable crystal and micro-structures. Uni-axial tensile test conducted before and after thermal cycling, showed excellent coating adhesion. The 20% drop in adhesion strength after 1000 thermal cycles is not detrimental, as the coating does



Fabricated Pump Core

not experience any mechanical loading during pump operation. The electrical resistance of the coating before and after thermal cycling was found to be 10^{12} Ω and $1O^{10}$ Ω respectively and no electrical break down observed up to 600 V DC. Sodium carrying SS duct was brazed, using a novel Ni based braze material, onto the multi-layer coated bus bar, with a joint tensile strength of 44 MPa , and the pump core was fabricated. The system is being tested in auxiliary sodium circuit.

Bi_2Se_3 -based Topological Insulators (TI) are exotic materials in which two-dimensional (2D) surface states exist within the insulating band gap of a 3D bulk crystal. Interestingly, the 2D states in TI are spin polarized and immune from backscattering which makes these systems more promising candidates for application in spintronics and quantum computing. However, the 2D contribution is often masked by excess charge carriers due to the unintentional defects, impurities, antisite disorders and vacancies states in bulk. To circumvent this problem, we resorted to grow thin films of Sb-doped Bi_2Se_3 topological insualtor with nominal composition $Bi_{1.95}Sb_{0.05}Se_3$ using a pulsed laser deposition system at different deposition pressures of Ar (0.002 Pa vacuum, 4 Pa Ar, and 50 Pa Ar) and different substrate temperatures. With increase in deposition pressure, a striking three order decrease in carrier density has been recorded and with additional control through the substrate temperature a carrier density value as low as 2×10^{18} cm^{-3}, typical value for a TI, has been observed. The magneto-transport studies performed on the films reveal a sharp cusp like feature of magneto-conductance (G) vs. magnetic field (B) in Tesla (T) which is indicative of Weak Anti-Llocalization (WAL) behavior. The obsevance of WAL is a characteristic feature of 2D surface states in topolgical systems. The present study provides an alternate recipe to prepare good quality TI films preserving 2D character.

High resolution Rutherford Backscattering Spectroscopy (Hi-RBS) is a proven technique for analysis of thin films with a sub nanometer (0.1–0.2 nm) depth resolution.. A block diagram representation of the Hi-RBS system is shown, IGCAR developed and established a personal computer based indigenous instrumentation hardware and LabVIEW based software for automation of multiple sample ion implantation, standard Rutherford Backscattering spectrometry, and Hi-RBS experiments. This involves control and measurement of ion beam fluence and sample positions, controlled collection of back scattered particles and their yields, online display of energy spectra and its auto storage, and vacuum interlocking, etc. Satisfactory field performance of the system was established using Si samples with 1–2 MeV H^+ and He^+ ion beams. Hi-RBS carried out on a 3 nm thick Ag film grown on Si substrate with 0.3 MeV H^+ ion beam showed well separated Si edge and Ag peaks in the energy range of 200–300 keV, an energy resolution and relative energy resolution (ΔE/E) of 1.2 keV and 0.4% respectively were shown. The automation has greatly improved experimental throughput, reduced the work load, improved the performance in terms of efficiency, precision and accuracy besides amenability to easy integration of other ion beam analysis experiments.

At RRCAT, an early arc detection system based on indigenously made GaAs PIN photodetectors is developed. The system is deployed in an indigenously developed Radio Frequency (RF) circulator to work as a safety device. A dual element based balanced



Single element based early Arc fault detection System



Dual element based balanced photodetector system developed for laser spectroscopy

photodetector unit, consisting of two identical photodetectors on the same chip, is also developed and deployed in laser spectroscopy experiments. Both the systems are in regular use at RRCAT.

GaAs photodetectors find interesting applications in X-ray region of electromagnetic spectrum due to their radiation hardness along with a high photon absorption efficiency when compared to Silicon. Silicon detectors are not ideal for X-ray applications in 20–100 keV range since Silicon has quite a low absorption above 20 keV. In view of this, GaAs based PIN photodetectors with very thin p-GaAs layer are indigenously developed. The complete device structure is grown by Metal Organic Vapour Phase Epitaxy (MOVPE) technique. X-ray detectors are then fabricated and are successfully tested against laboratory based CuK X-ray source. The energy-dependent X-ray response of GaAs PIN detectors is also measured by using a monochromatic X-ray beam with energy varying from 8 to 25 keV at BL-2 beamline of Indus-2 Synchrotron radiation source. It confirms the suitability of indigenously developed GaAs detectors over a wide x-ray spectral range. Efforts are in progress to further extend the spectral response of X-ray detectors. Such detectors are attractive for medical imaging applications.



An indigenously developed GaAs based X-ray prototype detector along with its spectral response

The impact of radiative and non-radiative processes on the photovoltaic response of GaAs/AlGaAs multiple-quantum wells is investigated by temperature, excitation power, and chopping-frequency-dependent Surface Photo-Voltage (SPV) measurements. It is shown that a systematic study of SPV amplitude along with phase spectra can provide important information on thermal escape, carrier localization, and spatial redistribution of charge carriers. Characteristic features in SPV-phase spectra related to Quantum Well (QW) transitions and their variation under an external perturbation are explained by the electron–electron interaction. From the chopping-frequency-dependent SPV measurements, it is concluded that carriers during the drift in barrier layers are repeatedly captured by point defects and other QWs, which enhances the effective time response of the photo-voltage signal. Results obtained in this study are beneficial in the engineering of quantum structures for high-efficiency photovoltaics and non-invasive characterization of electro-optical processes.

Micro-cavity structures are grown by MOVPE by placing a Quantum Well (QW) in between two high reflecting distributed Bragg reflectors separated by $3\Lambda/2$. The QW is placed carefully inside the cavity so that the excitons can couple with the standing wave formed by the luminescence light. Well defined splitting in the luminescence spectra is observed for the case, when the QW is placed at one of the anti-node of electric field, indicating finite coupling between exciton and photon.

Spin dynamics of electrons in the X valley of $Al_xGa_{(1-x)}As$ is explored by measuring the degree of circular polarization of luminescence arising from adjacent GaAs QW. Experiments are conducted for two different sample, one with x=0.26 (direct band gap) and another with x=0.63 (indirect band gap). Same polarity

of luminescence following photoexcitation with energy (Eex) ≈Eg and Eex ⩾ Eg + ΔSO is identified as one of the signatures of electrons being captured in the X-valley of AlGaAs. Optical spin orientation is also observed by exciting higher energy levels inside the QWs. Detail analysis are in progress.

Piezoelectric Ultrasonic Transducers (PUT) have emerged as promising candidates in Non-Destructive Techniques (NDT) to inspect passive components of nuclear reactors. Herein, sensitivity, response and detection limit of PUT devices largely depend on material properties of thin films possessing piezoelectric response. In this context, a thin film hetrostructures Metal/AlN/Metal PUTs with its inherent piezoelectric integrity at high temperatures (2800 ºC) is aimed to be developed as an alternate to lead Zirconate Titanate (PZT) based PUTs used in nuclear environments. First step towards the fabrication of such PUTs is the choice of metallic electrodes which serve the purpose of electrical biasing of PUTs. Due to its low resistivity and high acoustic velocity, molybdenum (Mo) can be considered as an efficient electrode material for the fabrication of thin film PUTs. As the work function is one of the fundamental electronic properties, variation of which decides the direction of current flow at metal/piezoelectric interface, work-function anisotropy across the electrode surface must be investigated carefully at nano-scales. Keeping this in consideration, Mo-thin films were deposited at different RF-powers varied as 25 W, 100 W, and 200 W, while other parameters were maintained at same values. Grazing Incidence X-Ray Diffraction (GI-XRD) and Amplitude Modulated Kelvin Probe Force Microscopy (AM-KPFM) investigations revealed that the films deposited at 200 W were predominantly constituted by crystalline Mo (110) grains possessing an average work function ~4.94 ± 0.06 eV, which is closed to that reported in the literature. The genesis of distinct periodic changes in work function is attributed to the formation of the surface dipole layer associated with the adsorbates of different polarities (O_2^-/OH^- or H^+). A phenomenological model is also presented to elucidate their effect.

By injecting Rb-vapor through a glass nozzle into the chamber, a simple and compact setup for loading a Magneto-Optical Trap (MOT) for ^{87}Rb atoms in an Ultra High Vacuum (UHV) environment (3.5 ×10^{-9} Torr) has been developed. This design is a compact design for MOT loading in UHV environment, without the need of complicated options requiring Zeeman slower device or double-MOT setup.



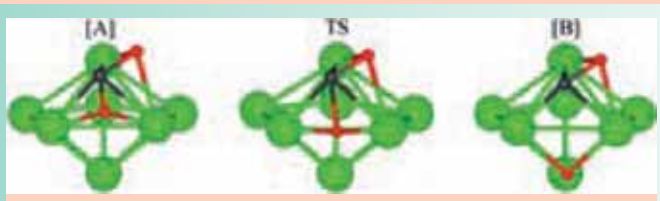
The magneto-optical trap setup



Actual photograph of MOT setup with new configuration

A single laser operated Magneto-Optical Trap (MOT) has been assembled using a new vacuum chamber with laser beams in [1,1,1] geometry. This geometry is more suitable for launching the cold atoms fountain for gravity measurements experiments. In this configuration, three pairs of counter propagating MOT beams are aligned at 45 degree from vertical direction such that vertical direction is kept free for launching atoms.

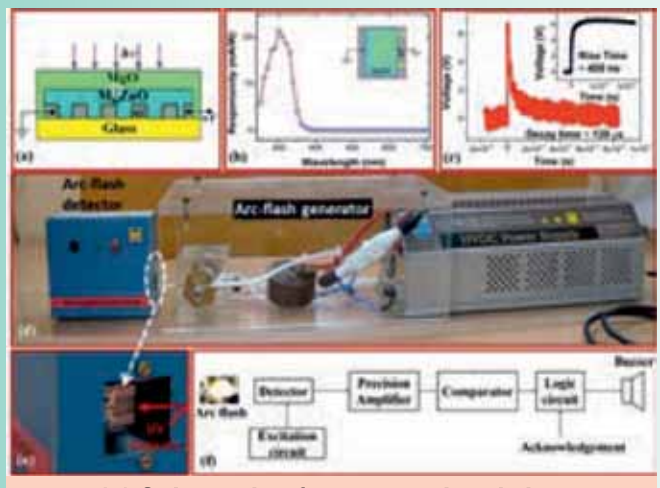
The reactivity of small sized zirconium clusters (Zrn, n = 2 -7) towards adsorption and activation of



Optimized structures of reactant ([A]), TS, and dissociated product ([B])

carbon dioxide (CO_2) molecule has been investigated by employing first principles density functional theory based method. It has been found that the zirconium clusters are very reactive towards the adsorption and activation of CO_2 molecule, and these clusters may serve as highly efficient catalyst for the hydrogenation of CO_2 to useful fuels.

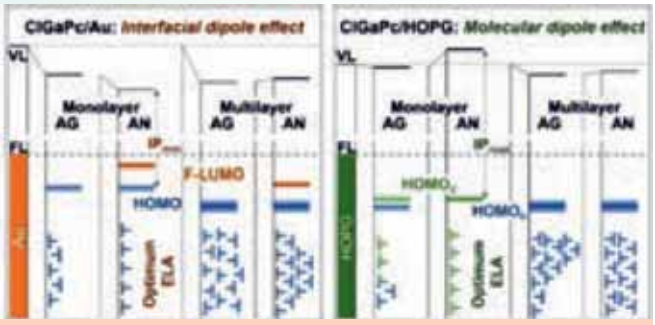
Visible-blind UV photodetectors have been developed in-house using $MgxZn_{1-x}O$ thin film based metal-semiconductor-metal devices with interdigitated metal (Al and Pt) electrodes. The optimized $Mg_{0.15}Zn_{0.85}O$ MSM UV photodetectors showed characteristics such as UV to visible rejection ratio 2.7×104; Responsivity 20 mA/W at 310 nm; ON/OFF ratio ≥ 10^2 ; Cut-off wavelength 350 nm and Photocurrent rise and fall time 400 ns and 139 μs. The picture (a,b,c) present cross sectional view of device, spectral responsivity and temporal response of $Mg_{0.15}Zn_{0.85}O$ based MSM photodetector, respectively. The $MgxZn_{1-x}O$ based visible blind UV photodetectors have been successfully utilized to develop a prototype version of hand-held arc-flash and fire detection system as shown in picture (d). The close view of UV photodetector and block diagram of arc-flash detection system is shown in picture (e) and (f), respectively.



(a) Schematic of cross sectional view (b) spcetral responsivity (c) temporal response of Mg0.15Zn0.85O MSM UV photodetector, (d) image of arc-flash detector test setup, (e) close view of UV photodetector in arc-flash detection system, and (f) Block diagram of arc-flash detector

Understanding the interactions of drugs with Lipid membranes, the appearance of different anisotropic nanostructures in chemical synthesis the influence of finite size and image charge screening on the antiferromagnetic ordering, the effect of oxygen content and crystallization temperature on the insulator-to-metal transition properties of metal oxide thin films, etc. are some of SINP's current activities under materials science.

The interfacial and molecular dipole moments in the monolayer on Au and HOPG substrates, respectively, creates the optimum Energy Level Alignment (ELA) for both the systems, while the opposite shift of the Vacuum Levels (VL) in two different substrates makes the Ionization Potential (IP) for such a monolayer either minimum (on Au) or maximum (on HOPG), which is useful information for tuning the charge injection across the interface in organic semiconductor-based devices.



Tuning electronic structure of metal-organic interface for improved charge injection

Nanofibers of conjugated polymer can be formed due to combination of solvent vapour and thermal annealing, that can improve the Edge-on Oriented (EO) ordering both near and away of the substrate. Such improvements, which are probably through the alignment and growth of nanofibers, promoted by combined annealing induced diffusion, are of immense importance for obtaining better device properties.

In a recent study at TIFR, the Nanoelectronics lab in TIFR found a novel route to generate and detect a

chargeless valley current. Valleys represent energetically degenerate but structurally distinguishable points in the band structure of a material. Engineering systems that can carry valley current has remained a big challenge, and very few systems thus far have been shown to host such a current. The team was not only able to generate and tune this current in a new engineered 2D system but also showed that the underlying bands that host these currents are of topological nature.

INTERDISCIPLINARY AREAS

Development of Digital Current Integrator

The current integrator is an important imported instrument used by the experimental physicists for measuring the total dose received by the target during an experiment. The dose is measured in terms of total electrical charge deposited by ion beam on the target. The instrument also displays the instantaneous beam current which is used by the accelerator operators for optimization. There is high requirement of this instrument among the accelerator user community. In view of the above, an advanced version of Digital Current Integrator has been designed and developed to measure the DC beam current or average value of pulsating beam current and then integrate it to measure total charge value for accelerator facilities. The instrument can measure bipolar currents ranging from 50pA to 100μA with an accuracy of <0.5% (of reading). All the five input ranges, having full scale value from 10nA to 100μA, are auto-selectable according to instantaneous current value. Other than a large LCD to display the current and charge with high accuracy, an analog meter on the front panel also displays the scaled input current whose full-scale value (similar to selected range) and polarity is shown on LED array. This advanced instrument is equipped with RS232 port, by which parameters can be monitored or configured from a remote location through predefined command set and also with 32 bit (9.5 digits) counter for integrating charge for each range. VECC has taken up stride towards indigenous development of state-of-the-art self-reliant integrated circuits from design to fabrication within India to cater to the requirements of the institute along with an initiative in realizing the ambition of Atmanirbhar Bharat and successfully designed and developed two Application Specific Integrated Circuits (ASIC) for the deployment in nuclear physics research and radiation monitoring.



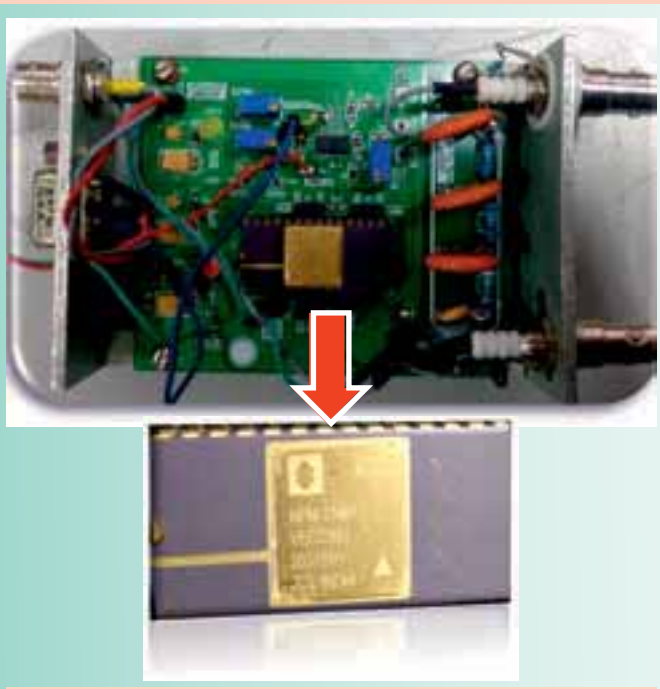
The digital current integrator

Development of multichannel ASIC towards self-reliant India in the field of electronics for frontier nuclear physics research

VECC has indigenously designed and developed a multichannel ASIC fabricated at Semiconductor Laboratory (SCL), Chandigarh which houses the only deep sub-micron CMOS fabrication facility in our country. GMDA ASIC would be deployed in front-end electronics for hundreds of detectors in particle tagged gamma spectroscopy for carrying out frontier nuclear physics research. This successful effort of self-reliant development of integrated circuits within the country will not only lead to development of electronics within the department as import substitution in the field of electronics, it will also ensure the development of state-of-the-art electronics for other spin-off technologies within the country itself.

Development of electronics module to measure neutron radiation using self-developed ASIC- an effort towards Aatmanirbhar Bharat

Neutron Flux Monitor (NFM) plays an important role in the safety of accelerator and reactors by sensing the neutron flux at suitable locations and safety actions are actuated on crossing the threshold. VECC has indigenously designed and developed an ASIC for the most critical part of this module and also developed the complete module for deployment with Boron Trifluoride (BF3) detectors. The fabrication and packaging were carried out at Semiconductor Laboratory (SCL), Chandigarh.



NFM Module and NFM ASIC

Development of Prototype Unmanned Aerial Vehicle

Two prototype quad-copters have been developed in VECC, Kolkata with the envisaged applications ranging from perimeter surveillance to Atmospheric Radiation Mapping etc. Both the Glass Fibre and the Aluminium 'X' frame vehicles have a payload capacity equal to their own weight. The prototype vehicles can operate in two modes manual and autonomous. In manual mode, the quad-copter is operated manually from a Remote Control and in autonomous mode, it can fly along a predefined GPS path. In both Manual and Autonomous Modes, safety failsafe safety features have been incorporated.



Development of Prototype Unmanned Aerial Vehicle



Development of an Enhanced Version of Handheld RFID Reader

Development of an Enhanced Version of Handheld RFID Reader

Prototype of an enhanced version of Handheld RFID reader (Figure 1) for attendance recording has been developed and tested successfully. The system has been specially designed to recognise only DAE issued ID card. The local LCD displays the information related to card swipe and system status. A GUI program on the local PC receives the data and displays the relevant information along with his/her image and uploads the same in the database. In case of Bluetooth communication failure, the information is stored in the local micro SD card. On restoration of the communication, it transfers the information. It has a real time clock synched with the NTS. After a full recharge, it can operate approximately 24 hours.

Development of Prototype Employee Face Recognition System for Access Control

A prototype face recognition system has been developed using state of the art of Artificial Intelligence



Face Recognition System in action

Tools. Pre-trained Deep Convolution Network has been used to extract facial features of the input image of an employee. The same features for the employees of VECC are precomputed based on their identity card photographs and stored in a database. Whenever a person stands in front the camera, the recognition system searches for the nearest match of features of the face of the person in front of the camera and the features stored in the database. In case there is a match the name of the person is displayed on screen otherwise it is declared that the person is "Unknown".

Durability has been a long-lasting concern for halide perovskite-based photovoltaics. At TIFR, in this work, high-resilience perovskite solar cells, based on formamidinium-cesium lead-trihalide perovskite absorber, have been demonstrated by incorporating a piperidinium-based ionic compound into the absorber layer. This piperidinium additive enhanced the open-circuit voltage and cell efficiency. The bandgap of the perovskite material makes is suitable for perovskite-on-silicon tandem cells.

INTERNATIONAL RESEARCH COLLABORATION

The Higgs boson (H), discovered in 2012 by the ATLAS and CMS experiments, is the pinnacle of the scientific results obtained so far from the CERN-LHC. The experimental measurements are compared with predictions from the Standard Model (SM), to vindicate it or to look for hints of physics beyond SM, nature of which is yet unknown. Using proton-on-proton collision data at centre-of-mass energy of 13000 GeV and collected by CMS experiment during 2016 through 2018, the CMS international collaboration recently derived the best constraint on the value of Λ to date. These results are extremely encouraging to pin down the nature of H.

VECC has been participating in design & development of the muon chambers (MUCH) for the Compressed Baryonic Matter experiment at the upcoming FAIR facilities, at Darmstadt Germany. The experiment will explore the medium at high net baryon density likely to be created in heavy ion collisions at FAIR. Such high density is said to be existing at the core of neutron star. The MUCH system at CBM will encounter an interaction rate of 10MHz thereby requiring detectors to cope with a particle rate of 400 kHz/cm2 to 4 kHz/cm2 as per the location from the target. Two advanced detector technologies have been decided to be installed as the detectors for MUCH. They are Gas Electron Multiplier (GEM) and high rate Resistive Plate Chamber (RPC). Over last one year VECC has made significant progress in R&D of both detector systems and associated services like HV, LV and Control software.

Data taking in the mini-CBM experiment

Two large size GEM chambers suitable for use in the 1st station of MUCH have been installed and took data with Pb^{206}, Pb^{208} & Bi^{209} at 1.075 AGeV with different intensities. The service and data acquisition system used is same as to be used in the main CBM setup. The data taking continued even during the lockdown period when VECC team participated remotely in controlling the experiment. Detailed analyses have been performed

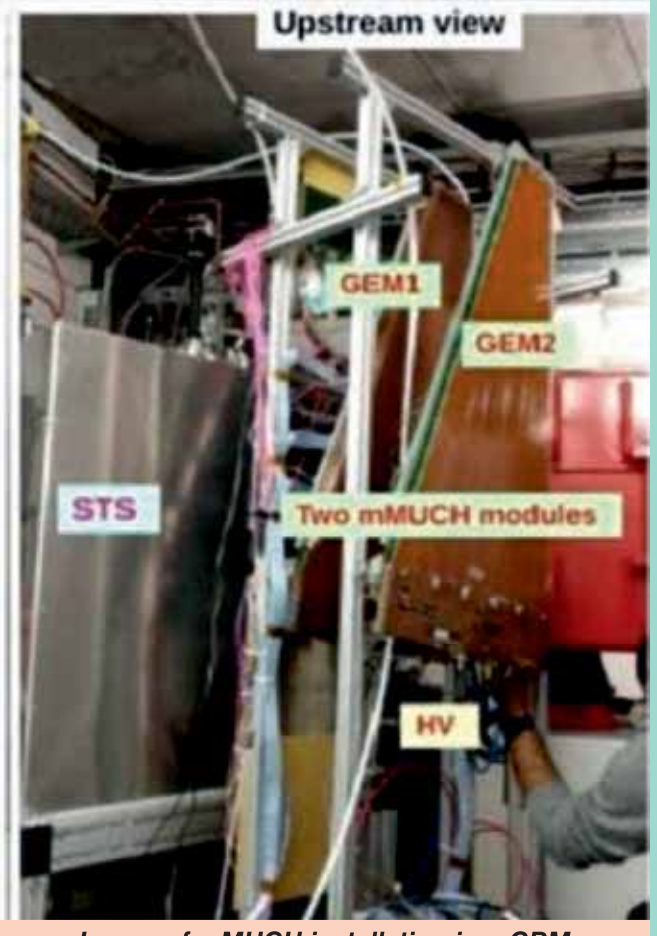


Image of mMUCH installation in mCBM



18-channel Radiation hard Low Voltage Distribution board with fault tolerant spartan-6 FPGA based control and monitoring board

and figures show the prominent results that represent the successful operation of the chambers.

Design and development of radiation hard fault tolerant low voltage distribution system for CBM-MUCH detector system to be installed at CBM experiment

Radiation hard 18-channel Low Voltage Power Supply (LVPS) module with over current sense and trip circuitry for individual channel is designed and developed at VECC for the CBM-MUCH. To control and monitor this LVPS a fault-tolerant firmware against radiation dependent errors had been developed using a Spartan-6 series FPGA board. The python based control scripts were developed which can be further integrated to EPICS based control system for final DCS of CBM. The design was tested in mCBM experiment and found to be working satisfactorily. The Conceptual Design Review (CDR) was done by the CBM Technical board and it passed the review successfully.

Development of Resistive Plate Chamber for the CBM Experiment at FAIR

VECC has tested the performance of a prototype bakelite RPC equipped with self-triggered front end electronics (MuCh-XYTER 2.0) for the CBM Muon Chamber. It is a 30 cm x 30 cm bakelite RPC with 2 mm gas gap, and the bulk resistivity of bakelite plates were 4 x 10^{10} Ω-cm. The prototype has been tested at a cosmic ray test bench at VECC and with muon beam in presence of photons at the GIF++ facility at CERN. The detector has shown 96% efficiency of detecting muons with high intensity muon beam and the efficiency reduces somewhat in the presence of photons. As the self-triggered electronics MuCh-XYTER is highly prone to noise, several efforts have been made to reduce the noise to operate the detector at lower threshold. Among them, most important changes were the introduction of a low pass filter in the high voltage line of the detector to block the AC noise, an EMI shielded copper box to put the detector inside, a common grounding scheme between the electronics and detector readout as well as the copper box, increasing the distance between the ground plane and the signal plane for reduction of the capacitance. As a result of all these efforts, the threshold could be reduced to 12 fC in some PCB as opposed to 50 fC used at GIF++. The chambers have been found to work efficiently upto a hit rate of 6 kHz/cm2 and efforts are on to improve both the rate capabilities and Signal to Noise Ratio (SNR).

At IGCAR, Indo-UK collaborative project on Sodium Boiling and Aerosol Dynamics in Liquid Metal cooled Fast Breeder Reactor (LMFBR) has been initiated with prime objective of investigating sodium boiling phenomena towards analysis of postulated partially blocked fuel sub-assemblies in LMFBR. The main thrust is to investigate boiling characteristics including bubble departure diameters, release frequencies and nucleation site aerial densities. It is proposed to develop and validate computational models for sodium boiling. Experimental and Large Eddy Simulation studies on Aerosol characteristics and dynamics in the cover gas region are being carried out under argon and sodium aerosol flow field conditions. Influence of bi-polar charging conditions on aerosol nucleation and condensation will be studied.

An experimental setup with Inconel test section and specially designed heater has been designed, fabricated and installed for studying incipient boiling phenomena in stagnant sodium. An X-ray unit is integrated with the setup for bubble imaging.



Experimental setup for sodium boiling and X-ray images of water bubbles

Simulation experiments were conducted by generating water bubbles and mapping their movement in liquid medium.

RRCAT plays a major role in the development of power converters for Facility for Antiproton and Ion Research (FAIR), Germany, which is a major Indian in-kind contribution to the FAIR project. In addition to the delivery of 73 nos. of RRCAT-designed 300 A power converters to FAIR during the last year, additional 6 power converters of the same type and 48 nos. of four-quadrant, 100 A power converters designed and prototyped at RRCAT, were manufactured and tested at ECIL, Hyderabad and delivered to FAIR, Germany during this year, thus, taking the total number of delivered power converters to 127. The total 'deviation' allowed in the output current of these power converters for FAIR is ± 100 parts per million (ppm).



Photograph showing the 300 A power converters



100 A power converters for FAIR

The experimental high energy physics groups at IOP continued to participate in the collider-based experiments at various international laboratories, such as CMS and ALICE experiments at CERN-LHC, STAR experiment at RHIC, BNL (USA), and the proposed CBM experiment at FAIR, GSI (Germany). The groups contribute to the studies of the properties of the observed Higgs boson and searches for beyond the Standard Model particles in proton-proton collision events at LHC as well as the studies of Quark-Gluon plasma, a state of matter in the early universe, which are recreated in heavy-ion collisions. Furthermore, the groups contribute to the R&D of state-of-the-art detectors for future experiments.

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.

Start of ITER machine assembly

In line with the 2016 Baseline schedule of the International Thermonuclear Experimental Reactor (ITER), machine assembly activities started at the ITER site in France. The first major step was the installation of the base section of the cryostat supplied by India in the tokamak pit. A worldwide telecast ceremony, organised on 28th July 2020 to mark the occasion, was addressed by the French President and included messages from the Heads of State/senior leaders of all the ITER participating nations. The address from the Hon'ble Prime Minister Sh. Narendra Modi was read out by the Indian ambassador to France, Shri Javed Ashraf.

Completion of cryostat manufacturing activities in India

The manufacturing of the cryostat activities at M/s L&T Hazira came to an end with the last shipment of the Top Lid segments commencing its journey to ITER. A ceremony organised at M/s L&T Hazira on 30th June 2020 was addressed by Dr. V.K. Sarawat, Member NITI Aayog, Shri K.N. Vyas. Chairman AEC and Secretary DAE, Dr Bernard Bigot, DG ITER Organisation, Dr. Shashank Chaturvedi, Director IPR, Shri Ujjwal Baruah, Project Director ITER India and senior officials of M/s



Clockwise from top : The ceremony at M/S L&T Hazira to celebrate the successful completion of manufacturing activities of cryostat in India, the top lid segments ready for shipment to ITER, the First of kind component 2020 award to cryostat team and the lower cylinder of the cryostat being placed on the cryostat base section

L&T. Another major achievement included the successful placement of the base section of the cryostat in the tokamak pit within tolerances, pointing to the high quality of manufacturing standards achieved during the fabrication of these first-of-a-kind components in terms of their size, shape and compliance with nuclear safety standards. This was followed by the placement of the lower cylinder on top of the base section of the cryostat.

Completion of manufacturing activities for in wall shielding blocks



Clockwise from top ; The ceremony at M/S ATL to mark the completion of the manufacturing activities of in wall shield element assemblies, the CAD model of the shield assembly, the shield elements manufactured by ATL and fitted in the vacuum vessel sector at Korea and the final consignment leaving the premises of the ATL factory

This year also marked the completion of manufacturing activities related to the In-Wall shield components in India. A video televised ceremony at the works of M/s Avasarala Technologies was held on 6th August 2020. The gathering was addressed by Dr. Anil Kakodkar, ex-chairman AEC and Secretary DAE, Shri K.N. Vyas, chairman AEC and secretary DAE and Dr. Bernard Bigot, DG ITER Organization.

99% deliveries of the cooling water systems

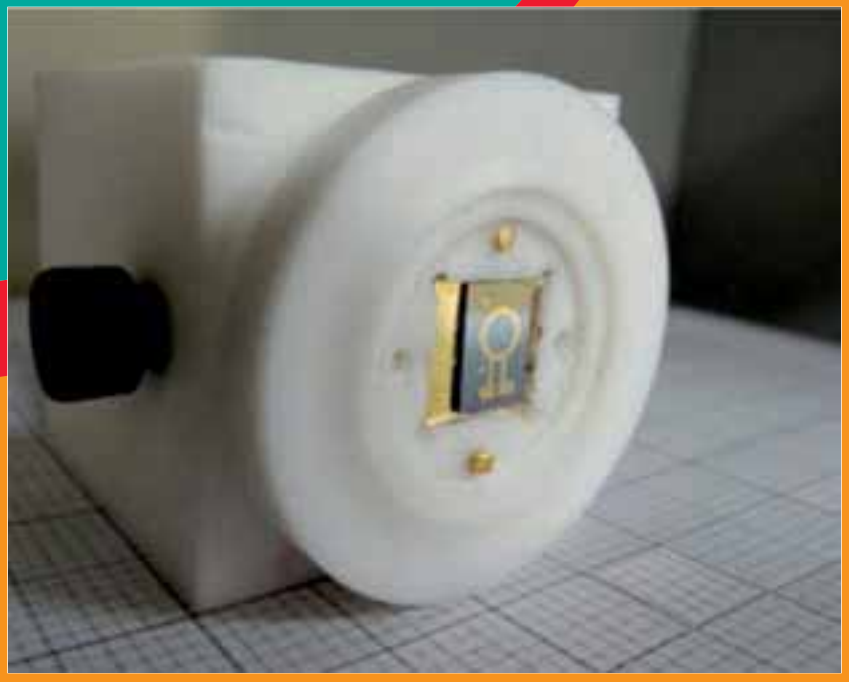
Substantial progress in the fabrication and delivery of the cooling water components to ITER has been achieved with the last consignment of the piping spools on its way to ITER. With this, 99% of the deliveries have been completed.



A bird's eye view of the CWS Installation and integration activities at ITER site

CHAPTER

6



An indigenously developed GaAs based X-ray prototype detector along with its spectral response

RESEARCH EDUCATION LINKAGES



Actual photograph of Magneto-Optical Trap (MOT) setup with new configuration

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

The human resource and knowledge management is developed through Homi Bhabha National Institute (HBNI), BARC Training School and the Administrative Training Institute (ATI).

The Board of Research in Nuclear Sciences (BRNS) an advisory body of the Department of Atomic Energy (DAE) provides financial assistance to universities, academic institutions and national laboratories for encouraging and promoting scientific research in the areas of relevance to the mandate of DAE.

The National Board for Higher Mathematics (NBHM) established under the aegis of DAE promotes excellence in higher Mathematics education and research in the country. The Board also provides grants for promotion of activities in pure and applied Mathematics under several schemes including support to research projects, travel grants for participation in workshops, conferences and undertaking collaborative research funds for organizing conferences etc.

HUMAN RESOURCE DEVELOPMENT AND KNOWLEDGE MANAGEMENT

Homi Bhabha National Institute

Homi Bhabha National Institute (HBNI), a Deemed to be University, is a grant-in-aid institute of the Department of Atomic Energy (DAE). It has successfully completed 15 years. During this period, it has established itself as one of the best research universities in the country, encouraging research in various facets of nuclear science and technology including mathematics. HBNI was placed in the 14th position in the Universities category, in the 2020 NIRF exercise. Based on high-quality publications during the calendar year 2019 in 82 Journals of high impact, the Nature Index 2020 has placed HBNI in the fourth position, among all institutions in India and in the top position among all institutions with regard to publications in the discipline of physical sciences.

The academic programs of HBNI are leading to Human resource development not only in core areas of nuclear sciences and engineering but also in several other areas of societal importance such as medical and health sciences. During the period January to December 2020, HBNI awarded 81 MD degrees, 24 DM and 22 MCh degrees, contributing significantly to the number of specialists in medical oncology in the country. Till December 2020, HBNI has awarded 1730 PhD degrees in a variety of disciplines.

In order to run academic processes smoothly in the time of pandemic, several measures were taken by HBNI. A new website, http://www.anuvidhya.in was launched by HBNI in the month of May 2020. The website allows for online submission of fee and all the documents required for issue of Provisional Degree Certificate (PDC) viz., soft copy of the thesis, alumni form and feedback form by the students. Processing of all the documents for result declaration is being done through online approvals, i.e. by e-mail transactions. HBNI has conducted several webinars by eminent scientists over WebEx platform for the benefits of its research scholars and students across all CIs/OCC during the period June'20 to December'20. The power point presentations of the listed webinars are available on website, www.anuvidhya.in. HBNI webinars are also streamed live on its recently launched YouTube channel (HBNI Webinar) and recordings of webinars are available on the channel for the benefit of students/faculty across all educational institutions in India and abroad.

An online course on “Neutron as Probe of Condensed Matter” is being conducted by HBNI presently which started on September 5, 2020. Thirty-five students from variety of educational institutes across the country as well as abroad are regularly attending the course.

The Foundation Day of Homi Bhabha National Institute was celebrated on June 3, 2020 in virtual mode due to the lockdown imposed because of COVID-19 pandemic during that time.

Training School

Human Resource Development Division (HRDD) of BARC mainly fulfills its mandate through BARC Training School (BARCTS), established in 1957 in Mumbai. It has 4 more Training Schools at - RRCAT, Indore (since2000); NFC, Hyderabad (since 2001); IGCAR, Kalpakkam (since 2006); and AMD, Hyderabad (since 2010). They provide highly skilled human resources to DAE through two flagship programmes–OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). Under OCES, the 1-year academic programme at each BARC TS is designed to fulfill course requirements for an MTech, MPhil or PhD degree of HBNI (Homi Bhabha National Institute). This linkage of BARCTS programmes with HBNI ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various units of DAE, and thus helping it to fulfill its main mandate to enhance share of nuclear power in the country and to contribute to national security.

While the academic programme of the 63rd batch was continuing, screening examination for 9 engineering and 5 science disciplines for the 64th batch was organized at 73 online test venues spread across 45 cities during March 13-18, 2020. However, during the last two days as there were local restriction imposed, especially in the State of Kerala and a few places in Maharashtra, to control spread of Covid-19, an additional online exam was conducted during October 30 to November 2, 2020 at 44 online test venues spread across 22 cities. All eligible candidates numbering 55, 803, who could not appear in the March exam for whatever reason(s), were permitted to appear in this exam and a total of 6,771 candidates appeared.

The number of online applicants for OCES-2020 was 1,21,332 as compared to 1,40,622 last year. Of them 71,341 candidates appeared in the online examination as compared to 83,003 in the previous year. A total of 2,449 candidates were shortlisted for the selection interview. This consists of 1573 candidates shortlisted on the basis of online examination score, 837 on the basis of GATE score and 39 from CBS and NISER. Interviews for selection of candidates for OCES/DGFS-2020 were scheduled during December 1 to 30, 2020. A total of 199 candidates have been selected for OCES-2020.

Fig. 3: Discipline wise total selection of candidate for OCES-2020

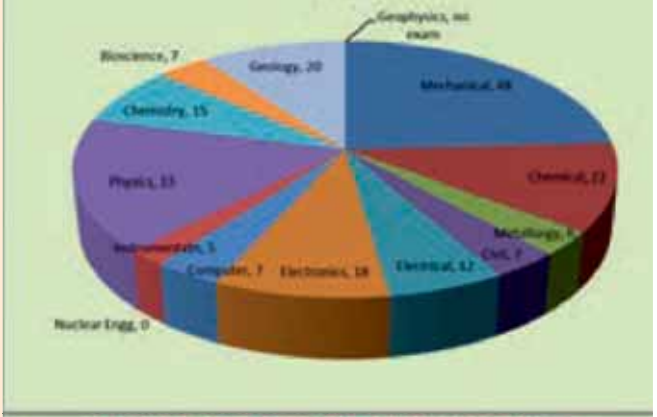
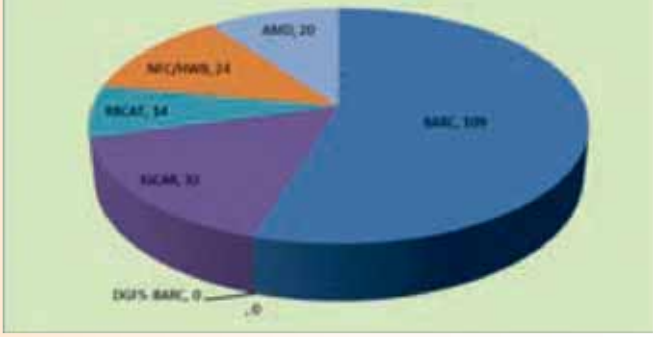


Fig. 4: Number of selected OCES-2020 candidates for various BARC Training Schools



Induction schedule for 64th batch is inordinately delayed. However, with the completion of online exam process in 1st week of November, and selection interviews on 30th December 2020, HRDD is now hopeful of commencing the OCES-2020 course work.

A total of 102 graduating TSOs as compared to 74 last year, were placed in various units of DAE. There were 6 Trainee Defence Officers (TDOs) who passed out were assigned to different Divisions/Units for undertaking project for pursuing MTech.

Due to the Covid-19 pandemic, the Graduation Function for the outgoing 63rd batch has been postponed indefinitely. Graduation Function is celebrated by each Training School to formally award a Graduating Certificate to each graduating trainee. Toppers from each discipline are also honoured at the Function. Chief guest invited to the Function, which is graced by Chairman, AEC and Secretary, DAE, and

Director, BARC, is an extremely accomplished personality of high repute. During the year, all TSOs and TDOs were taken on a guided tour of DAE facilities at Tarapur. HRDD hosted TSOs from other BARC Training Schools and facilitated their visit to BARC Mumbai.

The process for recruitment of scientific and technical manpower through OCES-2021 is expected to commence in April 2021.

The OCES-2019 elective coursework and also the placement of all TSOs, were held in 'online' teaching mode, and 'in-person' interaction was kept to bare minimum. Through this mode, all the elective course work, viva, mini projects and written exams were completed. The placement viva for all successful 101 TSOs was conducted on 27th July, 2020. During the present year, a total of about 140 of over 170 courses consisting of foundation, core and elective courses were taken by TSOs. To conduct such a wide variety of courses, HRDD depends on other Divisions/Units of DAE. A faculty of close to 500 practicing scientists and engineers were invited from various Divisions/Units of DAE. This year, the Mini-projects were allotted to TSOs in consultation with their prospective Divisions/Units. About 90 Scientists and Engineers supervised the project work of the TSOs.

Four trainees, who passed through OCES selection process and got recruited by ECIL, were provided training at HRDD. Six TDOs underwent the OCES training course at BARC Training School, Mumbai.

There were 9 full time PhD students in science disciplines and 10 DDFS PhD in engineering disciplines undergoing coursework in BARC Training School. Also, there were 6 persons (AERB) enrolled for the foundation course with the OCES-2019 batch.

HRDD is responsible for organizing QUEST under Continuing Education Programme of the Department. QUEST is a novel programme, approved by TC in 2008, which offers an opportunity for HBNI-PhD students and for employees of DAE units located in Mumbai/Navi Mumbai to upgrade their knowledge on advanced level courses approved by BOS (Board of Studies) of HBNI. For past several years now, HRDD has been successfully running the QUEST by proposing, executing and completing many advanced courses. During the year, two courses namely “State-space approach to Reactor Control” and “Natural Circulation Based Passive Safety System for Advanced Reactor” were offered by HRDD.

About 180 students from different institutes, who visited BARC for training/project work as compared to 1387 students last year were provided practical training (1 to 2 months) and academic projects (3 to 12 months) in BARC by HRDD.

Due to prevailing Covid-19 scenario, the process of allotment of MTech Projects to all the eligible fresh officers from OCES 2019 is yet to begin. Completion of the earlier projects has also been impacted. A total of 7 candidates (OCES-2017) could complete their MTech during the period.

HRDD maintained a well-stocked library consisting of 5455 textbooks, 2261 reference books, 98 NPCIL design manuals, 1708 BARC reports.

Human Resources Development activities at RRCAT revolve around imparting training to Ph.D. Scholars and M.Tech. students from various Indian institutes. The stipendiary programme for CAT-I and CAT-II is conducted for the Scientific Assistants and Technicians. The OCES programme at RRCAT was delayed due to COVID which has been resumed from January 2021. RRCAT has initiated "Trade Apprenticeship Scheme at RRCAT" abbreviated as TASAR to impart practical training to ITI trained boys and girls to expose them to modern technologies and improve their proficiency, skill and employability. About 85 are being trained in the current batches.

Twenty one young trained scientists and engineers (OCES-2019, 14th Batch) have successfully completed their orientation programme at BARC Training School at IGCAR and have been placed in various units of DAE. Also, 66 Category-I and 70 Category-II stipendiary trainees are presently undergoing class room training. The programmes of HBNI continued to progress with full vigour, and it is a matter of great satisfaction that 3 PhD thesis from IGCAR; 2 in physical sciences and 1 in chemical sciences were adjudged as the best theses by HBNI.

Human Resource Development has been continued where two (02) in-house training programmes were organised in which forty five (45) officials have participated. One (01) induction training programme was organised in which two (02) Technical Officers and seven (07) Technicians have participated. About 214 officials have participated in external training (including e-training) programmes organised by institutes like ASCI, NIAS, IIRS, NITS, GSI, ISTM, etc. Eight (08) students from various universities and institutions were imparted internship, field / laboratory training in AMD.

NPCIL has strong and dedicated workforce of 11054 employees as on 30.11.2020 consisting of Engineers, Technicians and Supervisors, Non-Technical Executives, Staff and Auxiliary support staff who spearhead the activities of the organization. All our HR initiatives are directed towards fulfilling the NPCIL's mission and vision by attracting, motivating and retaining the right talent and intellect. While developing the strategic and incremental packages for employees, the individual goals and aspirations are encouraged by way of training culminating in achievement of goals of NPCIL.

NPCIL being a Company carrying out special nature of business, the strategic dimensions of its business and the operational flexibility needs to be maintained in every aspect. The trained and skilled Human Resource is an asset of NPCIL. Hence, optimization of manpower is an important strategy towards best utilization of human resource. Accurate and comprehensive manpower optimization models for Construction Projects, Operating Stations, Design & Engineering, including multi-Unit Sites are developed separately in NPCIL. Staffing is done in accordance with these models in NPCIL.

Being a Central Public Sector Enterprise, NPCIL is committed to implement the Presidential Directives and all the Govt. of India orders on reservation, relaxation and concession for SC/ST/OBC/EWS and Persons with Benchmark Disabilities in recruitment and for SC and ST in promotion, wherever applicable. During the year 2020, as a part of annual induction programme, 289 young talents were recruited in Group A, B & C through direct recruitment process. Total 6 young talents were recruited through direct recruitment process under Persons with Benchmark Disabilities Category.

At TMC, most of the academic and research activities were put on temporary hold as the focus was on service. Teaching was later resumed through electronic media. Only nineteen (19) conferences were held; the rest were canceled and few were held as webinars. The annual graduation ceremony was also cancelled.

Administrative Training Institute

Administrative Training Institute started functioning on 2nd July, 2007 with the motto "Prashikshaneshu Dakshaprayate – Training Empowers". ATI continued the professional development of officials from various cadres working in DAE, through a wide range of training programmes. There has been a steady growth in the number of courses being conducted and number of employees being covered. ATI has organized over 1022 programmes for over 30,100 participants till date. This could be achieved because of the robust Training Management Information System (TMIS) in place. This takes care of major training activities right from drawing the Training calendar, preparing schedules, nomination data, confirmation, faculty database, feedback, budget and expenditure management, etc.

Due to the global pandemic COVID-19, the first quarter of the FY 2020-21 witnessed complete lockdown. Even after the lockdown was over, the protocol related to the COVID-19 such as social distancing, ban on gathering etc., posed challenges to ATI to conduct training programmes through offline mode. ATI converted this challenge into opportunity by exploring the possibilities of conducting online training and thus the programmes conducted during the year include RTI, Gender sensitization, Ethics and values, Role of Inquiry Officer/Presenting officer, Computer programmes etc. and there are still many more to come. These programmes are immensely appreciated by the participants.

Since the online training was a completely new way of training for the faculty, participants and also for

the coordinators, some modifications have been brought about in the course content and visual aids have also been developed. A three (3) minute video explaining the Do's & Don't's and general etiquettes/ behaviour during online training have been made.

The movement of paper etc. is also a cause of spread of COVID-19 in offices and in order to reduce the paper generation and their movements at various stages, the nomination forms were obtained only through online mode. The submission of hard copies of feedback forms were also stopped and the same were taken through online methods.

Online training has facilitated our mission of "reach the unreached" successfully. The participants from the distant areas are also benefitted. ATI could also avail the services of expert faculty/ professionals who were in different parts of the country. There was almost no expenditure towards TA/DA/Air fare of the faculty. This has brought down the cost incurred in training with no compromise on the quality of training.

Professional liaison and coordination by ATI have helped in strengthening network with the premier training institutes and faculty members. This helps in ensuring quality, variety and freshness in the programmes. The Institute has a blend of the external and inhouse faculty.

It has been the endeavour of ATI to innovate and adopt the best practices in training with an aim to make it a robust Institute thereby creating a strong, informed and skilled human capital.

SPONSORED RESEARCH

Board of Research in Nuclear Sciences (BRNS)

Board of Research in Nuclear Sciences (BRNS), being the extra mural funding agency of DAE, has been funding universities and research centres of the country for pursuing various research projects and for organising several scientific events of relevance to its programme. Over the years sponsoring such projects has nurtured many young members of the faculty in academic institutions and promoted research activities in topics of DAE interest in various academic and research institutes in the country. Through these activities, DAE research centres have established strong academic linkages with them. In early 2019, BRNS Board has been reconstituted with experts representing different themes as defined in the DAE vision document. The BRNS Board is supported by nine focused BRNS Committees on DAE Programmes (CDPs). Subject domains of these nine CDPs are listed on official website (www.brns.res.in) of BRNS.

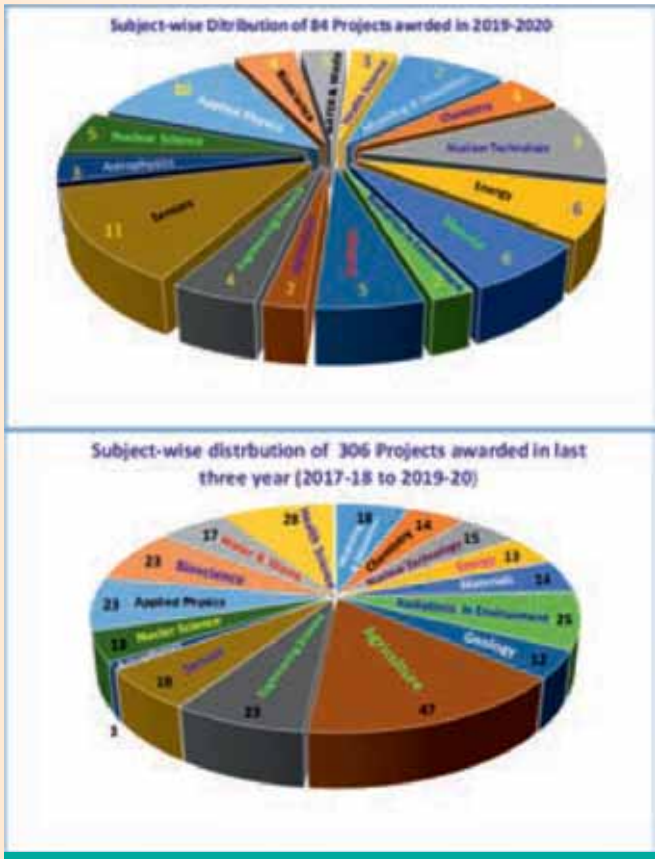
During this year (FY 2020-21), 61 new research projects were sanctioned. All the projects entering in the final (usually 3rd) year or requiring extensions were reviewed by CDPs. In addition, 11 completed research projects were also reviewed for their scientific completion. Total 35 projects files were closed and 217 Lakhs unutilized funds were received from Universities / institutions. To accomplish these tasks, 26 Meetings (known as Technical Programme Discussion Meetings, TPDMs) of the CDPs were organized. Apart from reviewing, evaluating and recommending new projects, CDPs were engaged in monitoring activities of ongoing projects and suggesting mid-course corrections. They also evaluated the projects when their tenure was completed. The deployment of Video Conferencing Mode in BRNS meetings since January 2019 has not only expediated the review and evaluation process quite substantially, there has been significant cost savings in organizing the meetings involving participants all across the country. Providing finance for Homi Bhabha Chairs, Raja Ramanna Fellowships, DAE-SRC Awards, Dr.K.S.Krishnan Research Associateship and Fellowships for Ph.D students of Homi Bhabha National Institute are also included within the BRNS budget.

In the pandemic year of COVID-19, BRNS initiated a new scheme for supporting fast track projects, for 18 months duration, targeted to diagnosis, therapy and prevention of the spread of the disease. In response to this initiative 75 project proposals were received which were evaluated by the Health Care Committee expeditiously and 9 projects were funded. They include 3 projects on diagnostics and testing, 5 projects on therapeutics and 1 project on personal protection material. The total funding for these projects has been ₹ 2.6 Crore.

On a request from BRNS, Scientists and Engineers from DAE units have been identifying thrust areas in which they are seeking collaborations from academia and research institutions outside DAE. Attempts are also being made for initiating Coordinated Research Projects (CRPs) on areas in which participation of multiple institutions will be fruitful. Such collaborative as well as coordinated research projects, which are initiated by DAE Scientists and Engineers but have sustained and substantial engagements of other institutions are expected to occupy prominent positions amongst BRNS funded projects. In order to follow the evolving trends of DAE activities, identification of thrust areas will be a continuing process and BRNS Secretariat will keep the scientific community updated, through its website, on the latest information on the DAE research interests. In response to the present search a good number of proposals for Collaborative/ Coordinated research have been received from scientific groups in DAE with the consent of their respective heads of units. Processing of the detailed proposals with identified collaborators will be given priority.

BRNS Secretariat has taken an initiative for streamlining DAE-BRNS Fully Funded Symposia (DBFFS). Based on the survey conducted by the Secretariat, a list of sequels of symposia with their periodicity and scope is prepared and this is circulated to different DAE units for their concurrence. The policy for publication of the Proceedings of these symposia is also being discussed. The recommendations of Inter-Ministerial Overseeing Committee (IMOC) on "Accelerate Vigyan (AV) Scheme" launched by Department of Science and Technology (DST) with regard to Symposia have been adopted for BRNS funded symposia.

The subjects-wise distributions of the new projects in FY 2019-2020, and for last 3-years are shown in the following pie chart. The subject "energy" includes solar devices and hydrogen energy. The subject "sensors" includes both basic research as well as device fabrication. It is interesting to observe that the reasonable numbers of the projects were awarded for the direct applications in Nuclear Technology. However, significantly much larger number of projects were awarded in the "Agriculture" and "Health Science" sector. These subjects require the participations of the



The subject-wise distributions of the BRNS funded projects

experts from outside DAE for the field experiments & deployment, and more trials for the actual applications. This appears to be the primary reason for awarding larger number of the projects particularly under the subjects "Agriculture".

As indicated in the above picture, large number of projects under "Radiation in Environment" are due to ongoing campaign of "National Uranium Projects" (NUP) – Phase IV, which has a large number of participations from small universities spread across the country. National Uranium Project (NUP) is a DAE initiative to generate a national database on uranium in drinking water" was initiated in year 2014 by Health, Safety and Environment Group (HS&EG), BARC under the flagship of BRNS funded collaborative research projects. The main objective of the NUP is to generate a national database on uranium in drinking water in all the districts of the country.

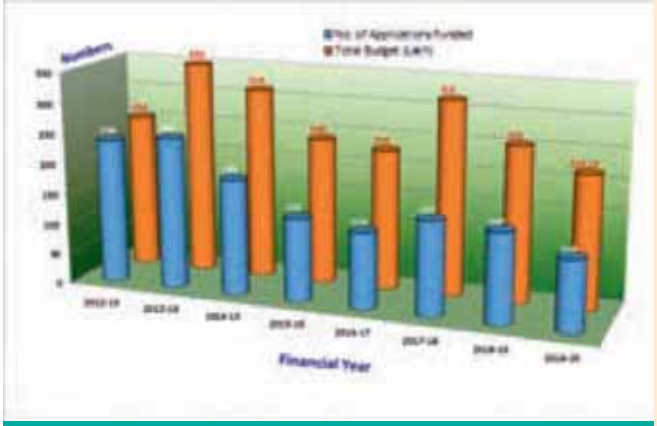
There are 123 publications originating from the projects under "Basic Research and Science Education" (BRE) committee. All BRE research projects

completed in last 2-years were analyzed in terms of "impact factor".

It may be noted that three patents were filed from the work originating from the BRE projects. These patents were not for any applications in DAE activities, but involved the DAE collaborators as the major contributors.

The financial assistance to symposia for the last eight financial years is summarized in the following chart. These funding to symposia includes fully funded DAE-BRNS events and partially funded events organized by the institutions outside DAE. It is evident from the chart that the symposia funding was almost same for the last five years with slight drop in 2019-2020. This year FY 2020-21, due to Covid-19 pandemic situation in the country, small financial support to the tune of Rs. 3.25 lakh was extended for conducting scientific events, mostly in webinar mode and closure grants of approximately 14 lakhs was released for events in previous year.

BRNS provides project funds for



Variation of budget utilized and number of events funded under symposia head

Memorandums of Understanding (MoUs) initiated by DAE institutions with the specific major objectives requiring participations of academic/research institutions outside DAE. Such MoUs are generally entered when a major facility or Centre is created in an academic / research institute outside DAE. These Centres are often National Centres where the facilities are accessible to nationwide users.

This year progress of 4 ongoing MoUs were reviewed by respective APEX Committees and Project Implementation Committees (PIC) of BRNS MoUs. These MoUs are: National Aerosol Facility; Development of technology for large sized Nd-doped phosphate LASER glass blocks and discs; National Facility for Atomic Scale Materials Characterization using Remote Atom Probe Tomography, and Improvement of Traditional Farmers Varieties of Rice of Chhattisgarh through Radiation Induced Mutation Breeding.

A grant of ₹ 305.2 Lakhs had been released to IIT Madras on 13.11.2019 for MoU on "Utilization of National Facility for Atom Probe Tomography". An MOU on "Improvement of Traditional Farmers Varieties of Rice of Chhattisgarh through Radiation Induced Mutation Breeding", was signed on June 24, 2019 and a grant of ₹ 76.22 L had been released.



A National facility for Atom Probe Tomography has been setup at IIT Madras

Promotion of Mathematics

The National Board of Higher Mathematics (NBHM) was set up by the Government of India under the Department of Atomic Energy (DAE), in the year 1983, to foster development of higher mathematics in the country, to formulate policies for development of mathematics, help in establishment and development of mathematical centres and give financial assistance to research projects and to doctoral and postdoctoral scholars. NBHM functions essentially autonomously framing its own budget taking into account the funds made available by DAE on yearly basis.

Main objectives and functions of NBHM are to promote growth of higher mathematics in the country and to coordinate activities for development of mathematics; to continuously evolve and implement

policies and programmes for development of mathematics in the country; help in establishment and development of mathematical centers; to give financial assistance to research projects and to doctoral and postdoctoral scholars; to assess the nature and extent of mathematical inputs necessary in application and to suggest steps for training adequate personnel, especially in areas where sophisticated mathematics in involved; to determine the funds required for these activities and to administer these funds through suitable machinery set up for this purpose and to support undergraduate and postgraduate teaching along with research activities in India by offering scholarships, travel support, support to libraries among other things.

Some of the schemes/ activities of NBHM are Financial Support to Mathematical Institutions; Travel Grant/ Conference Support/ Research Project Grant; Mathematical Olympiad/ Madhava Mathematics Competition (MMC); Mathematical Training and Talent Search Programme (MTTS); Undergraduate/ Postgraduate/ PhD Scholarships, PD(F) Fellowship; Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes.

Best efforts were made by NBHM during pandemic-forced lockdown to reduce the delay in recommending/approving fellowships to all eligible students. All the cases for financial support to institutes, research projects, teaching and training (in virtual mode) were also processed.The Board has set up several committeess to consider, throughout the year, proposals received, essentially for financial support for varied mathematical activities, from institutions and individuals. Decisions of the NBHM are based on the recommendations of these committees.

Postgraduate Scholarship for MA/MSc

The Board has instituted several scholarships for outstanding students with a pronounced aptitude for research, studying for the Masters degree in the Mathematical Sciencs. The selection for awarding these scholarships is done on the basis of a written test and subsequent interview. Due to pandemic no scholarships are expected to be offered during the academic year 2020–21.

PhD Scholarship

Students enrolled or aspiring to enroll in a doctoral programme leading to PhD degree in Mathematics/ Applied Mathematics are eligible to apply for the PhD scholarships awarded by NBHM. The selection of the scholars is based primarily on the performance in the written test and subsequent interview conducted by a selection committee constituted by the NBHM. During the year, a total of 3175 candidates registered to write the test, 2365 of whom actually wrote the test. Of these 84 were called for the interview and 47 were finally selected for the scholarship. The budget for PhD fellowships for the FY 2020-21 was ₹ 4 Crore.

Post-Doctoral Fellowship

NBHM provides post-doctoral fellowships for candidates who finish their PhD but cannot yet go for jobs which usually requires 3 years of postdoc experience. In the last few years, the Post Doc Fellowship (PDF) of NBHM is becoming more and more popular. During the year, NBHM awarded PDFs to 33 candidates out of a total of 89 applications. NBHM selects postdoc candidates twice a year - in the month of January and July. Funds of about ₹ 2.8 crore have been disbursed under this scheme during the year.

Visiting Professorship

NBHM provides funds to university departments and other institutions for inviting eminent mathematicians from within India or abroad for lectures, joint work and other academic activities. A sum of ₹ 54,00,000/- was disbursed to such mathematicians under this scheme during the year 2020.

Library Grant

NBHM operates a scheme to extend financial support to the libraries of various Universities and Institutions. There are eight regional centres, and each centre has several libraries falling within its region. Total approved budgetary estimates for Library support was ₹ 6.65 crore for the FY 2020-21. The funds are meant for purchase of books and journals.

Book Distribution Scheme

Under this scheme, NBHM supplies selected books to mathematics/ statistics departments of universities/ institutes/ postgraduate centres. Books sent under this scheme are meant for the institutional/ departmental libraries and not for individual collections. If any mathematics department of any university/ institute wants to be included in the mailing list of the Complimentary Book Distribution Scheme, they (should) write a letter to the Coordinator of this scheme. DAE released a sum of ₹ 2,32,000/- for this purpose.

Research Project Grant-in-aid

NBHM provides assistance for selected research projects on the recommendations of its Committee. Based on the recommendations of the committee, NBHM extended a financial support of about ₹ 1 crore to various selected fresh / on-going projects.

Travel Grant

During January 2020, the Travel Grant Committee looked at 16 Travel Grant applications from 2019. The committee recommended reimbursement of travel expenses for 5 of these applications, amounting to about ₹ 6,12,500/- These were mainly for travel in late 2019.

Conference Support

NBHM provides financial assistance for holding national and international conferences/ workshops/ seminars. Howener, during the year, no conference support was provided except before the pandemic when a sum of ₹ 4,40,000/- was released for the purpose.

Mathematical Olympiad & Madhava Mathematics Competition

The Mathematics Olympiad activity was undertaken by NBHM from 1986 onwards and is currently run in collaboration with the Homi Bhabha Centre for Science Education (HBCSE), Mumbai. Main purpose of this activity is to support mathematical talent among high school students in the country. DAE released a sum of ₹ 26,21,00/- to HBCSE for organising Mathematical Olympiad and Madhava Mathematics Competition for FY 2020-21.

Virtual International Mathematical Olympiad Training Camp (IMOTC) 2020

The IMO training camp for 45 junior batch students and 38 senior batch students was held via an online virtual mode from 1st to 29th May, 2020. All 83 students had registered for the online training camp. The training included dissemination of lecture notes and interactive sessions by faculty drawn from various research institutes all over the country.

The Indian Olympiad Qualifier in Mathematics (IOQM) 2021 (offline)

The Indian Olympiad Qualifier in Mathematics (IOQM) 2021 (offline) examination was held on January 17, 2021 at 176 centres across the country, including centres in north-east Indian states as well as Jammu and Kashmir. Around 27,000 students registered to appear for this examination.

Indian National Mathematical Olympiad (INMO) 2021

Based on the IOQM examination around 1117 students from all regions have been selected to appear for INMO 2021 to be held on March 7, 2021 at different centres across the country.

Indian Women in Mathematics (IWM)

IWM is a collective of mathematicians that has been in existence since 2009. Its objective over the years has been to encourage more women to pursue higher education in mathematics, and to provide an exposure and environment that enables them to take up careers in mathematics. In its pursuit to fulfill the objective, IWM organizes various workshops and conferences that focus on presentation of original research work and discussion about career opportunities in mathematics.

IWM conducted a follow-up mentorship programme for young undergraduate students in December 2020 in the virtual mode. This was in continuation to the last year's Young Women in Mathematics programme.

The IWM organised webinars every month from August 2020 - December 2020 by renowned mathematicians. The Visitor Programme Lecture Series by IWM in 2020 was an online series of talks by

renowned women Mathematicians from across the globe with an aim to reach out to women students, post-doctorals and mathematicians, especially from India, through mathematics. On an average, about 120 plus participants joined the sessions each time, over zoom and YouTube combined. The audience response was overwhelming, and each session extended to more than two hours.

Institutional Support

Institutional Support is provided by NBHM to Chennai Mathematical Institute, Chennai; Kerala School of Mathematics, Kozhikode; National Centre for Mathematics, Mumbai; Bhaskaracharya Pratishthana, Pune and Institute of Mathematics and Application, Bhubaneswar.

Chennai Mathematical Institute (CMI), Chennai

NBHM provides major grant-in-aid to CMI on an annual basis. CMI specialises in Mathematics, Computer Science and Physics. CMI faculty are active researchers, comparable to the best in leading institutions in the country. The teaching programmes offered in CMI are BSc Honours in Mathematics and Computer Science; BSc Honours in Mathematics and Physics; MSc in Mathematics; MSc in Computer Science and MSc in Data Sciences. In addition, CMI offers PhD programmes in mathematics, Computer Science and Physics. It makes significant contributions to India's scientific manpower.

Kerala School of Mathematics (KSoM), Kozhikode

KSoM organized an international conference on "Recent advances in Mathematics and related areas" from 18th to 22nd December, 2020 with both online and offline components in it. The conference featured more than thirty lectures in diverse areas of Mathematics and talks by eminent mathematicians.

Mathematics Training and Talent Search (MTTS), Hyderabad

MTTS Trust establishmed in 1993, holds a large number of cost-effective and immensely useful programmes for promotion of higher mathematics every year. During the year, a total of twenty five programmes were planned, out of which five were of four-week duration and the rest were of one-two week. The NBHM had sanctioned ₹ 1,00,00,000/- (rupees one crore) against the MTTS TRUST proposal of ₹ 1,59,25,200/- for the FY 2020-2021. A total of fifteen online programmes have been held during May – Dec, 2020 and another three follow-up programmes are in the offing. About 1000 students and 250 teachers have participated in these camps, and everyone felt immensely benefited by the programmes.

GRANTS-IN-AID

Grants to Aided Institutions

The aided institutions of the Department of Atomic Energy are an integral part of the Department in as much as there is a growing synergy between these institutions and the Research and Development Units of the Department. Several joint projects have been undertaken between the Units and Aided Institutions and there is frequent interaction between the academicians of the aided Institutions and the Scientists of the R&D Units. The Department has eleven aided institutions fully funded in terms of their recurring and non-recurring expenditure. These institutions are Tata Institute of Fundamental Research (TIFR), Mumbai; Tata Memorial Centre (TMC), Mumbai; National Institute of Science, Education & Research (NISER); Institute of Physics (IoP); Saha Institute of Nuclear Physics (SINP); Harish-Chandra Research Institute (HRI), Allahabad; Institute of Mathematical Sciences (IMSc); Institute of Plasma Research (IPR); Atomic Energy Education Society (AEES); Homi Bhabha National Institute (HBNI), Mumbai and University of Mumbai – Department of Atomic Energy – Centre for Excellence in Basic Sciences (UM-DAE-CBS) Mumbai.

Budget Provision of ₹ 2857.93 Crore in the year 2020-21 has been released for aided institutes towards salaries, creation of assets etc.

Olympiad Programme

The Asia Pacific Mathematics Olympiad (APMO) is a mathematical competition held annually for countries in the Pacific Rim Region. India secured 1 Gold, 2 Silver, 4 Bronze and 3 Honourable Mentions in the XXXII Asian Pacific Mathematics Olympiad (APMO)

2020 and was ranked 8th among 38 countries of the Western Pacific and in Asia.

INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

Development of Secure "Work From Home" Facility

The BARC Computer Division has developed and released Virtual Private Network (VPN) based secure Work From Home Facility. This infrastructure creates a VPN between home PC on Internet to BARC. Defence-in-Depth security provisions were made for strong protection against cyber attacks.



Secure Work From Home Facility

Development of secure web-based Video Conferencing (VC) System

VC is the order of the day to maintain social distancing during Covid-19 pandemic. VC tools available on Internet are not secure for internal meetings. Secure VC applications VMeet and DAEMeet were developed for meetings–on BARC Intranet and Anunet respectively. The system is implemented using WebRTC, which requires only a web browser at the client end.

Secure Network Adapter

Using off-the-shelf hardware and open source software tools, BARC has developed a robust, small form factor security appliance on VPN technology to securely access organizational resources using public network with a throughput of 1.5Gbps. It also supports custom encrypted algorithms and key management protocols.



1.5 Gbps Secure Network Adapter (SNA)

Design, development and deployment of scientific computing resources

Development of Resource Manager and Scheduler for HPC Cluster

At RRCAT, development of resource manager and scheduler for HPC Cluster compatible to TORQUE and MAUI has been completed. New resource manager and scheduler were developed and successfully tested on Tejas-1 cluster, which has both CPU and GPU processors.

Porting and deployment of PIConGPU and Impedance Wake2D on Kshitij-5

Porting and deployment of parallel scientific computing application PIConGPU on Kshitij-5 high performance computing cluster has been completed for Laser Technology Division. PIConGPU is a fully relativistic, many core Particle-In-Cell (PIC) code, which describes the dynamics of a plasma by computing the motion of electrons and ions in the plasma based on Maxwell's equations. PIConGPU implements various numerical schemes to solve the PIC cycle. Porting and deployment of parallel scientific computing application Impedance Wake2D on Kshitij-5 high performance computing cluster has been completed for Accelerator Physics Section. Impedance Wake2D (IW2D) provides a tool to study beam coupling impedances and wake fields in 2D flat or cylindrical structures. It computes the resistive wall impedance and/or wake functions for multi-layered flat, cylindrical or elliptical structures.

Development of intelligent web-based software for automated detection of Diabetic Retinopathy using Deep Learning

An intelligent web-based software was developed for automated preliminary detection of Diabetic Retinopathy in digital fundus images of retina of diabetic patients. The developed software will act as an aid to the manual diagnostic process by referring DR patients to an ophthalmologist for further examination (if detected positive) well in time to reduce the risks of vision loss. This Artificial Intelligence based software has been developed using the contemporary concepts of Machine Learning and Deep Learning. Deep learning models have been developed and trained using publicly

available dataset, which contains 75,000 images and the results of developed models are very encouraging.

Enhancement of RRCAT links concentrators to support predefined link selection for timeslot based routing

Public Financial Management System (PFMS) has two mode of operations – Billing and Approval. Both modes of operations are required to be performed on different terminals identified by different IP addresses. The required implementation issue was solved by implementing support for predefined link selection for timeslot based routing in link concentrators for the specified website address of PFMS. The system is deployed in compliance with IT security policy of the organization.

Commissioning of advanced security management station for vulnerability assessment of RRCATNet

A security scanning station has been configured and commissioned as a facility for performing vulnerability scans on RRCATNet connected resources. It has enabled to get a view of the complete security posture of RRCATNet. The security scanning station is capable of identifying the vulnerabilities of the systems that need attention with high-speed, accuracy and minimum false-positives. This facility will be helpful in generating daily/ monthly/ quarterly security audit reports of RRCATNet for compliance with security guidelines of Computer and Information Security Advisory Group (CISAG) and Indian Computer Emergency Response team (CERT-In).

Deployment of OFC Network Infrastructure Management System

OFC Network Infrastructure Management system has been designed, developed and deployed to manage OFC network infrastructure in a systematic manner. The system has various modules for management of detailed information about networked buildings, network rooms, racks, OFC patch panels, OFC segments including OFC core end-point and its connection details. This system is expected to improve the OFC network infrastructure by helping in better decision-making regarding laying of OFC segments in future.

Mock Drill Management System for Alarms of Critical IT Infrastructure

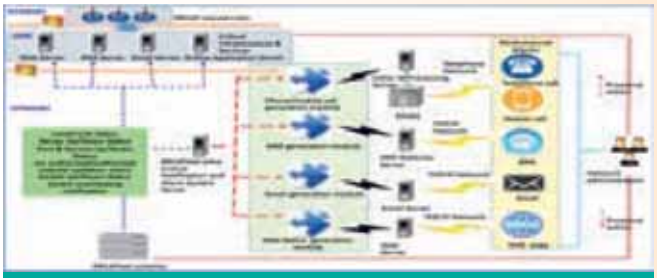
For proactive management of the ultra-critical cyber resources of RRCAT in 24 x 7 mode, a multi-channel event capturing and alarm generation system is in place. Mock Drill Management System for alarms of critical IT infrastructure has been designed and developed to perform tests on simulated data on the existing alarm generation and management system. This system generates signals affecting changes in status of ultra-critical services. The simulated signals are passed to the actual multi-channel event capturing and alarm generation system, which in turn generates notifications in the form of Web, Email, Phone/ Mobile call and SMS to the concerned persons. The system will help in ensuring almost error free functioning of ultra-critical alarm generation and management system.



Block diagram of mock drill management system for alarms of critical IT infrastructure

Design and development of a multi-channel event capturing and alarm generation system

A multi-channel event capturing and alarm generation system has been designed and developed for 24 x 7 unmanned and proactive management of the ultra-critical cyber resources of RRCAT. The ultra-critical cyber resources of RRCAT include Internet Leased Links, ARPF Leased Link, Web, Email, DNS, Email over Internet & Online Recruitment servers. The developed system enables continuous, 24 x 7 unmanned monitoring of the ultra-critical cyber resources for any malfunctioning, up/down status, transport layer port & service status, website update status and network switches status. The alarm generation system includes all major modern day alarm communication modes like SMS, Mobile Call, Intercom Call, Web and Email. Web based portal is developed for monitoring of resources/services and its integration with alarm



Block diagram of the multi-channel event capture and alarm generation system

communication module to send alerts in case of defined events.

Design, development and deployment of "e-सभा" Video Conferencing portal

"e-सभा" Video Conferencing (VC) portal has been designed, developed, deployed and released to the users of RRCAT. It is a secured, lightweight, multi-featured and fully encrypted solution deployed on RRCATNet. Meeting can be hosted on/ participated from any PC connected on RRCATNet. The "e-सभा" portal will provide VC facility within RRCAT and will aid in maintaining social distancing during the present situation of COVID-19.

Design, development and deployment of various Information Management Systems

i. Web based resource management and monitoring software has been designed, developed and deployed for management and monitoring of IT resources. This software can be used to forecast and plan resources, additionally it can also be used to maximize utilization and optimize usage of resources.

ii. Application server of IRPSU Information Management Software have been installed, configured and commissioned. Centralized file server was configured to provide e-tenders documents to indenting officers. Global configuration parameters for forms and reports have been incorporated in application sever to support active-passive configuration for fail-safe mode of operation.

iii. Annual Performance Appraisal Report (APAR) software was deployed on RRCATInfonet for time window based online submission, assessment and review of APAR of Scientific and Technical staff of RRCAT for the APAR period 2019-20. The Assessment module used by Reporting Officers and Reviewing Officers has been enhanced further to make it more secure and robust.

iv. A Time Window based Portal for secure document exchange among DAE units has been designed, developed and deployed over Anunet. The portal provides a facility to securely exchange documents over Anunet within specified time window. The software facilitates uploading of documents by authorized users in their respective area within the specified time window and downloading/ viewing of documents by the Administrator. This software can be used for secure exchange of questions paper and other confidential documents among DAE units.

v. To facilitate automated server-side digital signing and time-stamping of digital documents, central management of signer services as a server component of open source sign server has been configured and deployed on RRCATNet. Digital Signature Certificate (DSC) enabled software applications deployed on RRCATInfonet have been programmatically integrated with open source sign server to generate valid e-documents with embedded RRCAT timestamp to ensure long term validity and integrity of digital documents.

Commissioning of multi-party voice conferencing facility

To facilitate ease of collaborative working, post COVID-19 outbreak, multi-party voice conferencing facility has been configured and commissioned on Lab area Telephone Exchange of RRCAT. Telephone exchange has been programmed such that this facility is accessible from the extensions of Head of Divisions/ Independent Sections and Functional Heads.

Access to e-Journal Gateway "J-Gate"

e-Journal Gateway "J-Gate" is now accessible online to the scientists and engineers of RRCAT. J-Gate is an electronic gateway to global e-journal literature and it provides seamless access to various journal articles online from a single gateway. J-Gate will also help to share e-Resources of other units of DAE: BARC and IGCAR.

Development of Secure Webmail Service for IGCAR

Prior to the COVID-19 induced lockdowns, access to the IGCAR email facility was restricted to IGCAR Intranet except for a few higher officials who could access the facility from official laptops which are configured to connect to the Intranet through VPN. But, during the work-from-home period, a need has arisen for all the senior officials of IGCAR to communicate with each other to carry out their duties effectively. Considering this requirement and the sensitivity of the data handled by IGCAR and DAE, secure webmail has been developed using open-source software to access IGCAR mails from a web-browser, with OTP based two factor authentications. Further to thwart any brute-force login attacks, a CAPTCHA module was developed and integrated to the login page.



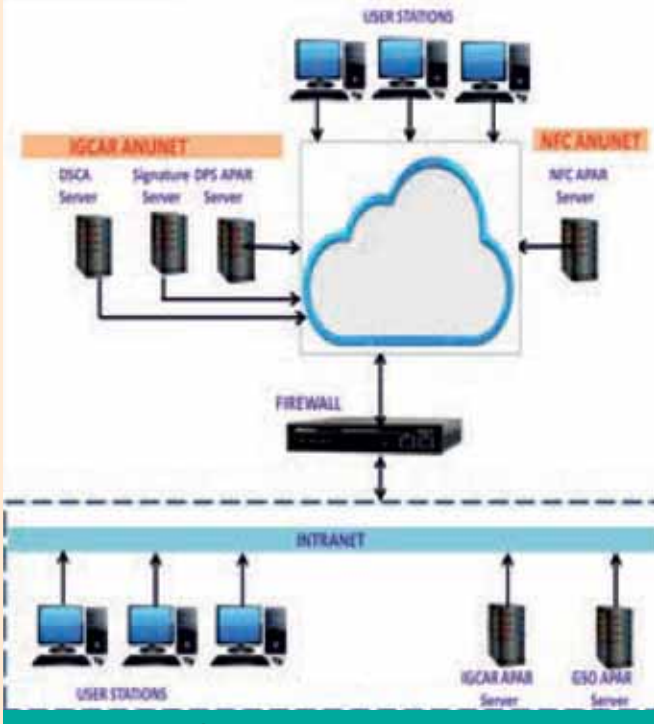
IGCAR Webmail

Development and Implementation of Indigenous Video Conferencing (VC) Solution - IGCAR Vi-Meet

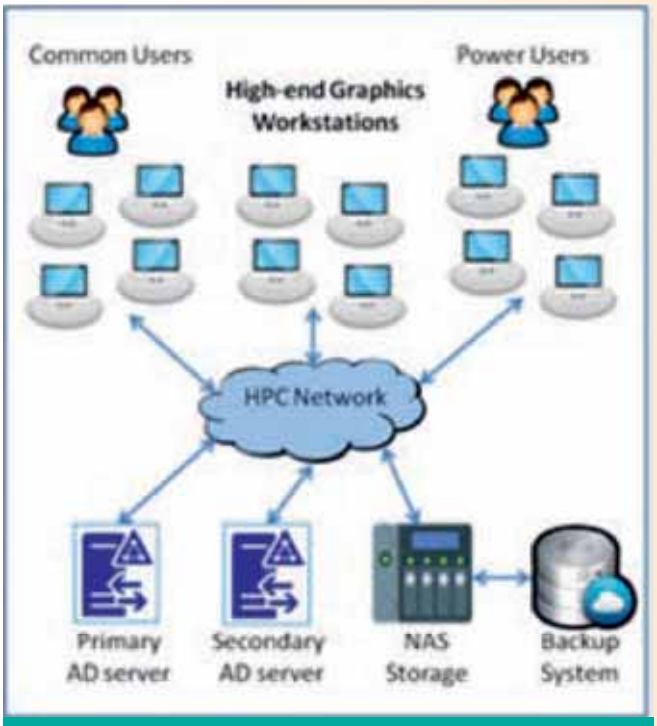
Across the world, COVID-19 pandemic related lockdowns and travel restrictions provided an impetus to depend more on online solutions to conduct meetings, share documents, carry out collaborative works, etc. In this context, considering the confidentiality and sensitivity of the data handled by IGCAR and other units of DAE, IGCAR Vi-Meet desktop VC solution has been developed to facilitate conducting official video meetings securely over Internet. IGCAR Vi-Meet is a clientless Video Conferencing (VC) system developed using open-source tools and packages with on-premises infrastructure. It is independent of any third-party server/licensing. It also supports features like desktop or presentation sharing with presenter's video as PIP, displaying meeting banners and server-side recording facility. This platform has been used widely by IGCAR and other DAE Units to host peer review committee meetings, project review meetings, pre-dispatch inspections, PhD Viva-Voce exams, training programs, webinars, press meets, vendor meets etc.

Development and customization of Online APAR for deployment at DAE units

Online APAR Software has been developed in-house to make the entire APAR creation & submission process online with the implementation of digital signature. It is a full-fledged end to end APAR system. A process of creation of APAR by the administration, online filling & submission by the employee, work assessment by the reporting officer, review of work by the reviewing officer, acceptance by the accepting officer, communication of APAR by communicating officer and final acceptance/non-acceptance by the employee. The software has been customized to meet the specific requirements of IGCAR, GSO, DPS and NFC and successfully deployed for the units to enable online submission and processing of APARs of all employees.



APAR Server Distribution Network



Overall view of Design & Simulation Centre setup

Design & Simulation Centre with High-end Graphics Workstation

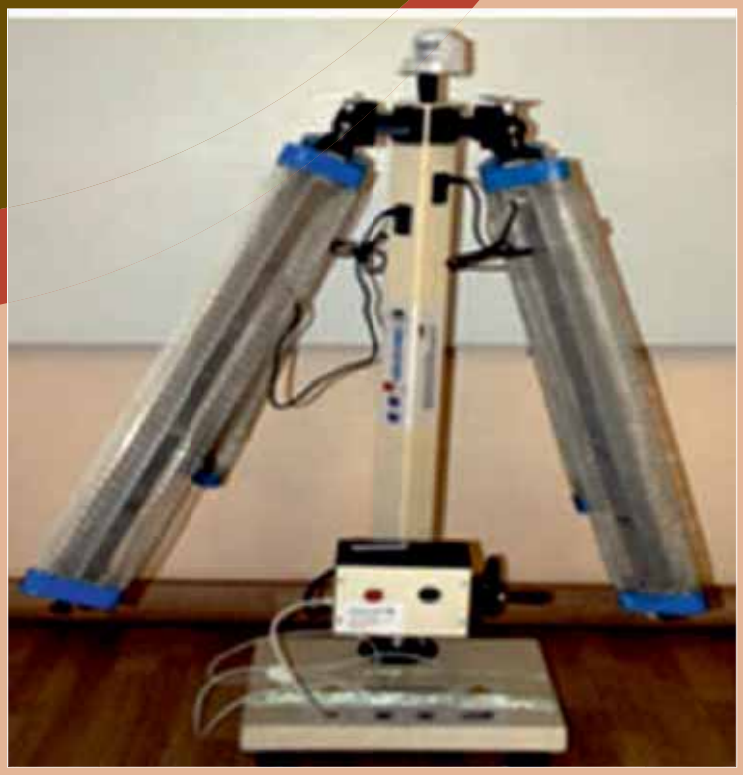
In order to address the ever-growing requirement for carrying out better computer aided design, analysis and simulation studies, a new Design and Simulation Centre facility has been setup. The facility consists of 32 numbers of high-end workstations with twelve-core Intel Xeon dual processors, NVIDIA Quadro (16GB) graphics cards, 128 GB RAM and a local storage capacity of 6 TB. Many advanced compute and graphics intensive application software are loaded and configured in these workstations. Centralized user authentication, network attached additional storage, folder redirection and automated backup of user data are the major features implemented in the facility for achieving better resource utilization. The facility is run in 24x7 basis and being extensively used by scientists and engineers of IGCAR.

IPR's ANTYA in India's Top Supercomputers List

IPR had earlier established a High-Performance Computing facility having a theoretical peak performance of 1 Petaflop. This HPC system named ANTYA (meaning 1015 in Sanskrit), has more than 10,000 cores that can perform 1015 Floating-point Operations Per Second (FLOPS). It is a mix of CPU and GPU based servers. CDAC Bengaluru maintains and publishes a Top Supercomputers-India list (TopSC.in). Counting only the CPU contribution to this computing power, IPR's ANTYA stands at 11th position in the July 2020 list.(http://topsc.cdacb.in/jsps/july2020/index.html). A variety of indigenously-developed as well as commercial software has been ported to ANTYA and are in regular use. A Newsletter called “Gananam” has recently been started to keep users updated about scientific results from the facility and also about hardware/software upgrades.

CHAPTER

7



The developed UV based area sanitization device (NeelBhasmi) to inactivate various micro-organisms including corona viruses

TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES



Standalone LN2 based refrigerated Container "SHIVAY"

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 ballistic limit of Bhabha Kavach has been evaluated against AK47 Hard Steel Core (HSC) bullets. Not a single AK47 HSC bullet could penetrate Bhabha Kavach till the velocity of 832 m/s. Bhabha Kavach technology has been transferred to 5 companies. One of them has received orders for more than 500 Bhabha Kavach Jackets. Fifty Five Bhabha Kavach Jackets were handed over to CISF personnel stationed in BARC.



Bhabha Kavach being handed over to DG, CISF by Director, BARC



Sodium Hypochloride Electrolyser plant

Sodium Hypochlorite Electrolyser Plant was developed for on-site production of sodium hypochlorite (NaOCl), used as disinfectant for COVID-19. The production capacity of the plant is 25 litres per 8 hrs of operation, ideal for a small to medium level establishment. Electrolyser uses mixed metal oxide coated titanium mesh as anode and generates around 6 g/L (0.6%) NaOCl under optimum operating conditions with 3% NaCl aqueous solution feed. The technology which was developed during COVID-19 lockdown has been transferred to the industry.

Crystal Growth laboratory was setup at ECIL, Hyderabad, towards technology transfer for growth of CsI:Tl single crystals, used for radiation detection. ECIL has started growing these crystals for commercial applications.



Single Crystal Growth Lab at ECIL, Hyderabad and Grown Cal:T1 Crystal Size 50 mm Diameter and 100 mm Length

US patent was granted to "A Novel Versatile Phoswich Detector" consisting of two Single Crystals to discriminate various kinds of radiations – (US App No. 16/358427 dated 19-Mar-2019 – BARC) in mixed fields using a combination of Gd3Ga3Al2O12:Ce,B and CsI:Tl single crystals. The detector measures different kinds of radiation simultaneously and is very useful for various departmental programs. It was tested at Dhruva reactor beam-lines and is currently being used in the mixed radioactive waste assay.

At BARC, forty-Six Transfer of Technology Agreements under different areas as listed below were entered into for transfer of 28 technologies:

Agriculture & Bioscience

1. Ambient prolonged storable meal for natural calamities and other targets technology.

2. Safe and Prolonged Storable 'Legume Sprouts' and 'Sweet Corn Kernels technology.

3. Cost Effective Production of Xanthan gum (Food and Pharmaceutical Grade) technology (3 agreements).

4. A Rapid Composting Technology for decomposition of dry leaves, kitchen waste and temple waste technology (2 agreements).

5. Preparation of Biodegradable packaging films using extrusion process technology.

6. A process for development of zinc fertilizer formulation from biosludge (AB27NABTD).

7. A post harvest technology for development of intermediate moisture shrimp (AB32FTD).

8. A process for development of phosphorous fertilizer formulation from biosludge (AB26NABTD).

9. Microfine neem biopesticide (Ab21).

Environment

1. NISARGRUNA-Biogas plant Based on Biodegradable waste resource technology.

Advanced Instrumentation

1. Rigid Coaxial Transitions technology (RRCAT).

2. Fast Current Transformer technology (2 agreements).

Medical Equipment

1. NeelBhasmi- UV based area sanitization device to inactivate various micro-organisms including corona viruses (4 agreements).

2. DEAP - Device to Ease Apnea Problem technology.

Engineering

1. RF Amplifier Modules Technology (RRCAT).

2. Bhabha Kavach (EG08MMD) technology (3 Nos).

3. Compact Pulsed Plasma based high pressure shock wave generators for constrained liquid immersed spaces (EG09APPD).

Water Technologies

1. On-line domestic water purifier based on ultrafiltration polysulfone membrane technology (2 agreements).

2. Multi effect distillation with thermo vapour compression (MED-TVC) Desalination technology based desalination of sea water (WT22DD) (2 agreements).

3. Cellulose based water purifier for arsenic removal (WT21RTDD) (2 agreements).

4. Hybrid granular SBR for waste water treatment (GST) EV05WSCD.

Chemical

1. Sodium Hypochlorite Electrolyser Plant (SHEP) Technology

2. Production of Abrasive Grade Boron Carbide Powder (3tonns / annum) technology (2 agreements)

3. Synthesis of cathode (LiFePO4)/carbon and anode (Li4Ti5O12) material for lithium ion battery technology

4. Visual Detection Kit for alcohol content in hand sanitizers technology

5. Synthesis of cathode (LIFePo4)/carbon and anode (Li4Ti5O12) material for lithium ion battery (CH16ChD)

6. Production of the intumescent rigid polyurethane foam (CH09RTD)

Radiation Technologies

1. Super cotton (RT13IRAD).

New Technologies Released

Agriculture-Bioscience

1. Shelf Stable Oil Free Potato Chips of Different Flavors" developed by FTD.

Advanced Instrumentation

1. High-stability, Current-controlled, Card-based, Unipolar, Switch-mode Power Converter for Electromagnets developed by RRCAT.

2. High-stability, Current-controlled, Card-based, Bipolar, Switch-mode Power Converter for Electromagnets developed by RRCAT.

Medical Equipments

1. NeelBhasmi- UV based area sanitization device to inactivate various micro-organisms including corona viruses, the technology (developed by RRCAT).

2. DEAP- Device to Eliminate Apnea Problem developed by Division of Remote Handling & Robotics (developed by DRHR).

3. Half face mask Dust and Airline respirators (developed by HPD).

4. Cold Plasma Sterilization Device MD20 (developed by L&PTD).

Engineering

1. Liquid Nitrogen Based Transportable Refrigeration System- Sheetal Vahak Yantra (SHIVAY).

Radiation Technologies

1. Autonomous Gamma Dose Logger (developed by IGCAR).

2. Modified Polyurethane (PU) Sponge for oily substance removal technology (developed by IRAD).

Chemical

1. Sodium Hypochlorite Electrolyser Plant (SHEP) Technology (developed by Chemical Engineering Division, BARC).

2. Visual Detection Kit for alcohol content in hand sanitizers (developed by NCCCM).

3. Compact and Portable Metal Nano-powder Generator in repetitive mode technology (developed by TP&EMD, BARC).

4. Composite Metal Membrane Reactor for production/separation/recovery of high-purity hydrogen (developed by Membrane Development Section).

5. Mixed-Matrix Membrane Diaphragm for separator applications in electrochemical cells (developed by Membrane Development Section).

6. Large-scale Synthesis of Carbon Nanotubes (developed by Glass & Advanced Materials Division).

7. Dissolved Oxygen (DO) Monitor (Model-1) technology (developed by Analytical Chemistry Division, BARC).

8. Production of Zirconium diboride (ZrB2) powder and Fabrication of high density ZrB2 shapes" (developed by MP&CED, BARC).

Incubation

During a live-streamed ceremony held on 30th October, the 111th Birth Anniversary of Dr. Homi J. Bhabha, Incubation Centers inspired by the Atal Incubation Mission were inaugurated at several DAE Organisations by Chairman AEC and Secretary DAE. One of these incubation centers is at FCIPT, IPR, Gandhinagar, which has done two decades of pioneering work on development & deployment of plasma technologies for societal applications. A video was screened, showing several home-grown plasma technologies for Societal Benefit. The event also involved exchange of documents related to Technology Transfer for an IPR-developed Plasma Pyrolysis based system for eco-friendly disposal of Biomedical Waste. The proposed incubation center will focus on incubating technology-based startups involving IPR/DAE's core expertise, thereby fostering the technology enterprise culture in the country.



Inauguration of Incubation Centre at IPR

Technology Incubation Centre set up at DAE Convention Center and was inaugurated on 30th October 2020.

An advertisement of "Opacity Monitor for dust level of exhaust gas monitoring" technology was released on BARC web portal for incubation.



The developed UV based area sanitization device (NeelBhasmi) to inactivate various micro-organisms including corona viruses



The OncoDiagnoScope unit developed by RRCAT, Indore and made by ECIL, Hyderabad

At RRCAT, an Ultraviolet C (UVC) radiation based mobile system named "NeelBhasmi" was developed for remotely sanitizing the air as well as surfaces of various objects inside a room at research centers, hospitals, doctors' offices, or any other places of work. The efficacy of NeelBhasmi for disinfection against SARS-CoV-2 was evaluated at the Bio safety Level 3 Laboratory in ESIC Medical College, Hyderabad, an ICMR approved laboratory for Covid-19 test. The system was developed during the lockdown period and technology has been transferred to the industry.

'Oncodiagnoscope' is a compact and portable, stand-alone, field-usable optical spectroscopy based point-of-care device for instant non-invasive diagnosis of oral cavity cancer. The device is best suited for real-time detection of oral cancers at early stages. The 'Oncodiagnoscope' is developed by RRCAT, Indore. Six units of the device have been made by ECIL, Hyderabad. Using these units multi-center clinical validation is being carried out for detection of oral cavity neoplasia. Thus far these units have been validated on around 2500 patients at various cancer screening camps and hospitals including Homi Bhabha Cancer Hospital, Varanasi, Homi Bhabha Cancer Hospital, Sangrur, Raman Cancer Foundation and Hospital, Indore, and Government Dental College, Indore. The analysis of the acquired spectral data showed that OncoDiagnoScope units could provide an accuracy of over 90% in detecting oral cavity lesions.

A new technology has been developed for refrigerated transportation of fruits and vegetables, which uses liquid nitrogen for refrigeration. At present diesel powered and chloro fluro carbon based refrigerated trucks (reefers) are used. Such conventional systems are not very popular as diesel is



Standalone LN2 based refrigerated Container "SHIVAY"



Road trial of the system

expensive and systems breakdown frequently if used on rough roads. SHIVAY (the system developed by RRCAT) ameliorates these problems. This is a standalone system which has inbuilt storage of liquid nitrogen with a separate enclosure for storage of cold cargo. It can be used as a standalone container or can be built on the chassis of any vehicle. This standalone system needs no input from vehicle or the driver. It is multi modal i.e. it can be transported on truck, train etc. The system is 100% eco-friendly and generates no pollutant gases or sound. The system has several India specific features, and hence has the potential to find large user base in transportation of fruits and vegetables, pharmaceutical and other temperature sensitive cargo. Two prototypes of size 14 ft for light commercial vehicles and 20 ft for full truck sized system have been built and road tested for 1700 kms and 1000 kms respectively. A commercial system will now be developed with an industrial partner in technology incubation mode.

SOCIETAL INITIATIVES

A visual colorimetric method was developed for "on spot estimation" of nitrite, nitrate, ammonia and total available nitrogen in soil. It would be deployed for field applications though AKRUTI Centre (under the aegis of DAE outreach programme), Pandharpur.

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 2020-21, three DAE-IPR cell meetings were held, which reviewed thirteen new patent proposals. By the end of the last quarter of the current FY 2020-21, all new patent proposals including three from the last financial year will be filed. This includes; eleven in India, three in USA & one in Europe. One application was filed under the Patent Co-operation Treaty (PCT).

During this period, ten of the previously filed patents were granted to the Department. These includes; eight in India and two in USA. Following are the list of patents granted:

Niobium based superconducting radiofrequency (SCRF) cavities comprising niobium components joined by laser welding - from RRCAT (in India). The invention related to niobium or its alloy based Superconducting Radio Frequency (SCRF) Cavities involving at least one laser beam welded components in the SCRF cavity, welded from inside surface of the wall of cavity, directed to achieving more than half the thickness to full depth penetration with minimum Heat Affected Zone (HAZ), minimum distortion and shrinkage. The method ensures improved weld quality and surface finish substantially free of any weld defects, enhancing productivity, ensuring consistent quality and reliability, enhanced weld penetration with minimum HAZ, smooth finish of weld joints at reduced costs.

A method for large-scale synthesis of optically stimulated luminescence grade polycrystalline ceramic material – from BARC (in India). The invention related to a process of melting commercially available alumina (Al_2O_3) in vacuum followed by rapid cooling to yield polycrystalline material. This method is faster and more cost effective compared to conventional method for the purpose of dosimetry-grade alumina powder. Important properties such as thermoluminescence sensitivity, minimum detectable dose, linearity, repeatability, reusability and fading characteristic of the product helps find application in personal dosimetry.

Metal complex of chlorophyll derivative for magnetic resonance imaging and photodynamic therapy – from RRCAT (in India). The invention is related to a water soluble chlorophyll derivative containing a

paramagnetic metal and heavy elements, which can be used for simultaneous imaging and therapy of tumours using Magnetic Resonance Imaging (MRI) and Photodynamic Therapy (PDT). It can also be used for deep tumour imaging and treatment using Computed Tomography (CT) and photo activation therapy with X-ray radiation.

Nanofiltration membranes with surface negative charge for fractional separation of mono and multivalent ionic species – from BARC (in India). The invention relates to the development of a Thin Film Composite (TFC) type negatively charged nano filtration (NF) membrane using a new chemical composition of monomers, thereby making it unique and novel. The membrane is developed in-situ, by a polycondensation process where a polyfunctional amine undergoes controlled polycondensation reaction with a polyfunctional acid chloride, at the liquid – liquid interface which gets deposited as a semi-permeable barrier on a substrate. The TFC type NF membrane has wide industrial application and can be used for removal of heavy metal contaminants from water, water purification including production of potable water or for industrial applications and effluent management. It can also be used in treatment of brackish water and can be used in combination with RO membranes.

Displacement Decoupling Arrangement for Piping Systems – from IPR (in USA). The invention relates to a specialized design of piping systems for seismic events which involves differential movement in multiple directions (axial, vertical and horizontal) when pipes run from a base isolated to a fixed base building. It involves isolating the differential axial movement on the pipe by incorporating flexible bellows and hoses in the pipes and also by isolating the horizontal lateral and vertical movement at the supports of the pipes using springs and roller bearings respectively. The invention could find application in piping systems used in refineries, chemical plants, power plants etc. which are in seismic zones.

A Dual Purpose Atomic Device for Realising Atomic Frequency Standard and Magnetic Field Measurement – from BARC (in India). The invention related to a dual atomic device – an atomic clock and a magnetic sensor (magnetometer) and is based on Coherent Population Trapping (CPT) resonance. The radio frequency used for generating bi-chromatic field is stabilized to the centre of the CPT resonance in the low field regime to provide atomic frequency standard. The polarization rotation signal due to the CPT is used for measuring magnetic field with improved signal-to-noise (S/N) ratio.

Compact Pulse Transformer with Transmission Line Embodiment – from BARC (in USA). The invention relates to the generation of a fast rise-time, near flat-top rectangular, high voltage pulse / pulses. The critical elements of the invention are the winding scheme adopted with a non-magnetic metallic core, an insulation scheme and primary and secondary closing switches. The invention is a unique combination of transformer and transmission line and has use in pulsed power technology, modulators of radio frequency (RF) and microwave sources in linear accelerators (LINAC) and RADAR applications to drive pulsed electron beam loads.

Creep Machine for Conducting Creep Tests in Flowing Liquid Sodium with Enhanced Safety Features – from IGCAR (in India). The invention is a result of the design modification in the conventional creep machine to conduct measurements in the flowing sodium environment. Novelty of the invention is in the arrangement to maintain the lever horizontally by moving the fulcrum. Another feature is the special double-bellow design that isolates the specimen from the chamber.

Process for Determination of parts per billion (ppb) levels of Total Iron in Boiler Coolant water – from BARC (in India). The invention relates to in-situ determination of total dissolved iron up to 80 ppb, using a spectrophotometer or color chart. The method involves the formation anionic colored complex of iron (Fe^{2+}-phenanthroline and Fe^{3+}-ammonium thiocyanate) which reacts with Aliquat-366 and then extracted into an organic phase comprising of decanoic acid dissolved in tetrahydofuran. This method is particularly useful in determination of total iron in boiler water for early detection of corrosion without any preparation of the sample.

Multifunctional Superabsorbent Cotton and Process for Preparation thereof – from BARC (in India). The invention relates to a novel process for making cotton based multifunctional superabsorbent for the removal of surface and underwater oil / oily substances in water. The process uses isodecyl methacrylate (IDM), grafted onto cotton by gamma radiation in ethanol / water (90:10) mixture at 10 kGy dose, making it chemically and physically robust. It has an absorption capacity of about 30 to 40 gms of oil per gm of absorbent and can be used at high temperatures and also in acidic, alkaline and neutral medium. It is also cheap and biodegradable. The oil absorbed in the absorbent can be collected and absorbent reused again. It could find application in removal of oil from oil-water mixtures involving furnace oil, high speed diesel (HSD), crude oil, hydrocarbons, organic compound like tributyl phosphate (TBP), carboxylic acid, etc.

During the same period, the patented technology, "Online Domestic Water Purification based on Polysulfone Membrane" from BARC, were licensed to two companies in India.

Among the new patent applications that were filed, the following patent applications were published during the year.

1. **System comprising Sun Ray Collimating Central Mirror and Heliostat –** from BARC (in India – App. No. 201827036596 dated 27-Sep-2018).

2. **An improved laser welding method for enhanced weld quality and enhanced surface smoothness –** from RRCAT (in India – App. No. 202027031799 dated 14-Jul-2020).

3. **A Method for Diffusion Bonding of Piezoelectric Crystal to Metal Wear Plate –** from IGCAR (PCT App. No. PCT/IB2019/052373 dated 23-Mar-2019).

4. **Use of Jack bean Lectin for increasing the abundance of hematopoietic stem cells and progenitor cells in bone marrow and/or epidermal stem cells in skin in vivo –** from BARC (in USA – App. No. 16/239280 dated 03-Jan-2019, in Europe – App. No. 19159260.9 dated 26-Feb-2019).

5. **A Novel Versatile Phoswich Detector consisting of two Single Crystals to discriminate various kinds of Radiations –** from BARC (in USA – App. No. 16/358427 dated 19-Mar-2019).

6. **Escherichia coli Cell Factory for Producing Recombinant Phosphopeptides –** from BARC (in India – App. 202021008606 dated 28-Feb-2020).

7. **A Method for producing Stable Lithium Silicates Nanosponges for capturing CO_2 –** from TIFR (in India – App. 202021008717 dated 29-Feb-2020).

8. **Apparatus for Non-Destructive Evaluation of Cylindrical objects using gamma-ray emitting radioisotope source –** from BARC (in India – App. No. 202021011942 dated 19-Mar-2020).

9. **A Process for the Removal of ^{99}Tc from Liquid Intermediate Level Waste of Spent Fuel Reprocessing –** from BARC (in Japan – App. No. 2018-537517 dated 17-Jul-2018).

The above published documents can be accessed from the respective Patent Office websites:

Indian Patent Office
http://ipindiaservices.gov.in/PublicSearch/

US Patent Office
https://portal.uspto.gov/pair/PublicPair

European Patent Office
https://worldwide.espacenet.com/advancedSearch?locale=en_EP

During the year 2020-21, about 107 Indian patent applications were referred to the Department by the Controller General of Patent, Designs & Trademarks (Department for Promotion of Industry and Internal Trade, Ministry of Commerce & Industry), 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. Departments opinion on 106 applications received earlier were communicated to the Controller of Patents in India.

Following patent proposals were approved by TTSC, BARC for forwarding to DAE:

1. Process for the use of fermented Cereal-legume slurry to make synbiotic Indian ethnic chutneys.

2. Preparation of fiber fortified idli - using legumes (other than urad) and hydrocolloids – with improved textural properties.

3. A novel, low cost, modular and compact spiral Nisargruna biogas plant for processing biodegradable waste.

4. An efficient method for the recovery of radio-ruthenium from alkaline radioactive wastes using commercial ion exchange resign.

5. Process to determine parts per billion levels of ammonia in water with emphasis on boiler coolant water.

6. A process for preparation of liposomes using super cooled micelle and emulsion.

7. Use of Chlorophyllin Composition as a medicament for prevention, mitigation and treatment of Corona Virus disease.

8. Synthesis of poly (sulfone-co-amide) polymer and development of forward osmosis membrane thereof" sent to DAE IPR Cell for further processing.

CHAPTER

8



GCNEP Township – Type D Block

INFRASTRUCTURE



**Supply of recycled water for Flushing (Phase-I)
Vajra & Chakra Building inaugurated by
Shri K.N. Vyas, Chairman, AEC & Secretary, DAE
in presence of Dr. A.K. Mohanty, Director, BARC
and Shri B. K. Jain, Director, DCSEM**

CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible to provide infrastructure support to various Units of Department of Atomic Energy (DAE) including its aided institutions. DCSEM is involved in planning, design & execution of various construction projects for Housing, Schools and Hospitals, Laboratories, Institutional Buildings & infrastructural facilities to support Scientific &Technological programs of DAE. This Directorate is also responsible for operation and maintenance of various services & Estate Management for the housing colonies of DAE at Mumbai.

During the year, the gist of major works carried out by DCSEM are mentioned as under:

Construction of R&D Laboratory for AMD and Office Building for AERB eastern region at Kolkata; Construction of Type IIB DAE Housing 24 flats at RMP Mysuru, Karnataka; RMRC Project at Kolkata; Construction of Diamond Jubilee Guest House at Rajarhat; Construction of UGC- DAE-CSR Kolkata centre building at Rajarhat; Construction of Bituminous Road, SWD, External Sewer Line, External water supply at Rajarhat; Construction of Entry Portal & Boundary wall works at RMP Yelwal, Mysuru, Karnataka.; GCNEP project at Bahadurgarh; SINP Kolkata works; Installation of Dr. Vikram Sarabhai's bust in VSB compound wall; Sewage Treatment Plants (STP) with different technologies in operation; Harnessing of Solar Energy by providing Grid Connected Roof Top Solar Photovoltaic System at various buildings in Anushaktinagar; Online flat application system in DAE Niwas Portal; Construction of MADHBAN the Urban forest in Anushaktinagar etc.



Entry Portal at RMP Yelwal, Mysuru



GCNEP Township – Type D Block



Front view of UGC- DAE-CSR Kolkata centre building at Rajarhat



Grid Connected Roof Top Solar Photovoltaic System at various buildings in Anushaktinagar

Some of the Major Works of DCSEM under progress are, Restoration / Renovation of Old Houses more than 20 years old Phase-II; Up gradation of External Engineering services under 12th plan; Construction of 356 nos. residential quarters; Hostel for trainees of BARC/HBNI Phase- I&II; Construction of Extension to V.S. Bhavan; Construction of 312 flats of type V-E at Mandala, Anushaktinagar, Mumbai; Construction of 48 Flats Type I & II flats for SMF at Chellakare, Chitradurga, Karnataka; Construction of 100 Bedded Hospital building complex at Aganampudi, Visakhapatnam, Andhra Pradesh; Construction of

Residential Quarters Type III, IV & V, Guest House B, Central Block and New School Building for GCNEP under Phase II at Bahadurgarh, Haryana; Pre Project Activities of LIGO (India) Project at Hingoli, Maharastra; Construction of Office Building for AERB (Niayamak Bhavan-C) at Anushaktinagar, Mumbai etc.



Construction of 356 nos. residential Quarters at Anushaktinagar, Mumbai



Construction of 312 flats of type V-E at Mandala, Anushaktinagar, Mumbai

Maintenance of residential flats (10169nos.) including shops and Institutional buildings viz. DAE Secretariat, Dispensaries, AEES Schools, Community Centres, Shops, DAE Guest House etc. in Anushaktinagar, Mandala & City area, including execution of upgradation works required for these buildings were carried out by DCSEM. DCSEM continued to carry out the operation & maintenance and up gradation of electrical power distribution, water supply, sewer lines, sewage treatment plant, fire-fighting system, rain water harvesting system etc. for Anushaktinagar, Mumbai.

The Estate Management continued to look after the allotment & supervision of various public buildings like banks, post office, shopping centre, community centre, etc. within the residential colony.

PURCHASE & STORES

Directorate of Purchase & Stores (DPS), a service Organisation of DAE, carries out the Material Management function of DAE since 1972. Procurement of the right material at the right price from the right source at the right time adopting the right procedure and receiving, storing, preserving, issuing the material and disposing Surplus & Scrap items has been its mandate. It also concludes various service contracts such as transportation contracts, import/export clearance contracts, Marine Insurance Contracts, etc.

The procedures for purchase and sale were continuously reviewed and simplified for improving efficiency. The e-tendering system used for procurement was upgraded and extended for sale tenders and DAE users located at remote corners were able to use the system. Tender documents were modified for implementation of Government procurement policies and for proper contract management.

Usage of Information Technology tools for materials management

Usage of Information Technology tools for materials management is being continuously increased using the technical competence of the constituent units of DAE. All major units are able to process their indents

online. Software for processing indents is also available at large units.

DPS processed about 13,000 indents and entered into about 9553 contracts for supply of equipments and material worth about ₹ 1265 crores.

Major steps were taken to extend usage of GeM at different regional units. About 3000 orders were placed in GeM and the orders released in a month in GeM increased from about 300 to 500.

E-sale is presently being used at Central Stores Unit Mumbai, Stores Unit NRB Tarapur, Stores Unit IGCAR, Stores Unit AMDER Nagpur and Indore Regional Stores Unit. Users and vendors were trained for the new application. The process of transition from manual sale tender to E-sale tenders has been successful.

The complete inventory of all zonal stores at BARC, Mumbai comprising of over 70,000 items was codified in the new 11-digit material codification system. The staff and officers of DPS were trained for its usage. Stores Unit RMC, DAE, EBC Kharghar, Kalyan Stores, BRIT Vashi and DCSEM were codified using EMATMAN (Codification Programme). All items at other Stores Unit were codified using the respective codification system available there.

Monitoring of contracts

In order to ensure speedy processing of purchase files as well as timely execution of contracts monitoring of High value cases were carried out by officers of DPS at various levels. The review of files has resulted in considerable reduction in lead time and improved contract management.

User interaction

DPS has made considerable efforts in interaction with DAE users and its vendors as they need to be educated with the latest mode of procurement.

The vendor meets at Mumbai and Chennai were organized for manufacturers of Medicine, Medical equipment and associated accessories to create awareness about the requirements of hospitals of DAE and also to obtain their feedback. Vendor meets were also organized with MSME/NSIC Manufacturers, services providers etc., to create awareness of the requirement of DAE and also to educate the vendor community with regard to the latest changes introduced in E-tendering with revised tendering conditions of the Directorate. Training on E-procurement portal are arranged for the vendors.

In order to sort out the issues related to procurement regular meetings were arranged for Departmental users. The issues as raised by the users in these meetings were addressed and monitored. In addition to these meetings issues raised are addressed through separate mail ID created for the purpose. Video Conference connectivity was established with DPS Mumbai and HWP Tuticorin, Baroda, Kota and Manuguru, VECC Kolkata, GCNEP etc.

Uranium fuel import

During the calendar year, DPS has procured uranium from Canada and Kazakhstan. Discussions were also held with uranium suppliers from Canada and Kazakhstan for new contract.

Implementation of computerised solutions for Administration

APAR (Annual Performance Appraisal Report) of all employees working in units connected with ANUNET was submitted and evaluated online using a software developed by IGCAR. A new software module developed by Computer Division BARC was used for salary disbursement and leave management for employees at DPS Mumbai, Tarapur and Mysuru.

GENERAL SERVICES ORGANISATION

General Services Organization (GSO), Kalpakkam, provides essential services to the employees of various units of DAE situated at Kalpakkam and also acts as an active interface with the neighborhood. About 4700 families reside at Kalpakkam Township and 2600 families reside at Anupuram Township. The townships are separated by about 10 KMs and are situated far away from the city. GSO was started with the primary mandate of providing Medical,

Transport, Civil and Electrical maintenance services. However, today, it has grown into a full-fledged engineering establishment taking care of various engineering activities viz. architectural design, structural design, electrical systems design, computerization, civil construction, including construction of multi storied buildings.

GSO has two Groups, the Engineering Services Group and the Medical Group. The Engineering Services Group comprising of the Civil Engineering Division, Electrical Services Division and Resource Management & Utilities Division is responsible for development, augmentation and maintenance of civil, electrical, mechanical, telecommunication and IT Infrastructure in the two Townships. The Group ensured provision of essential services such as housing, water supply, power supply, sewage treatment, solid waste management etc. Its other major activities include maintenance of roads, operation and maintenance of electronic Telephone Exchange, industrial safety, fire safety, air conditioning, transport, auto shop activities and horticulture.

The Medical Group, catered to the health care needs of about 30,000 beneficiaries. The 100 bedded hospital at Kalpakkam, offered specialist services to the Out Patients and In patients and has an ISO certified Laboratory and Radiology services. The first Phase of the Anupuram Hospital has been set up. A well-equipped Casualty with round the clock DMO as well as Departments of Ophthalmology, Orthopaedics, Dental, Physiotherapy, Lab Services and an Outsourced Pharmacy are available on daily basis at Anupuram. During March 2020, subsequent to COVID-19 Pandemic fever clinics were opened for triaging of cases, both at Kalpakkam and Anupuram Hospital. Facilities were made for the testing and treatment of patients as well as for quarantine of primary contacts.

Along with the endeavour to augment the technical capabilities, the spirit of service has also been continued, and a number of steps have been taken to enhance the services and increase the satisfaction of the residents. All the activities of GSO were supported by Accounts and Administration, who look after Personnel Management, Estate Management and Recruitment.

Some of the significant works carried out during the year includes the following:

- In-house Architectural design of 5E Tower Block comprising of twin 5E towers of 12 floors each on a common podium consisting of shopping complex and parking area.
- Construction and Commissioning of 0.15 MLD Hybrid Biofilm Granular Sludge (HBGS) technology based Pilot plant at DAE Township, Kalpakkam.
- Construction of one Tower Block of 55 Nos. of type IVD quarters and 45 Nos. of type VE quarters (G+12 storey) and one Tower block of 120 Nos. of type IIIC quarters (G+15 storey).
- Construction of Guest house with sixty rooms and six VIP suites, at the Anupuram Township.
- Construction of Kindergarten school at Kalpakkam Township.
- Expansion of Dining Hall and Kitchen for Multipurpose Hall at Kalpakkam Township
- Expansion of Environment Survey Laboratory to accommodate Health Physics Laboratory, Instrumentation, Bioassay facility etc.
- Commissioning of Fire Hydrant mains for Kendriya Vidhyalay-2 and Atomic Energy Central School-2 Schools.
- Development of a medicinal garden at Kalpakkam Township with over a hundred medicinal herbs & shrubs and an eight way walk.
- Construction of the final phase of Security Isolation Fencing. Due to construction of this fencing, total isolation from the neighbourhood could be achieved during COVID Lockdown period. This helped to

contain spread of the pandemic and considerably reduced the number of COVID positive cases within the township.

- Refurbishment works: Old infrastructure are periodically refurbished to strengthen them and extend their life. During this year refurbishment of 0.6 MGD sewage treatment plant was completed. Refurbishment of residential buildings along with introduction of latest DAE Norms was carried out. Refurbishment of pathology lab, pharmacy and other areas at the DAE Hospital was also completed.

- Digitization of administration records, implementation of E-gazette, issue of smart cards for CHSS beneficiaries and introduction of online reservation system in Guest Houses.

- Organization of National Level Technical Seminar in Hindi – "Oorja Ke Kshetra Me Bharatiya Vigyan Evam Takniki Pragathi", along with Indira Gandhi Centre for Atomic Research.

- Release of the first issue of the Trilingual Magazine ANUNAD, on 10th January 2020 - World Hindi Day.



Tower Block of Type IVD-VE Quarters at Anupuram Township



Release of GSO Magazine – ANUNAD

Covid-19 Pandemic Management

During the COVID-19 Pandemic Lockdown, the Engineering Services Group and Medical Group worked in full strength to provide essential services to the residents. Stringent security measures, sanitization, barricading of Containment Zones, provision of essential commodities was ensured, at both Townships. Two fever Clinics, Four Quarantine Centres, a COVID Care Centre and a Post COVID Clinic were set up at the two townships. Sample Collection booths for RT PCR testing were started at Kalpakkam. Medical camps were held for contract workers and preventive medicines were issued. In recognition of their services the Engineering Services Group and Medical Group were felicitated as "COVID WARRIORS" during the Independence Day Celebration.



COVID Warriors

CHAPTER 9



MONAL Health Monitoring System

PUBLIC SECTOR UNDERTAKINGS

(FINANCIAL PERFORMANCE)



7.5m S/X-band 3 axis Tilt Antenna System

Financial performance of DAE's public sector undertakings namely, the Nuclear Power Corporation of India Ltd., Uranium Corporation of India Ltd., Indian Rare Earths Ltd. and Electronics Corporation of India Ltd. are given below. (BHAVINI is yet to commence commercial operations). Operational highlights of these public sector undertakings, except ECIL, have been covered under the relevant major programme heads. Gist of the financial performance of these units along with detailed operational performance of ECIL is given here.

NUCLEAR POWER CORPORATION OF INDIA LTD.

The provisional profit after tax (Total Comprehensive Income) up to December 2020 in current FY 2020-21 is ₹ 3601 crore and the estimated profit for FY 2020-21 is around ₹ 4065 crore. The net profit after tax (Total Comprehensive Income) for previous FY 2019-20 was ₹ 4339 crore. NPCIL Bonds are rated 'AAA' (Highest Safety) by CRISIL, CARE, ICRA and India Rating.

URANIUM CORPORATION OF INDIA LTD.

The performance of all major units of the company during the year 2019-20 remained quite satisfactory. The total income of the Company during the year 2019-20 was ₹ 2,419.60 Cr as against ₹ 2,034.79 Cr during the previous year. The Company has registered a Profit before Tax of ₹ 596.83 Cr in the year 2019-20 as against ₹ 392.69 Cr in the previous year.

INDIAN RARE EARTHS LTD.

During the financial year 2019-20, the company achieved highest ever sales turnover of ₹ 1038.74 crore, registering growth of 35% as compared to corresponding period of previous year. The company achieved highest ever Profit Before Tax (PBT) of ₹ 402.94 crore registering growth of 101% as compared to corresponding previous year.

During the period April to December 2020, the company has achieved Sales Turnover of ₹ 689.82 crore as against ₹ 773.21 crore achieved during the corresponding period of previous year. The Company achieved Profit Before Tax (PBT) of ₹ 253.30 crore during the period April to Dec, 2020 as against ₹ 312.68 crore during the corresponding previous year due to impact of COVID-19 pandemic.

Demand driving sector of IREL products viz Aviation, Automotive, Oil and Petroleum drilling Projects, e-mobility Robotics and Machinery severely impacted due to COVID-19. Chemical production was affected due to disruption in supply chain and closure of downstream industries.

ELECTRONICS CORPORATION OF INDIA LIMITED

Electronics Corporation of India Limited (ECIL) was established to support the Control and Instrumentation (C&I) requirements of India's Nuclear Program. The company 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. Self-Reliance in Strategic Electronics continues to be the driving force of the company in providing many innovative products and customised solutions to the customer. The journey of innovations driven by in-house R&D efforts have enabled the successful realization of the following solutions:

- High speed hot standby redundant PLC system for mission critical applications
- 100 KW Variable Frequency Drive for speed control of induction motors
- Area Iodine Activity Monitor for continuous monitoring of Iodine 131 in Nuclear Power Plants
- Solid State Pulsed Power Modulator for driving electron guns and microwave devices to power the Radio Frequency cavities of Linear Accelerators
- Fast Leak Detection System for real time leak monitoring of Oil and Gas pipelines from main Control Centre

- Online Flight Plan Management System that allows a Pilot to plan, log and fly from anywhere within minutes
- 500 MW UHF Power Amplifier for Electronic warfare applications
- Radar Digital Signal Processing System (RDSP) for RF Seeker
- 3 Axes stabilization system for S and X band Antenna for command/data reception from satellites
- IOT based solution for Remote Monitoring and Tracking of COVID 19 patients and quarantined people

Major contribution emanated from Defence vertical with 48% of turnover primarily from the supply of Electronic Fuses, Military Radios, Submarine Systems, Seekers and Strategic Communication Networks. Nuclear vertical contributed for 28% of turnover with the supply of Control and Instrumentation Systems for operating and upcoming Nuclear Power Plants. A share of 10% of turnover is contributed by IT and e-Governance vertical with the supply of election support equipment and services. Security vertical contributed 9% of turnover with the supply of Access Control Systems, Surveillance Systems and various types of Jamming equipment. Supply of Antenna Systems for Space programs contributed for 3% of turnover. SCADA systems for major Oil Companies and other equipment contributed for 2% of turnover.

Performance

The Company recorded a turnover of ₹ 1639 Crore in the year 2019-20 as against ₹ 2716 Crore in the year 2018-19. Correspondingly, the Company achieved a PBT of ₹ 81.39 Crore with a PAT of ₹ 50.43 Crore against PBT of ₹ 367.03 Crore with a PAT of ₹ 242.50 Crore in FY 2018-19.

ECIL has set a target of ₹ 1640 Crore as turnover in its MOU with the Department of Atomic Energy for the year 2020-21 and has achieved a turnover of ₹ 710 Cr. till end Dec 2020.

The sector-wise significant contributions during the year are as follows:

Nuclear

The major contribution came from Nuclear Instrumentation Package for upcoming Nuclear Power Plants, life cycle support for C&I Systems, Flash X-Ray, Ultra Stable Power Converters, Computer Alarm Annunciation System and Passive Catalytic Recombiner Devices (PCRD) for operating Nuclear Power Plants.

1. Nuclear Instrumentation Package (Control and Instrumentation) for upcoming Nuclear Power Plants



Nuclear Instrumentation Package (Control and Instrumentation) for upcoming Nuclear Power Plants



Flash X-Ray system



Entry Portal at RMP Yelwal, Mysuru

2. Flash X-Ray system

3. Ultra Stable High Voltage Power Converters for FAIR, Germany

4. Passive Catalytic Recombiner Devices for Operating Nuclear Power Plants

5. Nuclear Instrumentation for 700 MW PHWRs

Aerospace

In Aerospace, the major contribution came from supply of various types of Antennas and Rate Gyroscopes for national space programs, Online flight plan management system, Actuators and Solid State Cockpit Voice Recorders.

1. Rate Gyroscopes for national space programs

2. Solid State cockpit voice recorder

3. Ka Band Antenna System for Broadband Communications

4. Antenna Platform Unit for LCA



Rate Gyroscopes for national space programs



Solid State cockpit voice recorder



Antenna Platform Unit for LCA



Ka Band Antenna System for Broadband Communications

Defence

For Defence, the major contribution came from Electronics Fuzes, Strategic Communications Network, Seeker, Command and Control Centre for various Missile projects and Military Radios

1. V/UHF Military Radios

2. Universal Electronic Fuzes

3. Command and control centre for various missile projects

4. Seeker for Missile Programme

5. Actuators



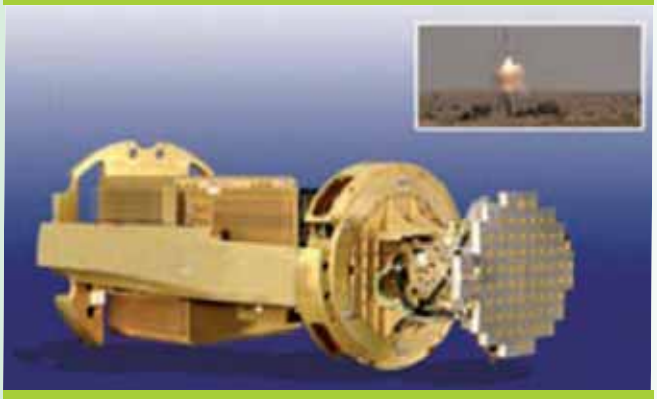
V/UHF Military Radios



Universal Electronic Fuzes



Command and control centre for various missile projects



Seeker for Missile Programme



Actuators

Security

The major contribution was from the Access Control Systems, Explosive Detectors, Integrated Security & Surveillance Systems and various types of Jammers.

1. Jammers
2. Biometric Access Controlled System
3. Tyre Killer and Active Bollards
4. Under Vehicle Scanner





Jammers



Biometric Access Controlled System





Tyre Killer and Active Bollards



Under Vehicle Scanner

IT, e-Governance & Others

For IT, E-Governance & others, the major contribution was from supply of EVMs and Voter Verifiable Paper Audit Trail (VVPAT) Equipment for Election Commission of India, State Election Commissions and various Local Government Elections, EVM Power Packs, SCADA for Oil Companies and IT training.

1. EVM and VVPAT
2. SCADA for oil companies



EVM and VVPAT





SCADA for oil companies

R&D Program and New Products

The in-house R&D Programme is guided and supported by the Technology Development Council

(TDC). Several new products that have been introduced into the market are:

Smart Energy meter

ECIL's Smart Energy Meter got Bureau of Indian Standard (BIS), license for Single Phase 2-Wire accuracy Class 1 Type EM5869P, Voltage-240V, Basic Current (Ib)-10A, Maximum Current (Imax)-60A, Frequency-50Hz, Load Switching Utilization Category UC1, Insulating Encased Meter of Protective Class II with Virtual Token Carrier Interface.

It's a Prepaid Electronic Energy Meter used for smart metering solutions intended for Domestic & Agricultural applications. It has built in RF/GSM modems and used are both single-phase and three phase distribution systems. It is compliant to IS: 15884:2010.



Smart Energy meter



7.5m S/X-band 3 axis Tilt Antenna System

7.5m S/X-band 3 axis Tilt Antenna System

ECIL has indigenously designed and developed 7.5m S/X-band 3 axis Antenna System. It can deliver high performance for transmit/receive application in S/X- band with high gain, low noise and low microwave interference. It is a Cassegrain type Antenna system with reflector mounted on Elevation over Azimuth over train mount (3 axis tracking pedestal). The Elevation drive system can scan the entire sky from about an elevation axis between 5º below the horizon to zenith and Azimuth drive system can achieve movement of ±360º rotation about the Azimuth axis. It's an import substitute and complies with statutory & regulatory requirement for satellite tracking.

Duel View X Ray Baggage Inspection System

The prototype testing has been completed and the final version will be ready by end Jan 2021. AERB and CE certifications are being pursued.



Duel View X Ray Baggage Inspection System

Explosive Detector

IMS based explosive detectors has been jointly developed by ECIL & IGCAR, under funding from PSA office. The systems have been supplied to IB, CISF, CRPF and other paramilitary forces for field evaluation.



Explosive Detector

MONAL Health Monitoring System

Social distancing is the new norm under present pandemic. Monal is one of the need based product developed which facilitates remote monitoring of vital health parameters of Corona affected patients on near real time basis.



MONAL Health Monitoring System

The product is IOT based wrist band which measures vital health parameters like body temperature, heart rate, oxygen saturation, respiration rate of patient and can transmit to a designated doctor through cloud, mobile phone or Bluetooth enabled network.

Network Switches – 8 Port Industrial Grade Switch

ECIL has initiated in-house production of 8 Port Industrial grade Ethernet switches. These switches find application in various Networking Projects such as CCTV surveillance, Campus wide Networks, Smart City, Bharat Net etc.



Network Switches – 8 Port Industrial Grade Switch



Thermal Cameras for Entry Point Screening

Thermal Cameras for Entry Point Screening

ECIL has developed application software for integration of commercially available Thermal and Optical cameras into a robust and reliable temperature measurement system for human bodies, for deployment at entry points of offices premises for screening of suspected cases of COVID-19.



PRANVAYU Ventilator

PRANVAYU Ventilator

The ventilator has been designed and developed by RRCAT & ECIL. The functional and validation testing of the prototype is under progress.

New Facilities

The company is currently investing in creation of new facilities for manufacturing of Carbon Fiber Technology based Antenna Systems, Scintillator Crystals and Solid State RF Power Amplifiers which would help to bring out niche technology products of strategic importance. Some of the facilities that have been augmented/ created are as follows:

Special Component Manufacturing Facility (SCMF)

ECIL has set up state of art machining facility comprising of state-of-the-art sophisticated CNC machines, High Precision Medium CNC Turn Mill Centre, High Precision 5 Axis Machining Centre, CNC Cylindrical Grinding Machine and EDM Wire Cut machine for manufacturing of precision components for strategic applications. This facility will have advantage of cost savings and less dependency on the market to meet demand of DAE requirements.



Special Component Manufacturing Facility (SCMF)

Automated rework station for repair of PCBs

Automatic rework machine ZEVAC ONYX 29, performs precise, accurate, and safe rework of SMDs, Plastic, Metallic & Ceramic BGAs, PoP, Flip Chip, QFP, QFN, SOIC, PLCC, Connectors and all other standard (chip components) & non - standard SMD packages. The machine has the capability to perform replacement (De-soldering + Pad cleaning + Solder paste / flux dispensing + Pick & Place of the component + Soldering of the component with programmed profile) of multiple components on a single PCB in single cycle under single execution program.



Automated rework station for repair of PCBs

Flying Probe Tester

The Pilot H4 Next automatic version is a fully automated flying probe test facility, eliminating the need for continuous operator presence to manage the operation. This has integrated SMEMA conveyor and can be combined with automatic load/unload magazines or lines, executing in-circuit, functional and visual tests of electronic boards in a completely automated mode. This is the ideal solution for medium and even high-volume production test needs.



Flying Probe Tester

SSRFPA Test Facility

Test and evaluation facility for Solid State RF Power Amplifiers (SSRFPA) was established to meet the stringent quality requirements of international mega science accelerator programme. High Power SSRFPA has been designed and maintained by ECIL in partnership with BARC (325MHz) and RRCAT (650MHz).



SSRFPA Test Facility



Environmental Test Chambers

Environmental Test Chambers

The facilities have been upgraded with Dust Chamber and Thermal test facility to augment the in-house testing facility. To improve upon the quality and defect free manufacturing, the Company has also installed Vibration Test Facility, Thermal Shock Chamber and Environmental Stress Screening (ESS) Chamber.

CHAPTER

10



Shri K. N. Vyas, Chairman, AEC and Secretary, DAE participated in the cleanliness drive organised by DCSEM at Anushakitnagar, Mumbai

OTHER ACTIVITIES



Oxygen concentrators and ventilators were provided to Civil Hospital, Fatehabad District, Haryana by NPCIL. This is to help people affected by Covid-19

BARC-SAFETY COUNCIL

BARC Safety Council (BSC) is responsible for safety review of all nuclear, radiological, industrial facilities of BARC. They include operating and upcoming facilities, such as research reactors, fuel fabrication, fuel reprocessing, waste management and post irradiation examination facilities; industrial irradiators; radiological laboratories; particle accelerators; and other radiological, industrial and research facilities. BSC undertakes safety regulation through BARC Safety Framework, consisting of about 90 safety committees.

In the year 2020, more than hundred meetings of various committees of BSC were held and some of the major achievements of BSC during 2020 includes Granting of about 60 regulatory consents, such as siting, construction, equipment installation, commissioning and operation, including their extensions, for various facilities and projects; Authorised procurement, handling, storage and use of 13 radioactive sources; Authorised safe transfer of 11 radioactive sources; Approved 33 Competent Persons for testing and certification of Material Handling Equipment (MHE); Approved 28 Radiological Safety Officers (RSOs); Monitored and reviewed radiation / fire / chemical emergency exercises conducted at 24 facilities; Monitored and reviewed regulatory inspections conducted at 22 facilities; Reviewed dose data of 32 nuclear and radiological facilities on a quarterly basis; Reviewed solid, liquid and gaseous waste transfer / disposal data of 32 nuclear and radiological facilities on a quarterly basis; Reviewed effluent water quality monitoring survey report on a quarterly basis for 20 sampling points of BARC; Apportioned public dose and radioactive effluent discharges for one facility; Authorised safe transfer, storage and disposal of radioactive waste for 14 facilities; Type-approved four transport containers for transporting radioactive materials; Reviewed reports of significant events; Prepared and released safety manuals such as Radiation Protection Manual for BARC Facilities and Industrial Radiography Testing in BARC Facilities by External Agencies; Prepared the safety directives such as Safety Directives for Construction Activities in BARC Facilities and Safety Guidelines on Management of Category-I Solid Radioactive Waste; Conducted Training Courses on Safety and Regulatory Measures for BARC Facilities and Crane and Forklift Operations and Developed a software for estimating Fire Safety Index of buildings.

CRISIS MANAGEMENT

The Crisis Management Group (CMG), which is the standing Committee of senior officials of the Department of Atomic Energy (DAE), carries out the function of overseeing the Department's emergency preparedness for responding to any radiation emergency in the public domain and coordinating response actions with state or national level public officials / agencies.

Testing of the formal emergency response systems on a regular basis was ensured during the year with an objective to check its efficacy. Also, CMG continued to function as the contact point of DAE to provide its expertise in the field of nuclear / radiological emergency management at various National and International fora.

Availability of the Emergency Control Rooms (ECRs) located at two different places in Mumbai, which are backing-up one another, was ensured throughout the year. These control rooms, manned on round-the-clock basis and equipped with diverse means of communication; remained in contact with various nuclear facilities in the country, with Ministry of Home Affairs (MHA) as well as with the International Atomic Energy Agency (IAEA) in Vienna. The Emergency Control Rooms of DAE are the National Contact Point for nuclear and radiological emergency. Uninterrupted 24 x 7 functioning of the control rooms was ensured even during the lockdown period due to Covid19 pandemic.

During the year 2020-21, India participated in three numbers of International Convention Exercises, known as “ConvEx”, conducted by IAEA, which are designed to test various aspects of the international emergency preparedness and response (EPR) framework. As the Competent Authority, Crisis Management Group (CMG) coordinated India's active and satisfactory participation in these exercises.

To ensure that the emergency plans are in high state of readiness, major nuclear facilities like nuclear power stations and heavy water plants periodically carry out variety of emergency exercises. The numbers of such exercises monitored / participated by CMG during the year 2020-21 are Communication Exercises – 438; Fire Emergency Exercises – 81; Plant Emergency Exercises – 51; Site Emergency Exercises – 14 and Off-Site Emergency Exercises – 02; Rad. Emergency Exercise at Airports – 04 numbers.

CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Rawatbhata, Rajasthan as well as Kakrapar, Gujarat NPP sites. The exercises were found to be effective and satisfactory.

In order to finalise the revision of the "Standard Operating Procedure (SOP) of BRIT for 'Safe and Secure Transportation of Radioactive Materials', comments of the Ministry of Home Affairs on the security measures prescribed in the document were obtained and conveyed to BRIT. The revised document incorporating the MHA suggestions was issued.

Review of the security aspects in the NPCIL document for 'Transport of spent fuel by road' was done and suggestions were conveyed for incorporation in the ongoing revision.

Annual review / updating of the 'Crisis Management Plan of DAE for Nuclear and Radiological Emergencies' was done on the basis of the 'Crisis Management Plan of the Government of India-2019'.

INTERNATIONAL RELATIONS

India, a founding member of the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA), continued to take active part in policy management and programmes of the IAEA. India was represented on a number of IAEA Committees, including those on safety, safeguards, nuclear radiation, nuclear engineering and application, nuclear law etc. India hosted several IAEA Workshops, Technical Meetings etc., and offered the services of its experts under the IAEA Technical Cooperation programme in a number of fields. India made contributions towards Innovative Nuclear Reactors and Fuel Cycles (INPRO), Technical Cooperation Fund (TCF) and Regular Budget of the IAEA.

India's participation in the 64th Annual session of the IAEA General Conference, Vienna during 21st-25th September 2020

Considering the primacy of the IAEA General Conference in India's international engagement in the field of civil nuclear energy, Chairman, AEC and Secretary, DAE led the Indian delegation and gave a pre-recorded video statement for delivering in the Conference. Secretary, DAE led the Indian delegation comprising of Director, BARC, Chairman, AERB and Joint Secretary (ER) to the IAEA 64th General Conference which was held at Vienna, Austria from 21st-25th September, 2020. The participation of Secretary, DAE and his delegation was virtual, through Video Conference. In addition to this, H.E., the Ambassador and officials from Indian Permanent Mission in Vienna, participated in the event.

Bilateral meetings with our international partners

On the sidelines of General Conference, Chairman, AEC had virtual bilateral meetings with delegations from AFCONE, Uzbekistan, France, Kazhakstan, Vietnam, U.K., Ghana and Russia.

The following Agreements and MoUs were signed:

- **India - EURATOM Agreement**

An Agreement between Government of India and European Atomic Energy Community (EURATOM) has been signed for Research and Development Cooperation in the field of Peaceful Uses of Nuclear Energy. On the Indian side the Agreement has been signed by Secretary DAE and Chairman AEC; on the EU side by Ms. Maria Gabriel, Commissioner for Research, Innovation and Education. The 15th Summit between India and the European Union (EU) was held in virtual format on 15th July 2020. India was represented by Hon'ble Prime Minister. The EU was represented by Mr. Charles Michel, President of the European Council, and Ms. Ursula von der Leyen, President of the European Commission. In the Joint Statement issued on the occasion the leaders welcomed the signing of the India-EURATOM Agreement on Research and Development

cooperation in the peaceful uses of nuclear energy. The leaders endorsed "India-EU Strategic Partnership: A Roadmap to 2025" as a common roadmap to guide joint action and further strengthen the India-EU Strategic Partnership over the next five years. One of the action points is to implement the India-EURATOM Agreement on Research and Development cooperation in the field of the peaceful uses of nuclear energy. The proposed agreement mainly envisages cooperation in research and development areas including in nuclear fission, advances in development techniques and methodologies of nuclear safety security and safeguards, basic and applied research in nuclear sciences, non power applications of nuclear technology such as agriculture, health care, industrial isotopes, controlled thermonuclear fusion and education and training. The membership of EURATOM includes 27 European countries.

- **Signing of New GCNEP MoUs**

GCNEP and AFCONE

On the sidelines of the 64th General Conference held during September 21-25, 2020, Memorandum of Understanding (MoU) between Global Centre for Nuclear Energy Partnership (GCNEP) and African Commission on Nuclear Energy (AFCONE) was signed virtually on 21.09.2020. From the Indian side the MoU has been signed by Secretary, DAE and Chairman AEC; and from the AFCONE side by Mr. Messaoud Baaliouamer, Executive Secretary, AFCONE. AFCONE is a treaty body and an inter-governmental organization mandated by the 42 African State Parties to the Pelindaba Treaty to encourage regional, sub-regional and international cooperation programs for peaceful uses of nuclear science and technology.

GCNEP and M/s.Uzatom Agency, Uzbekistan

On the sidelines of the 64th General Conference held during September 21-25, 2020, MoU between GCNEP and the Agency for the development of Nuclear Energy under the Ministry of Energy of the Republic of Uzbekistan was signed virtually on 21.09.2020. From the Indian side the MoU has been signed by Secretary, DAE and Chairman AEC and from the Uzbek side by Mr. J. Mirzamahmudov, First Deputy Minister of Energy-General Director of Uzatom Agency.

Both the MoU's facilitates organizing training, seminars, workshops and lectures by research experts from both sides on topical issues to develop a pool of trained human resource in the areas of peaceful uses of nuclear energy.

- **Renewal of the MoU between GCNEP and USA**

In view of the strong and successful cooperation activities under the MoU, an Arrangement extending the duration of MoU between the Government of India and the Government of the United States of America concerning cooperation with the GCNEP, India was signed on 26.10.2020. The validity of the MoU will be upto 6th November 2030.

- **Extension of IAA between GCNEP and BAEC**

Amendment No.1 to the Inter Agency Agreement Between GCNEP, DAE, Government of India and Bangladesh Atomic Energy Commission (BAEC), Ministry of Science and Technology, Government of the People's Republic of Bangladesh on cooperation regarding Nuclear Power Plant projects in Bangladesh was signed on 03.12.2020. The Amendment extends the validity of the IAA by three year with automatic renewal clause after that.

- **Renewal of MOU between DAE and CEA France**

An MoU extending the validity of the Cooperation Agreement was signed between DAE and the Commissariat a L'energie Atomique Et Aux Energies Alternatives France (CEA) in the field of Nuclear Science and Technology for Peaceful uses of Nuclear Energy. The validity of MoU is extended till 21.02.2024.

- On 21.12.2020, a virtual meeting between the Hon. PM of India and the Hon. PM of Vietnam was held. During the meeting, among others, the following two documents pertaining to DAE were listed as outcome:

  i. Memorandum of Understanding (MoU) between Tata Memorial Centre (TMC) and Vietnam National Cancer Hospital (VNCH), Vietnam.
  ii. Memorandum of Understanding (MoU) between Atomic Energy Regulatory Board

(AERB), Government of India and the Vietnam Agency for Radiation and Nuclear Safety (VARANS), Vietnam.

Apart from the above the following additional activities were undertaken:

i. Frequently Asked Question (FAQ) version 2 on CLND Act was notified on 25.08.2020 and the same is displayed on DAE's website.

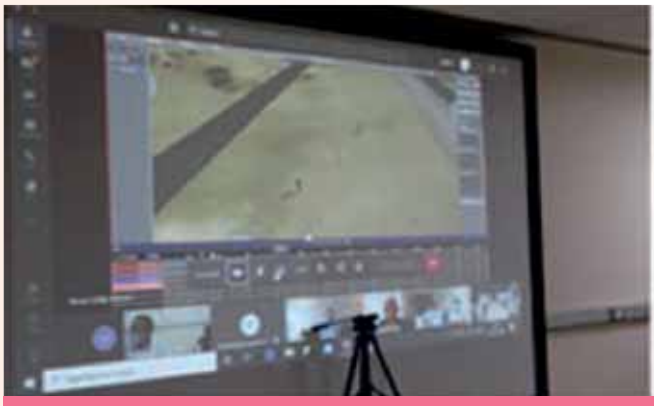
ii. The 'Notification' declaring Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP), Gorakhpur Site as "Prohibited Area" and 'Order' declaring the authorities for restricting entry under the Atomic Energy Act, 1962, have been published in Gazette of India on 06.08.2020.

Global Centre for Nuclear Energy Partnership (GCNEP) is being established at Kheri-Jasaur, Bahadurgarh, Haryana to promote safe reuse and sustainable nuclear enery for the service of mankind through Global Partnership. GCNEP is the sixth R&D unit under the aegis of Department of Atomic Energy (DAE). GCNEP Phase-I is operational since April 2017 while Phase-II is under construction.

Inspite of COVID-19 pandemic situation, construction & facility augmentation progressed fairly well at GCNEP. During nationwide lockdown, all essential services and activities were continued as per the government guidelines. June 2020 onwards, all activities including Phase II construction were resumed to full scale, while observing all necessary precautions for COVID-19. Under Phase-II, construction of Central Building, School Building 2, Service Building, Gate House, Guest House Block-B, Dining & Recreation facilities & Residential Blocks are in advanced stage.



Central Building Work in Progress



Online Indo-US Modelling & Simulation Workshop



GCNEP Guest House Block-B work in progress

Several meetings & review of on-going activities were carried out using virtual platform. One program on Modelling & Simulation for Nuclear Security was also carried out using virtual platform, under Indo-US collaboration.

Work is in progress to equip extended Guest House Block-D with essential facilities including IT infrastructure, Electrical System, furnishing etc. Setting up of Sensor Evaluation Test Bed Facility (SETBF) is in progress at GCNEP Campus. Majority of the equipment including sensors for Physical Protection Systems has been received at GCNEP and shall be installed post completion of on-going civil and electrical works. During 2020, the Centre also expanded its activities for experiments on mutated seed for wheat & mustard with the help of NAB&TD, BARC. An approximate area of one acre has been put under cultivation for this purpose.

As per IAA between GCNEP and BAEC, Bangladesh Indian technical experts are regularly being deputed for Roopper Nuclear Power Plant (RNPP) project in Bangladesh for providing advisory services as per request of BAEC. Indian experts got stuck up at RNPP site due to COVID-19 pandemic. They were

brought back to India under Vande Bharat Mission with the help of MEA and Indian Embassy in Dhaka. A total of 17 Indian experts have been deputed so far.

NPCIL is a member of international organizations namely World Association of Nuclear Operators (WANO) and Candu Owner's Group (COG) and is actively participating in their programs for enhancing the safety and reliability of nuclear power plants.

NPCIL is one of the founding members of WANO and most of its nuclear power plants are affiliated with two WANO regional centres namely WANO Tokyo Centre and WANO Moscow Centre. WANO was established in 1989 and its mission is to maximize the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices. Almost all nuclear power plants (except a few) operating in the world or under construction are its members. NPCIL representatives are in the Governing Board of WANO Tokyo Centre and WANO Moscow Centre. In this year, WANO initiated a COVID-19 Human Performance Forum to raise awareness of potential human performance challenges, to share good practices for human performance reliability, to identify practical leadership at all levels and to agree how WANO can continue to provide support to members in achieving reliable operational human performance. A few remote meetings of the forum were held through video conferencing / virtual meeting. All the related documents have been made available on WANO website for the benefit of its members. During this year, WANO Peer Reviews of TAPS-1&2, RAPS-5&6 and WANO Follow-up Review of NAPS were scheduled. However, these reviews have been postponed by a year due to travel restrictions due to COVID-19 pandemic.

As visit by WANO subject experts to its member utilities including NPCIL was mostly restricted due to COVID-19 pandemic, WANO restructured its programmes through virtual meetings using MS Meeting or equivalent facility. It conducted virtual workshops like Operators Fundamentals, Maintenance Fundamentals and Equipment Reliability. It also conducted Simulator Training Expert Group Meeting, Training on WANO Event Report (WER) Direct Entry and Self-Assessment of WANO SOERs and Leadership, etc. In these virtual programmes many persons from NPCIL stations and HQ participated. NPCIL successfully conducted Emergency Response drill exercise with WANO.

NPCIL participated in some of the COG meetings held through video conferences to discuss the issues of mutual cooperation. NPCIL participated in the information exchange programme of COG.

NPCIL continued to provide information for IAEA PRIS (Power Reactor Information System) database. NPCIL representative was involved in the testing of new web based PRIS Data Acquisition and Validation Application (DAVA). The system was later released by IAEA for use by members.

VIGILANCE

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

The activities of Vigilance section of DAE Secretariat during the year included submission of 27 monthly/quarterly/annual returns to various authorities such as Central Vigilance Commission (CVC), Department of Personnel and Training (DoPT), and Central Bureau of Investigation (CBI); Processing of 9 new Disciplinary cases of Group 'A officers; Processing of complaints: 28 complaints were downloaded from CVC portal and 3 complaints received through PG Portal which were forwarded to respective Units for investigation after thorough examination and reporting. Besides, complaint from CBI has also been processed. 26 cases have been closed with the approval of Competent Authority after necessary investigation; About 42 complaints have been received directly in the Department. After confirming the authenticity of the

complaint, carried out necessary investigation and 12 complaints were closed with the approval of Competent Authority; Vigilance clearance were given for various purposes to 2491 Group 'A' officers of Units, Aided Institutions and PSUs as well as staff in the Secretariat; Appointment of Vigilance Officer/ Chief Vigilance Officer of Constituent Units/ Aided Institutes in the Department; Scrutiny of Annual Immovable Property Returns in respect of Officers and staff of DAE Secretariat; Co-ordination between CVC and Units for conducting of CTE (Chief Technical Examiner) examination and few establishment case / work orders of DAE Secretariat were verified as a part of preventive vigilance activities.

As per the directives of Central Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2020" was observed in DAE during October 27th to November 2nd, 2020 on the theme of "सतर्क भारत, समृद्ध भारत (Vigilant India, Prosperous India)". The week commenced by administering integrity pledge; it was displayed through DARPAN portal to the all employees of DAE Secretariat on 27.10.2020. Various competitions such as Slogan writing, Poster drawing competitions etc. were held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Prizes for the winners of the respective competitions were distributed in cash with due precautions as per COVID-19 guidelines. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance in any organization is an integral management function like any other function of management such as finance, personnel, operation, contracts etc. Vigilance Directorate of NPCIL works to spread awareness and to sensitize employees against malpractices and corruption to achieve organizational goals. The important activities and events to achieve this during the period April to December 2020 are summarized below:

As part of preventive vigilance measure and to spread vigilance awareness amongst the stakeholders, 26 Vigilance Awareness Programmes/ Seminars/ Interactive sessions were organized at Head Quarters (HQs) & Sites. Vigilance Officers carried out 122 surprise/ regular inspections at all NPCIL units. Seven Chief Technical Examiner (CTE) type inspections were also carried-out.

Vigilance Awareness Week (VAW) was observed to achieve the objective to eliminate corruption in public life with zeal and enthusiasm in NPCIL HQs and at all its Units located in different parts of the country during the week from 27.10.2020 to 02.11.2020.

Mass Integrity Pledge was administered to employees at HQs & all sites during the opening ceremony of VAW. Mass integrity pledge was also administered to contracts workers at various sites. Total 1430 employees have undertaken online integrity pledge on Central Vigilance Commission (CVC) website and on internally developed systems.

In spite of the prevailing COVID-19 pandemic situation, NPCIL organized various activities/ competitions on the theme and vigilance awareness topics viz. Essay Writing, Slogan Writing, Poster/Cartoon Drawing, Vigilance Quiz, Elocution, Debate Competitions, Speech Competition, Spot painting etc. at NPCIL HQs and at its Units for employees, their family members, contract workers etc.

Artistic wall painting relevant to this year's theme was painted at prominent places where maximum foot fall occurs in the Townships of the Units. Large size visually appealing banners in Hindi, English and local languages were displayed at prominent places in HQs, Townships, Plant Sites, important road junctions and nearby areas to refresh the spirit of vigilance amongst employees, residents and general public visiting from outside.

Wide spread propagation of vigilance messages was carried out through e-Notice Boards and pop-up messages on the home page of intranet of HQs and Units. Also, LED installed at various locations within the plant premises were utilized for continuous display and spreading the anti-corruption messages with this year's VAW theme.

Around 14 Vigilance Officials of HQs and Units were imparted short duration online training from reputed institutes to enhance their capability and skills.

RTI COMPLIANCE

An elaborate RTI Application management mechanism exists with functional arrangement of 8 CPIOs and 7 APIOs, one at each NPCIL Station/Sites along with one CPIO, one APIO and one Appellate Authority at NPCIL Head Quarters, to deal with the requests received under the RTI Act 2005.

The mandatory information required under the Act [section 4(1) (b)] is posted on NPCIL website and the information is updated from time-to-time. Presentations/ lectures/ Training were organized in NPCIL for creating awareness about the importance and ways to implement the Act.

During the FY 2020-21 as on 31.12.2020, 592 RTI applications and 30 Appeals were received under the RTI Act, 2005 and disposed off. In the case of NPCIL, there were 10 cases (Second Appeal) heard by Central Information Commission, New Delhi.

Department of Personnel & Training (DoPT) RTI online portal is used effectively in NPCIL. The online RTI applications and appeals so received are being disposed through portal online.

IGCAR complies with the provisions of RTI Act, 2005. In this regard, the Unit has suo moto declared information under the provision of Section 4 of RTI Act 2005. This suo moto declaration is updated regularly as and when there is any change. During the year 2020, 134 applications were received and processed.

RTI related issues have been dealt with efficiently at AMD. A total of 302 RTI applications were received out of which 292 were replied and 10 are transferred. 24 appeals for first appellate authority were received and replied. 3 CIC hearings on second appeal were attended and orders passed by CIC on 2 hearings and while date was fixed for 1 appeal but later cancelled.

During the period from 01.04.2020 to 31.12.2020, 90 RTI applications were received by IREL, out of which 88 applications have been replied as per RTI Act, 2005.

ECIL received 90 requests for information during the year 2020-2021. In addition to that, 15 requests were carried forward from the previous year. Information was provided against 91 requests; 3 requests were returned due to non-conformity and the balance 11 were pending for disposal as on 30.12.2020. Most of the requests were for information on recruitment, service related and commercial related matters.

At UCIL, the number of RTI queries received and replied during the FY 2019-20 were 150 and 150 respectively. The same for the year 2020-21 (up to December 31, 2020) were 97 and 92 respectively.

During the year, BHAVINI received 46 RTI applications out of which 44 were replied and it received 9 appeals of which 4 have been replied.

The number of RTI applications received at RRCAT were 86 out of which 73 applications were disposed of.

During the year, DPS received 58 RTI applications and out of this 56 were answered.

OFFICIAL LANGUAGE IMPLEMENTATION

The Official Language activities towards promotion of use of Official Language (OL) Hindi in the various fields of Nuclear Sciences and Technology were carried out despite Covid-19 pandemic lockdown in the constituent Units of DAE, its PSUs and Aided Institutions. Some notable efforts are mentioned below:

DAE has carried out 10 OL inspections in the Offices of its Units/PSUs/Aided Institutions. During this period, Hon'ble Parliamentary Committee on Official Language inspected 06 Units/ PSUs namely, AMD, New Delhi; NPCIL, Noida; NPCIL, Narora; ECIL, New Delhi; NPCIL, Kota and AMD, Jaipur.

A total of 48 offices of the Department have been notified in the Gazette of India under Rule 10(4) of OL Rules, 1976 so far. A total no. of Hindi Officers and employees are working in DAE Units, PSUs and Aided Institutions 99.

Cabinet notes to be submitted to various Committees of the Parliament were prepared bilingually.

Similarly, annual reports, various documents, agreements and MoUs were prepared and submitted bilingually.

A total of 13 Seminars and Talks on various topics related to the Nuclear Science and Technology were conducted. Souvenir of some of the seminars were also published in Hindi.

A total no. of 40 Hindi workshops were conducted to impart training of "Noting and Drafting" in Hindi in which around 260 officers and 592 employees were trained.

A total no. of 163 employees participated in the various Incentive Schemes introduced in the Department, to increase the use of Hindi in official work.

Quarterly meetings of Official Language Implementation Committee (OLIC) in DAE Secretariat were organised and progress of Official Language implementation was monitored regularly. Quarterly progress reports and minutes of OLIC meetings of offices of all Units, PSUs and Aided Institutes were reviewed regularly. Hindi Week/Fortnight/Month was celebrated in all the offices of the Department.

Websites of DAE and its 25 establishments are in bilingual and they are being updated regularly.

House magazines/News Letters (only soft form) of various establishments of DAE were published in Hindi/Bilingual.

Hindi competitions were organised during "Hindi Fortnight" and "World Hindi Day".

NPCIL has been progressively increasing its achievement in the field of Official Language along with its prime objective of power generation. Total compliance of Orders, Instructions and Circulars issued by Department of Official Language, Ministry of Home Affairs, Government of India and Department of Atomic Energy from time to time has been ensured by NPCIL. To ensure official language implementation in all the Units, time bound review of works related to Official Language in all the units was done by the apex level Official Language implementation committee of NPCIL which is chaired by CMD NPCIL. Also, most of the sites have ensured to meet the targets mentioned in annual program of official language implementation. Some of the units are continuously putting their efforts to achieve the targets.

During Covid-19 pandemic, the essential works with regard to official language implementation in NPCIL have been completed through digital mode.

The concept of e-note has been introduced as a new initiative for departmental noting. Where in, the standard noting has been made available in Hindi, due to which the use of Hindi in noting is getting increased. The candidates who had passed Parangat examination were honoured during the meeting of apex committee. Minutes of apex level meetings of management were ensured to be issued in bilingual.

NPCIL HQ participated in online meetings of Town Official Language Implementation Committee (TOLIC) on 30th July 2020 and 23rd December 2020. Similarly, all the units have also ensured their participation in TOLIC meetings. An online essay writing and reminiscence writing competitions were conducted in the month of August 2020. Online meetings of official language Implementation committee were held on 29th May 2020, 25th August 2020 and 13th November 2020. On the occasion of Hindi Diwas on 14 September 2020, programs were conducted through digital mode and the messages of Honorable Home Minister, Government of India, Secretary Department of Atomic Energy and Chairman and Managing Director, NPCIL were read in HQ and in all the units.

Two employees of NPCIL HQ have attained 6th position in the Vetter and 5th position in the Translator category respectively in the Kanthasth competition organized at All India level by Department of Official Language, MoH, in the month of September 2020.

NPCIL Liaison office & Quality Assurance office, New Delhi and Narora Atomic Power Station were inspected by the Parliamentary committee on Official Language in the month of October 2020 and November 2020 respectively.

The Chitrakatha Lekhan competition, was organized in the month of December 2020 through Digital mode. Publication of in-house magazine Urjaswi was ensured by the HQ. Similarly, publication of

localized Hindi house magazines by the units was ensured. Also, the policy decision regarding publication of future issues through digital mode in HQ and in all the units has been taken. Two Hindi e-workshops were organized on 17th and 18th December 2020. World Hindi Day was celebrated on 10th January 2021.

SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC has subscribed to 661 online journals, 8 Standards and 12 Databases and added 488 books and 24 CDs to Library collection. Besides their availability in the BARC campus, they were also made available to the readers through the remote access facility HOoA. This facility was widely used by the scientists during the lockdown to access library resources.

A new initiative for digitisation and archival of DAE-BRNS Conference Proceedings and other old books at the end of their life cycle and not available for purchase has been started. Nuclear News Web Digest (NNWD) – a collection of global news on Nuclear and related areas from different online platforms - was launched in August 2020. The weekly editions are being circulated to different units of DAE.

Videography services were provided during the lockdown for recording of lectures for trainee officers of BARC Training School. Services were also extended for virtual meetings both during the lockdown and the gradual unlocking. The Foreign Language translations and Interpretation services were provided on demand.

COVID-19 Corner was introduced on the BARC homepage to host important information on the COVID 19 pandemic to serve the CHSS beneficiaries and DAE community during the lockdown as well as after the gradual unlocking. BARC website clocked total annual sessions of 4,616,778 with 10, 021, 689 page views during the year with 79% new users 21% returning users.

BARC brought out DAE Technology bulletin featuring various technologies and products developed in DAE in the fight against COVID. Four editions of BARC Newsletter have been released during the year. A coffee table book “Ore. Core. Much More...” chronicling the historical perspectives of materials research in BARC and its impact on the Indian technology landscape has been brought out jointly with Materials Group.

A total of 1290 publications were published in 2020 by BARC (as per Web of Science database).

The SIRD, IGCAR is providing information resources to the scientific, academic and administrative fraternities of DAE campus at Kalpakkam, including IGCAR, BARC(Facilities), MAPS and HBNI. It has an extensive collection of resources. With physical access to the campus restricted due to the pandemic, SIRD proactively provided remote access to its e-resources, including the Royal Society of Chemistry, Proquest, Institute of Physics, Springer nature and Scifinder. SIRD has facilitated the Remote Access to IGCAR Subscribed E-resources (RAISE) facility through a mobile app, which can be accessed via individual desktops or smartphones of the registered users on a 24x7 basis anywhere off the campus. For those working from home, plagiarism checks were done through mails. Auditorium services were deployed for streaming virtual meetings hosted by HBNI, Mumbai, to be accessed from anywhere within IGCAR campus. Publisher user interaction arranged through webinars. The library portal was revamped with dynamic access and few of the value additions include classification of e-books and digitization of old standards. Research contributions of IGCAR were analyzed through citation databases like Scopus, Web of Science and Google Scholar and H-Index generated.

PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a host of Public Awareness programmes to alleviate unwarranted fears, misconceptions, to address apprehensions harboured against nuclear energy. To keep the public abreast of the latest developments and contributions of atomic energy towards societal welfare, DAE participated in and organized a spectrum of events comprising exhibitions, seminars, workshops, essay and quiz contests in different parts of the country which were well received by the targeted audience.

DAE participated in “सार्थक Eduvision 2021”, a three-day exhibition held during 15th-17th March 2021



DAE Pavilion at "सार्थक Eduvision 2021", Bhopal, Madya Pradesh during 15th-17th March 2021

at Bhopal, Madhya Pradesh organised by Bhartiya Shikshan Mandal. Relevant ministries of Central Government, representatives of various State Governments, Departments, Universities & Institutions showcased their activities, achievements, mission & vision in the exhibition. DAE participated in this exhibition along with its units viz. RRCAT and HWB. The exhibits such as posters, panels, LED panels, 700 MWe Nuclear Power Plant model, Indus synchrotron radiation source model, working model of Neelbhasmi and Shivay, Bio-medical application models, various products of Heavy Water Board etc. were kept in the exhibition. Students and faculties from Rabindranath Tagore University, Bhopal and Aurobindo University, Eminent educationists, Students and faculties of various other colleges of Bhopal, Parents & citizens of Madhya Pradesh were the main visitors who visited DAE stall. Information booklets, brochures and leaflets about DAE developed technologies were disseminated. Practical demonstration of various scientific experiments with Liquid Nitrogen and its uses were the highlights of the event.

An event was organized by Achievers Foundation, New Delhi for awareness on different Research and Development Programs of Government of India and their programs and schemes during 19th to 21st March 2021 at Rudrapur, Uttarakhand. The main theme was Atma Nirbhar Bharat (Self- reliant, India) to revive Indian economy and focus on promoting local products. AKRUTI (Advanced Knowledge and Rural Technology Implementation) Team Members from BARC participated in this exhibition. BARC scientists presented the AKRUTI Techno-preneurship program to all the visitors. The non-power related technologies of BARC were explained to the audience that comprised school and university students, civil servants, farmers, doctors, businessmen and Members of State Assembly (MLA) from Uttarakhand and Uttar Pradesh. More than 500 visitors participated in the 3-day exhibition. The



BARC Delegates with local MLA, Farmers and Media



BARC Delegates with the students of Uttarakhand



BARC delegates receiving the 2nd prize for DAE AKRUTI program

AKRUTI program of BARC received the second prize for its societal format on non-power programs education to masses.

A one-day seminar on "Radiation and Environment" was organised under the aegis of the Indian Nuclear Society (INS), Hyderabad Chapter on 15th March, 2021 in the premises of Atomic Minerals Directorate for Exploration and Research (AMDER), AMD Complex, Begumpet, Hyderabad. The prime agenda of the seminar was creating and spreading societal awareness about the benefits of nuclear science and technology to mankind and removing the myths on its environmental impact. Theme specific lectures by eminent scientists and academicians, with vast domain knowledge were delivered in the seminar. The seminar was also hosted live on Webex platform through which several eminent personalities joined the proceedings. Altogether, 172 people (60 online), including INS Members and serving and retired officials from DAE Units attended the seminar. The event was covered by prominent print and electronic media and 18 media representatives were present at the venue. The media agencies, which participated in the event include The Hindu, The Hindu Business Line, Times of India, The New Indian Express, The Economic Times, Deccan Chronicle, Eenadu, Namaste Telangana, Siasat, ETV News and 10TV. Besides, a freelance journalist also attended the seminar. The seminar concluded with an interactive session and Panel Discussion on the proceedings by the dignitaries, academicians and scientists.



Glimpses of one-day seminar on "Radiation and Environment" organised under the aegis of the Indian Nuclear Society (INS), Hyderabad Chapter on 15th March, 2021 in the premises of AMD Complex, Begumpet, Hyderabad

The year-long celebration of Birth Centenary of Dr. Vikram Sarabhai concluded on 23rd September, 2020 through a virtual event with participation from ISRO and DAE. It was graced by Shri K.N. Vyas, Secretary DAE and Chairman AEC, Dr. K. Sivan, Secretary DOS and Chairman ISRO and Dr. A. K. Mohanty, Director, BARC among others.



Public Awareness Programmes conducted by Environmental Survey Laboratory established at BARC-Visakhapatnam

The Environmental Survey Laboratory established at BARC-Visakhapatnam, carried out public awareness programmes in colleges, universities etc., in nearby districts, on nuclear radiation, natural and manmade radiation and the uses of radiation for peaceful and beneficial purposes, on a regular basis.

NPCIL has been executing series of public outreach campaigns to a larger section of society on regular basis to convey factual and authentic information on various power and non-power applications of nuclear energy in a lucid manner with a long-term structured approach.

Organizing plant visits of villagers, students, officials from various organizations; regular interaction with the persons around the vicinity of Nuclear Power Plants, opinion makers, members from the media and public representatives; execution of various public outreach campaigns on nuclear power for various target groups like policy and decision makers, media personnel, people's representatives, students and teachers, state officials, medical and health professionals and the public at large are some of the activities, which is being continuously carried out across the country for the last so many years. NPCIL is also participating in setting up of a number of permanent and miniature galleries on nuclear energy at the science centres across the country to provide useful and authentic information in an interesting, innovative and lucid way.

Use of online portals for webinars, lectures, exhibitions, distribution of public awareness publications, scientific meets, screening of various informative films and multimedia presentation in vernacular languages, relationship with press and media, professional tie-ups with other Govt. agencies like Prasar Bharati, National Council of Science Museums (NCSM) and Department of Science and Technology at the State and Central Level etc., use of social and digital media for online public outreach campaigns are also being adopted to develop positive public perception about nuclear energy at large.

Web based Public Awareness

NPCIL web site has been providing large amount of authentic and beneficial information on multiple aspects of nuclear power including significant developments and achievements. Regular updates of the web portal, posting of information about various developments and answering of queries raised on web portal are carried out on our website.

Webinars / Online Lectures

Due to recent pandemic, NPCIL adopted virtual mode of communication to reach out the larger section of audience. Many webinars and online lectures were carried out on multiple aspects of nuclear power for wider reach. A large number of students were briefed about the importance of nuclear energy across the country.

NPCIL has also used various social and digital media platforms including Facebook, YouTube, Twitter, Google etc., for sharing of information related to nuclear power in innovative, interesting and lucid ways. During the period April to December, 2020 more than 20 innovative online contests were organized in which thousands of contestants participated.



Use of various social and digital media platforms

Halls of Nuclear Power

Under the long term and structured approach, “Halls of Nuclear Power” have been setup at three science centres, located at Mumbai, Delhi and Chennai, where millions of people visit every year. Similarly, fabrication and installation of Halls of Nuclear Power at various science centres located across the country are also planned.

Miniature Nuclear Galleries

Miniature galleries are planned in various cities for wider reach to the public. Miniature galleries are





Miniature Nuclear Galleries

relatively smaller in size, covering area of around 300 sq. feet and is established in prominent science centres, planetariums and museums. Miniature galleries comprise of panels, banners, interactive models, LED screens for screening of short films, publications etc. giving information about nuclear energy. In the first phase eight miniature Nuclear Galleries are being established in different parts of the country. As on December 2020, four such galleries have already been established at Karwar, Mangalore, Hyderabad and Vijayawada. Similarly, four more Miniature Nuclear Galleries are going to be established at Kota, Bhopal, Jalandhar and Coimbatore.

Nuclear Power Plant Models

The semi-dynamic NPP models with synchronous commentary in multiple languages are being installed at various Science Centres and Educational Institutions to educate general people and provide information about the functioning of nuclear power plants with special focus on various safety features. New proposal to install more NPP models at other science centres and educational places is under process.

Films and Multimedia

NPCIL has signed an MoU with Mumbai Doordarshan to make short films and documentaries on various subjects and activities being carried out under CSR around all the nuclear power plants. The films will be telecast in multiple languages through all the regional channels of Doordarshan including DD National. Recently during the criticality of KAPP Unit-3, special interview based programme of 30 minutes was telecast on DD Gujarati and DD News.

Public awareness programmes have been conducted in various cities as well as in remote field areas at 38 venues by AMD. A total of 70 events have been organised for students, teachers and general public.

SOCIAL WELFARE

Corporate Social Responsibility, Sustainability and Rehabilitation & Resettlement

NPCIL is committed to economic and social development of the local communities around all its Sites. CSR programme is implemented at the 14 Sites of NPCIL, where either the operating stations or the projects under construction are located. These Sites are located mostly in rural and underdeveloped areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme.

During the FY 2020-21, the Company allocated an amount of ₹ 95.52 Crore for implementation of CSR programme. It is a matter of satisfaction that for the last four consecutive years, NPCIL has spent more amount on CSR programme than that was mandated by Companies Act during that year.

The CSR Policy of NPCIL is available at the company website. Board Sub Committee (BSC) for CSR and Sustainability functions as CSR Committee as defined in the Company (Corporate Social

Responsibility Policy) Rule 2014 notified under companies Act 2013. Additionally, Guardian Directors have been assigned to the operating Sites of NPCIL to review and assist the CSR programmes of the Sites.

The effective and expeditious implementation of CSR program is monitored and facilitated at various level in NPCIL including the Board Sub Committee (BSC) for CSR and Sustainability.

The CSR projects have been taken up in line with Schedule VII of Companies Act, 2013 which falls in the areas of education, healthcare, infrastructure development, skill development, sustainable development.

Education

Under education category the projects like construction of school buildings, hostel building, furniture for schools, class rooms, multipurpose hall in Girls School, boundary wall, development of playground, footpath and anganwadis, assistance to schools like drinking water, toilets, science laboratories, digital class rooms, green boards, ceiling fans, furniture, open area flooring, kitchen with store, deployment of teachers in schools, assistance to students like study materials, note books, sports kit, archery sports equipment, scholarship and sponsorship, organizing quiz etc. were taken up during this year.



A 6 class room school building was constructed at Sadras, Chengalpattu District, Tamil Nadu



Construction of 6 room Primary School building at Chaniyala, Bhavnagar District, Gujarat



Establishment of science lab. was carried out at Government High School building, Kuzhipanthandalam, Chengalpattu District, Tamil Nadu

Healthcare

Under healthcare, the CSR projects included running of primary health center, providing mobile



Oxygen concentrators and ventilators were provided to Civil Hospital, Fatehabad District, Haryana. This is to help people affected by Covid-19



Mobile medical services at Seoni and Mandla Districts, Madhya Pradesh



OPD dispensary at Community Centre, NAPS Township, Bulandshahr District, Uttar Pradesh

medical van services; organizing medical, eye and special health care camps; providing medical treatment and medicines (OPD services) for villagers; procurement of various equipment's and ambulance for hospitals, construction of Mortuary in Government Hospital, nutritional supplementation to anganwadi children, assisting differently abled students through Anubalvikas Sansthan, installation of water purifiers and distribution of passive water filters etc.

Also, distribution of health related materials as lifesaving equipment/kits, necessary items and grocery packets for the people to contain Covid-19 was done.

Infrastructure Development

Under infrastructure development, the projects like laying of approach roads, development of integrated drinking water facility by constructing water tanks, laying of supply and distribution network,



A community hall comprising of indoor stage, toilet, water and electricity facilities was constructed at village Benadgule of Yellapur Taluka near Kaiga, Uttar Kannada District, Karnataka



Integrated drinking water system 3 nos. at 6 villages were commissioned near Kalpakkam, Chengalpattu District, Tamil Nadu

construction of community hall and retaining wall, drainage, black topping of the damaged roads, installation of paver blocks in streets, construction of cremation ground with water facility, development of infrastructure facility for PHC, deployment of artificial reefs etc. were taken up.

Skill Development

Skill development initiatives were undertaken for income generation by unemployed adults. Skills in tailoring, computers etc. were focused upon. Training was also provided to the children with special need. Distribution of sewing machines were carried out.



Skill development training in the field of welding was carried out through NSDC at Kudankulam, Tamil Nadu



Distribution of 12 sewing machines were carried out at Kasturba Gandhi Balika Vidyalaya, Kumharia, Fatehabad District, Haryana

Sustainable Development

Some sustainable development initiatives were also undertaken this year. These included projects to rainwater harvesting, development of village ponds, ground/ underground natural water bodies, turtle rearing program, release of fish and prawn seedlings in Tapi river, installation of solar high mast and street lights, capacity building of farmers on organic agriculture, setting up of Akruti Centre to introduce BARC technologies etc.



Neonates are being grown through Turtle Rearing project and are being released to their natural habitat like river Ganges and Hakimpur wetland at Narora, Bulandshahr District, Uttar Pradesh



Bottle crusher plants to Vyara and Mandvi authorities, Tapi District, Gujarat

Akruti Programme of DAE

Akruti is "Advance Knowledge and Rural Technology Implementation" programme of DAE. It aims to disseminate the technologies developed by DAE for rural sector leading to societal benefits.



Rapid bio-composting with dry leaves and garden waste at Kakrapar Site, Tapi District, Gujarat



Nano composite ultrafiltration membrane device were dedicated to nearby village of Kakrapar Site, Tapi District, Gujarat



Passive water filters were distributed to anganwadis at Chhoti Sarwan and Aabapura Tehsils, Banswara District, Rajasthan

Under CSR Programme of NPCIL, Akruti Technology Demonstration Centres are being developed at Tarapur Maharashtra Site, Kakrapar Gujarat Site and at Kudankulam Atomic Power Plant to create awareness about technologies developed by DAE. NPCIL intends to deploy these technologies for rural development in the field of agriculture, agro-processing, waste management, health and safe drinking water at these sites. Some of the BARC technologies that are being introduced to the people in the nearby villages include nano-technology based water filters, rapid bio-compost facility, solar dryer and Tele ECG machine, etc.

Swachha Bharat Mission

As a part of Swachh Bharat Mission, Swachhta Pakhwada was observed in DAE headquarters from 16th February – 28th February 2021 on the occasion of World Science Day. Various competitive programmes such as Swachh Section Competition, Quiz Contest, Essay Contest, Poster Contest, Poetry Contest and Slogan Contest etc. were conducted by keeping the COVID guidelines in mind and by maintaining proper social distancing. The DAE officials participated in the above contests wholeheartedly. The prizes were distributed to all the winners of the various contests and also felicitated the employees of the Department who were selected for their contribution in cleanliness.



Shri K. N. Vyas, Chariman, AEC and Secretary, DAE participated in the cleanliness drive organised by DCSEM at Anushakitnagar, Mumbai

DCSEM have engaged an agency namely Stree Mukti Sanghathana, expert in the field of domestic waste management and are in the field for last 25 years. Door to door campaign was started. Resident's Associations of the various buildings and volunteers of a group of residents were also involved in this campaign. The campaign teams were formed having members from DCSEM, member from the concerned resident's association of the building, Stree Mukti Sanghatana and member from a volunteer group of the colony. The teams carried out door to door campaign and made the residents aware of the Importance of segregation of domestic waste; Various categories of domestic waste and how to handle them; How to recycle reduce the domestic waste and Ban on Single Use Plastic. A pamphlet displaying pictures of various types waste and how to handle them is also distributed to the residents. As a part of awareness programme, a drama showing the various harmful effects of plastic unsegregated waste and present behaviour of the people towards

waste is enacted in the various Ganpati Pandals of Anushaktinagar during recent Ganpati festival. DCSEM has also organized a campaign for scientific disposal of "Nirmalya" collected at all the Ganapati Pandals. The organisers were contacted and they were taught about how to compost the "Nirmalya" quickly with required dignity. All the materials like drums, culture etc. was provided to them by DCSEM. The culture however was provided by NABTD/ BARC. The same facility was also provided for the residents at "Visarjan well" in Anushaktinagar, where normally they bring their "Nirmalya" during immersion of the idols. The banners were displayed at the prominent locations in colony regarding Swachhata awareness. DCSEM has decided to inculcate the Swachhata habits in children of the colony. For this AEES has been contacted and in co-ordination with them an awareness campaign is proposed in all the schools and college in Anushaktinagar.

A "Certificate of Excellence" was awarded by Shri K.N. Vyas, Chairman, AEC and Secretary, DAE to RRCAT, Indore with Third Rank among all its constituent Units in recognition and appreciation of the Swachhata activities undertaken in the Centre as part of Swachhata Pakhwada from 16th - 28th February, 2020. In addition, "Swachhata Pakhwada Award - 2020", sponsored by the Department of Drinking Water and Sanitation, was also awarded to RRCAT. Indore Municipal Corporation (IMC) awarded a "Certificate of Excellence" to the RRCAT Colony for achieving First Rank in Indore Swachhata Ranking under Swachh Survekshan 2021 conducted by the IMC. The award carried a certificate and a memento. The results were declared on August 20, 2020 by Union Minister of State (Independent charge) for Housing and Urban Affairs, Shri Hardeep Singh Puri.

In order to maintain cleanliness in all DAE units, stores located at different locations collect and dispose different types of scrap, unserviceable and surplus material. During the current year at DPS, about 278 sale orders were issued with a total value of about 29 crores handling about 6600 MT involving 1059 truck load of scrap, about 14,460 unserviceable/surplus items and 55 vehicles. Swachhta Abhiyan programme was conducted in all units, with special cleanliness drives and implementation of the aforesaid measures.

At IGCAR, construction of toilet for contractor workers in FBTR has been completed. Renovation of toilet for Accounts Office is in progress. Tender has been floated for rain water harvesting pond restoration near DFRP.

At GSO, Swatchhta rallies, quiz and talks were conducted during the Swatchchta Pakhwada.

EMPLOYEES' WELFARE

Employees' Health Care

To provide specialised and personalised health care to its employees and the members of their families 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.

Health Care is one of the most important social security measures in which NPCIL always focused on. To provide best medical facilities to its employees and their dependent family members, NPCIL follows the Contributory Health Service Scheme (CHSS) of DAE. Under the Scheme, all the eligible employees and their family members are provided with hassle free medical facilities in its established hospitals as well as referral hospitals empaneled by respective Units. The Occupational Health facilities are provided at health centres and hospitals.

Children's Education

Atomic Energy Education Society (AEES), an autonomous institution under the Department of Atomic Energy (DAE), Govt. of India, was established in the year 1969 with an aim to provide quality education to the children of the employees of the DAE units working at different centres/establishments across the country in an environment in which every student discovers and realizes his/her full potential. AEES currently administers 31 Schools/Junior colleges at 15 centres located all over India and provides education to over 27,000 students. AEES provides education to the economically backward children from the rural/tribal areas around its establishments through its Societal Enrichment and Education Programme (SEEP). This programme is meant for some children, who are

identified only from those admitted under the Right to Education Act (RTE) category.

National Award

It is a matter of pride for AEES that Dr. A Jebin Joel, PGT (Physics) AECS-4 (Atomic Energy Central School No.4) Mumbai was bestowed upon with National Award for Teachers for the year 2019, conferred by Ministry of Human Resource Development. Smt. Sangeeta Sohni, PGT (Chemistry), AECS-4, Mumbai received the prestigious National Award for the Best Teacher from the hands of Mumbai District Collector and in the virtual presence of Honourable President of India on the occasion of Teachers' Day on 5th September, 2020.

Board Results

All India Secondary School Examination (AISSE)-2020

About 1927 students from 27 AEC schools which are affiliated to the CBSE appeared for the Class X in March,2020. The Pass percentage is 98.48% (99.33% last year) as compared to all India CBSE pass percentage of 91.46 and the quality Index is 7.46 (7.71 last year). The overall excellence Index stood at 80.32 (85.80 last year). The pass percentage of 16 schools is 100%.

All India Senior Secondary Certificate Examination (AISSCE)/HSE Exam, 2020 - CBSE

About 1155 students from 13 AEC Schools which are affiliated to the CBSE appeared for the Class XII Examination in March, 2020. The Pass Percentage is 95.24 (92.80% last year) as compared to All India CBSE Pass Percentage of 88.78 and the Overall Excellence Index stood at 83.84 (76.48 last year). The quality Index is 7.04 (6.74 last year). AECS, Mysore and AECS, Indore, produced 100% result. The pass percentage of 11 schools is above 90%.

Important Academic Achievements

Fourteen students from AEC Schools of different centres got selected in different IITs in the Academic Year 2019-20. There are 6 students from AEC Schools of different centres got admission in various institutions like NIT/BITS/IIIT/Other Engineering Colleges. Master Abhisek Narayan Gorti of AECS, OSCOM got selected in Indian Institute of Science Education and Research, Pune.

KVPY (Kishore Vaigyanik Protsahan Yojana)

The "Kishore Vaigyanik Protsahan Yojana" (KVPY) is a program started in 1999 by the Department of Science and Technology (DST), Government of India to encourage students who are studying Basic Sciences to take up research career in Science. The aim of the program is to identify and encourage talented and motivated students to pursue career in research. The Department of Science and Technology, the nodal agency of the Government has entrusted the overall responsibility for organizing and running the KVPY Program to the Indian Institute of Science, Bangalore and set up a Management Committee and a National Advisory Committee (NAC) for overseeing its implementation.

KVPY Fellowship Award by Indian Institute of Science, Bangalore

Four students got KVPY Fellow Award. They are Master Prayas Sandeep Satkar of AECS-4, Mumbai; Master Vighnesh Deshpande of AECS-4, Mumbai; Master Mitul Vashista of AECS-3, Tarapur and Master Samarth Tripathi of AECS, Narora

National Talent Search (NTSE) Examination

Several students of AEC Schools performed well in the Talent Search Examinations conducted by different states. Many cleared the National Level competition as well. There were 13 students qualified at State Level and 5 students got qualified at National Level.

Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition (JNNSMEE):

The exhibit “Graph Theory: A Basic Model” developed by Miss Akshaya Reddy, Miss R. Vishwaja, Miss K. Abhilaya Reddy and Miss Harshitha M Krishna of class X was displayed in the 46th Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition for Children at Raipur, Chhattisgarh and got selected for 107th Indian Science Congress.

Rashtriya Kishore Vaigyanik Sammelan (Children Science Congress)

Miss Akshaya Reddy and Miss K. Abhilaya Reddy of class X exhibited a project: "Graph Theory: A Basic Model" in the 107th Indian Science Congress held at Rashtriya Kishore Vaigyanik Sammelan.

Other Academic Achievements

Regional Maths Olympiad

Miss Anika Bhardwaj of AECS-2, Mumbai has cleared the Regional Maths Olympiad.

INSPIRE Programme

Eight students became eligible for award of Scholarship for Higher Education (SHE) under Innovation in Science Pursuit for Inspired Research (INSPIRE) by virtue of performance within top 1% of the School board at class XII.

Indian National Mathematics Olympiad (INMO)

Master Arihanth Vashista of X has won acclamation in the National Mathematics Olympiad and National Mathematics Talent Competition. He has been qualified for Indian National Mathematics Olympiad and has been invited to attend the INMO training camp at Tata Institute for Fundamental Research at Homi Bhabha Centre for Science Education (HBCSE). He has been qualified for National Mathematics Talent Competition final.

Swachha Bharath

AEES, under the directives of DAE organized Swachha Bharat Programme in the form of Plogging Run on 23.02.2020.As part of this programme, a group was formed under the initiatives Sri R.Rajeev Kumar, Coordinator of DCSEM. The Principal, Mr.Lokesh Joshi, Headmaster-Mr.Ajay Kumar and the teachers of AECS-3 along with local residents of Gangotri formed five groups and took Swachha Bharat Pledge and collected dry waste by strictly adhering to wearing hand gloves and masks. The Programme of collection of dry waste lasted for an hour and half and concluded at a Programme at AEJC. The Programme was attended by Shri.K.N.Vyas, Secretary, DAE.

The students along with teachers raised slogans of Swachhta during their RUN. The clean India Campaign received a great response from every resident of the campus as they woke up to the voices of Swachhta. The students carried placards with captivating slogans which made the onlookers pause and think on the need for cleanliness in all walks of life. The students along with the teachers participated in a Procession bringing Awareness among the common people. The skit Programmes were conducted in the morning Assemblies-turning them in to Learning Platforms in all AEC Schools.

The students took part in Swachhta wall Painting Programme and painted the schools walls with the pictures depicting the importance of Cleanliness.

Workshops, Seminars and In-Service Programmes

Vigyan Pratibha Programme

'Vigyan Pratibha' is a major talent nurture programme in Science and Mathematics for high school students initiated by the Government of India. The Homi Bhabha Centre for Science Education and Tata Institute of Fundamental Research (HBCSE, TIFR) are involved in this initiative, which was formally launched on 31st July, 2017 at HBCSE, Mumbai. The workshops would be continued further to support the teachers and students.

Other achievements in Art

All India Stamp design Competition

In the All India Stamp design competition organized by India Post and UNICEF, the student of AECS-1, Tarapur-Miss Nidhi Rahul Mhatre of X bagged first position. Her entry was selected among 14,000 entries and the topic for the competition was Child Rights. She has received certificate from the Vice President of India Shri Venkaiah Naidu at Parliament Annexe in Delhi.

PCRA Saksham National Level Painting Competition

In the PCRA Saksham National Level Painting Competition organized by Min of Petroleum and Natural Gas, Govt of India, New Delhi, the student of AECS-1, Hyderabad-Miss C.Soumya of class VI won consolation

prize. She was awarded with a cash award of 10,000 rupees and gift hamper at a grand function, held in New Delhi.

Inter – AECS/JC Cultural Meet in Music

Inter AECS Cultural meet (Music) was held 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.

National Level Youth Festival

In the National Level Youth Festival organized by the Ministry of Sports and Youth Affairs, Govt. of India. Miss Vaishnavi S Velaye represented the State of Maharashtra at the National Level in Odissi Classical Dance.

Online Classes for the students

The pandemic conditions paved the way for Online Classes in AEES. The topics of the entire syllabus of various subjects of all the classes were divided into Modules. All the teachers of AEC Schools were assigned the preparation of different modules with each module consisting of 4 components a Power Point Presentation; a Work Sheet; Audio of the Topic and Handout (Summary of the topic).

First Phase: Online Theory Classes

The Online theory Classes were started in the 3rd week of April and has been successfully catering to the needs of the students till today. All the Modules of e-content were uploaded to the AEES Website from where the students will download the content as per the Pre planned academic schedule. In addition to the contents prepared by AEES Teachers, the e-Content of NCERT was also at the disposal of the students to supplement their teaching-Learning Process.

Second Phase: Practical Classes

After successful implementation of Theory Classes, AEES has started Online Practical classes for the classes 9 to 12 in Physics, Chemistry, Biology and Computer Science. The schedule for the practical classes was prepared and accordingly access was given to the students (Topic wise/subject wise) through hyperlinks sent to their mobiles. The students utilized this unique way of online classes and got benefitted.

Theme Meeting Commemorating" 150 Years of Periodic Table"

A symposium on "150 years of Periodic Table" was organized by Atomic Energy Education Society jointly with Homi Bhabha National Institute at DAE Convention Centre. The Symposium was chalked out and organized by AEES and HBNI

Golden Jubilee Celebrations

The AEES celebrated its Golden Jubilee Programme. Since its inception in the year 1969, AEES achieved many milestone achievements like -Reaching the State of an Autonomous Body under Department of Atomic Energy, Govt. of India, Establishing 31 AEC Schools and Imparting Quality Education to its stake holders etc. To coincide with the Golden Jubilee Celebration, Logo & Essay Writing Competition and Online Quiz Competitions were conducted for the students and teachers. The Programme of Golden Jubilee Celebration was organized at Anushakti Nagar, Mumbai.



Golden Jubilee Celebration of the AEES

Republic Day Celebrations

The 71st Republic Day was celebrated in all AEC Schools and Junior Colleges with great enthusiasm. A common function of all Mumbai schools & Junior college was celebrated collectively with great enthusiasm at AEJC ground. Various awards given on this occasion includes AEES trophies namely Dr.Vikram



Inter AECS Quiz Competition 2019-20



All India AEES GK Quiz Competition 2019-20

Sarabhai, Dr. Raja Ramanna, Dr. Homi Sethna and Dr. Homi Bhabha trophy etc. were given to various AEC Schools and Junior Colleges for their best performance in the field of Academics, Co-scholastic Activities, Sports & games and for Overall Performance, respectively. The winners in the AEES General Knowledge Quiz were given the prizes on the occasion. Souradip Ghosh Memorial Award was given to the meritorious students who performed excellently in the Scholastic and Co-scholastic (including sports & games) areas from amongst all the AEC Schools /Junior Colleges. One prize each, for a student of class X (Cash award of Rs.11,000/-) and XII (Cash award of Rs.21,000/-), was given for the academic year 2018-19.

Dr. B.R. Ambedkar Jayanti

The 128th Birth anniversary of Dr. B. R. Ambedkar Jayanti was celebrated in AEC Schools. The special cell for SC/ST Employees of AEES organized the celebration in a common function of AECS / JC, Mumbai. The programme was a grand success.

International Day of Yoga

The International Day of Yoga was organized in AEC Schools. Some of the Yoga experts were invited



International Yoga Day organized at AEC Schools

from the various Yoga Clubs to conduct yoga for our students. Teachers & students actively participated in the programme. All the students and teachers got benefitted.

Communal Harmony Week

The Communal Harmony Campaign week was celebrated by the schools to instill sentiments of peaceful co-existence, mutual respect, amity and brotherhood amongst the diverse segments of our society and also to spread the message of communal harmony, patriotism and national integration. Employees took the national integration oath as well.

The Vigilance Awareness Week

Vigilance Awareness Week was celebrated on the theme - "Eradicate Corruption-Build a New India". Various activities like art competition, quiz etc. were conducted in the schools to stress on the importance of the theme.

Teachers' Day

Teachers' Day is celebrated to express our gratitude and appreciate the hard work of our teachers. The same was celebrated in all the schools with great enthusiasm. A common Teachers' Day celebration was held in Mumbai. Awards like, AEES awards and mementoes for completing 25 years of service in AEES etc. were given to the teaching and non-teaching staff members of AEES family, followed by cultural presentation by the students.

Official Language Implementation

AEES continued to carry out various activities to promote the use of Rajbhasha Hindi in daily routine work.

DAE SPORTS & CULTURAL ACTIVITIES

DAE Sports and Cultural Council (DAE S&CC) has been facilitating promotion of sports, physical fitness, yoga and cultural activities among DAE employees and their family members located at various units all over India for more than thirty-five years now. Considering that the mandate of sustainable nuclear power needs the inculcation of positive attitude, team work, nurturing of excellence and building up of competitive spirit amongst the employees, DAE S&CC's thrust has been to encourage facilitation of activities towards these themes. In addition, programs are also designed to develop positive health and attitude towards achievement of excellence amongst family members of employees.

The 35th DAE Lawn Tennis event and 35th DAE Carrom event which was to be hosted by Kakarapar Gujarat site and RRCAT Indore respectively has been postponed till further notice. Out of 16 events scheduled in the 35th Annual DAE S&CC meet, only 14 events have been conducted.

About 1000 employees participated in the 35th Inter DAE meets which aimed at encouraging healthy competition amongst DAE employees in various sports and cultural events to facilitate inter as well as intra-unit synergy, constructive team work and sportsman spirit among employees. Teams to participate in National events like Kabbadi, Bridge, Table Tennis, Ball Badminton, Badminton etc. are also selected during the meet. Participation of all DAE units are through eight leader groups (Ajanta, Dwaraka, Ellora, Golkonda, Konark, Nagarjuna, Pushkarand Rameswaram).

DAE S&CC also supports the participation of players in National Championships by payment of affiliation fees, provision of kit allowance and arrangement of training camp.

As per the unlock guidelines issued by Govt. of Maharashtra and DAE, it was decided to open up various sports activities in a graded manner following all the social distancing norms and relevant protocols.

The doctors and staff members (Covid-19 warriors) of TMC/TMH played a Cricket match amongst themselves and showcased as to how the sports activity is to be conducted during this ongoing pandemic situation. Players adhered to social distancing norms and played the game as per the SOP (Standard Operating Procedures). Dr. Shailesh Shrikhande, Deputy Director, Tata Memorial Hospital, Mumbai, a passionate cricketer led the team of doctors and set an example as to how safely the sports activities could be conducted under prevailing pandemic situation.



TMH/TMC Team at Anushaktinagar NCC Cricket ground

International Yoga Day-2020 was celebrated on 21st June 2020 at New Community Centre (NCC), Anushaktinagar and about 150 people participated in the event online. Due to social distancing norms, event was held on-line and response was overwhelming. Appeal was also made to employees and their family members to practice yoga at home on regular basis during lockdown period.

Under Nature & Adventure related activities, Team Girisanchar was fortunate enough to complete "Girisanchar-31, All India DAE Annual trekking expedition by January end 2020. Girisanchar-31: Girisanchar-31(31st All India DAE Trekking Expedition) was held in "RRCAT Indore-Simrol-Kajaligad–Baigram–Kalakund–Kushalgad–Raskundiya –Rosayabari –Mahadeo Khodra –Jam Gate & Wanchoo Point" in the Malwa-Nimar region of Vindhyachal range near Indore, Madhya Pradesh from January 13th 2020 to January 24th 2020. Participants also explored flora and fauna of the region. Each participant was provided with a small size Trash bag (waist pouch) to keep all the trash like chocolate wrappers, plastics etc while one trekked through the forest. This has helped in keeping the trekking trail litter free. The trek route was of approx. 80 Kms and runs mostly in teak forest, evergreen &



Girisanchar-31: Malva-Nimar Range

deciduous forest, valleys, fields situated amid hills (Wheat fields, cotton fields, Mustard and Tur fields etc), waterfalls and streams. This route was picturesque and mostly on offbeat nature trails. The attractions of this trekking expedition were Kajaligad Fort, Kushalgad, Kalakund Heritage train station, Choral River, Mahadeo Khodra cave (Chota Amarnath), Jam Gate, Narmada Valley view and Wanchoo Point.

Girisanchar Cycling group has initiated cycling activity in a gradual manner in very small groups keeping in mind all the necessary Covid-19 guidelines.



Girisanchar Cycling group has initiated cycling activity

On account of Covid-19 pandemic situation, the Know Your Trees (KYT) Walk could not be conducted by team Girisanchar Nature & Adventure circle. However, the lockdown period was utilised to document the floristic diversity of Anushaktinagar. Exhaustive surveys were conducted and the plants were identified in consultation with authentic taxonomic literatures and herbarium specimens deposited at the Herbarium of BARC, Mumbai. This documentation will be of great help while we conduct KYT walks in future.

Some of the promotional activities undertaken by DAE S&CC included participation of DAE teams in National Level inter institutional tournaments supported by national federations (Table Tennis, Kabaddi, Badminton, Bridge & Ball Badminton); Support to district level promotional tournaments at Anushaktinagar to facilitate the advanced coaching children in Table Tennis, Tennis, Cricket & Badminton; Financial subsidy to welfare groups of various units (ARWA for sports, BARC Hospital, BARC Staff Club Yoga Circle, etc.) and new community center for Annual competitions SPLASH and financial grants to Special children for conducting sports camp Shoushilya at Anushaktinagar.

New Community Centre (NCC), in Anushaktinagar, is an entity formed under DAE S&CC, DAE to encourage and promote sports and cultural activities among employees, ex-employees of DAE and their family members, stationed in Mumbai. This year the regular activities of the NCC were suspended due to nation-wide lock down in view of COVID 19 pandemic.

AWARDS & PRIZES

Several awards in areas of Safety and Performance and Official Language (OL) were bagged by various units of NPCIL and Headquarters. These are mentioned as under:

TAPS-1&2 has bagged CERTIFICATE OF APPERICIATION -2019 from NSC, India during the year 2020.

TAPS-3&4 received Envirocare Green Award-2020 on June 25, 2020. It also won Maharashtra Safety Award Competition-2019 conducted by National Safety Council for achieving Lowest Average Accident

Frequency Rate and Longest Accident Free Period.

KGS-1&2 has received "Sarvashreshtha Suraksha Puraskar" (Golden trophy) NSCI Safety award - 2019 from National Safety Council, Mumbai.

KGS-3&4 received "Shreshta Suraksha Puraskar" (Silver Trophy) from NSCI for the year 2019.



KGS-1&2 has received "Sarvashreshtha Suraksha Puraskar" (Golden trophy) NSCI Safety award - 2019 from National Safety Council, Mumbai

IREL received the National Awards for Excellence in PSU, 10th PSE Excellence Awards 2019 for HR initiatives and got Adjudged Runner-up in Rajbhasha Shield successively for the 2nd year for outstanding performance in Official Language implementation, IREL.

The HWP Thal has won "Certificate of Merit" in National Safety Council Maharashtra Chapter for "Zero Accident Frequency Rate" in Maharashtra safety Award Competition for the year 2019.

Lifetime Achievement Award and Dr. G.R. Udas – K.K. Dwivedi Medal by Indian Society of Applied Geochemists (ISAG) and Young Sedimentological Award – 2019 by Indian Association of Sedimentologists have been conferred on AMD officials.

Scientists from TIFR won prestigious awards during this period. Prof. Vatsala Thirumalai of the National Centre for Biological Sciences, Bengaluru was awarded the Shanti-Swarup Bhatnagar Award for 2020. Prof. Nilmani Mathur of the Department of Theoretical Physics, TIFR, Mumbai was awarded the Dr. A. P. J Abdul Kalam HPC Award by Cray Supercomputers in an online ceremony on 18 September 2020. Prof. Hariharan Narayanan of the School of Technology and Computer Science was awarded the Swarnajayanti Fellowship by SERB in Nov 2020. Dr. Deepa Agashe (NCBS, Bengaluru) was nominated as the Vice President of the American Society of Naturalists (2021–2023) by the American Society of Naturalists in May 2020. Dr. Riddhipratim Basu, ICTS faculty member in the Mathematics group, was awarded the INSA Medal for Young Scientist (Mathematics) for 2020. Dr. Shyam Sundar Ghoshal (CAM, Bengaluru) and Dr. Karthik V. Raman (TCIS, Hyderabad) received the INSA Young Scientist Award (2020) by the Indian National Science Academy, New Delhi.

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 01.01.2021 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 IN RESPECT OF **CONSTITUENT UNITS**

Group	Number of Employees					Direct Recruitment									By Promotion							
						No. of vacancies reserved				No. of appointment made					No. of vacancies reserved			No. of appointment made				
	Total	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)
Group A	8396	1	4	47	3	0	0	1	0	121	0	0	0	0	0	0	0	21	0	0	0
Group B	7193	5	8	73	2	0	2	3	0	13	0	0	0	0	0	0	0	110	0	1	1
Group C	9164	13	44	105	1	3	9	16	1	193	0	0	0	0	0	1	0	50	0	0	1
TOTAL	**24753**	**19**	**56**	**225**	**6**	**3**	**11**	**20**	**1**	**327**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**181**	**0**	**1**	**2**

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2021AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 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	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)	
Group A	1778	3	0	11	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Group B	3067	7	4	25	1	0	2	13	0	1	1	0	1	0	0	0	0	0	0	0	0	
Group C	2504	5	17	32	1	2	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	
TOTAL	**7349**	**15**	**21**	**68**	**2**	**2**	**5**	**15**	**0**	**1**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **PERSONS WITH DISABILITIES** AS 01.01.2021 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Group	Number of Employees					Direct Recruitment									By Promotion							
						No. of vacancies reserved				No. of appointment made					No. of vacancies reserved				No. of appointment made			
	Total	Category (a)	Category (b)	Category (c)	Category (d&e)	Category (a)	Category (b)	Category (c)	Category (d&e)	Total	VH	HH	OH	D &E	VH	HH	OH	Total	VH	HH	OH
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)
Group A	6953	13	6	73	0	518	12	3	18	142	1	0	2	0	0	0	0	9	4	0	5
Group B	4495	11	11	69	0	180	3	3	6	42	1	1	0	3	1	0	0	0	0	0	0
Group C	4048	14	11	50	0	234	3	4	9	157	0	0	4	0	0	0	0	3	1	0	2
TOTAL	**15496**	**38**	**28**	**192**	**0**	**932**	**18**	**10**	**33**	**341**	**2**	**1**	**6**	**3**	**1**	**0**	**0**	**12**	**5**	**0**	**7**

Respective Categories:

(a) Blindness and low vision;

(b) Deaf and hard of hearing;

(c) Locomotor disability including cerebral palsy, leprosy cured, dwarfism, acid attack victims and muscular dystrophy;

(d) Autism, intellectual disability, specific learning disablility and mental illness;

(e) Multiple disabilities from amongst persons under clauses (a) to (d) including deaf-blindness;

CHAPTER

12



CITIZEN CHARTER

Government of India
Department of Atomic Energy

CITIZEN CHARTER

I) OUR VISION

The vision of the Department of Atomic Energy is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

II) MANDATE

The mandate of the Department, on which its programmes are based, covers :

- Increasing share of nuclear power through deployment of indigenous and other proven technologies, along with development of fast breeder reactors and thorium reactors with associated fuel cycle facilities ;
- Building and operation of research reactors for production of radioisotopes and carrying out radiation technology applications in the field of medicine, agriculture and industry, cancer care, water related technologies, waste management etc.;
- Developing advanced technologies such as accelerators, lasers, supercomputers, advanced materials and instrumentation, and encouraging transfer of technology to industry;
- Support to basic research in nuclear energy and related frontier areas of science; interaction with universities and academic institutions; Support to research and development projects having a bearing in DAE's programmes, and international cooperation in related advanced areas of research, and
- Contribution to national security.

III) OUR ACTIVITIES

- The Department is engaged in the design, construction and operation of nuclear power / research reactors and the supporting nuclear fuel cycle technologies covering exploration, mining and processing of nuclear minerals, production of heavy water, nuclear fuel fabrication, fuel reprocessing and nuclear waste management. It is also developing advanced technologies which contribute to the national prosperity. The human resource developed and technical services being rendered by the Department have been greatly helping the Indian industry.
- The Department is also developing better crop varieties, techniques for control/eradication of insects thus protecting the crops, radiation based post harvest technologies, radiation based techniques for diagnosis and therapy of disease particularly cancer, technologies for safe drinking water, better environment and robust industry.

IV) OUR CLIENTS

- User Ministries/Departments of Central Govt. and State Govt. dealing with energy, agriculture, food, health, education, oil and petroleum, industry, science and technology etc.
- Quasi Govt. Organisations, NGOs, industrial organizations, educational institutes.
- Electricity Boards, Hospitals, Research / Medical / Educational / Academic Institutions, agriculturists etc.

V) LINK TO RTI PORTAL

- Visit the link **www.rti.gov.in**

VI) WHOM TO CONTACT

I. Public Grievance and complaints

Shri Sanjay Kumar, Joint Secretary (A&A) &
Public Grievance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

II. Vigilance Complaints

Shri Sanjay Kumar, Joint Secretary (A&A) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

III. Nodal Officer / Contact Officer for Citizen's Charter of DAE

Shri Sanjay Kumar, Joint Secretary (A&A) &
Nodal Officer/Contact Officer for Citizen's Charter of DAE
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

IV. Public Relations

Dr. R. K. Vatsa,
Head, Public Awareness Division,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No. 022-22862505
Email: - rajesh.vatsa@dae.gov.in

Government of India
Department of Atomic Energy
Anushakti Bhavan, C.S.M. Marg,
Mumbai - 400 001

NOTICE

We, the public servants of India do hereby solemnly pledge that we shall continuously strive to bring about integrity and transparency in all spheres of our activities. We also pledge that we shall work unstintingly for eradication of corruption in all spheres of life. We shall remain vigilant and work towards the growth and reputation of our Department. Through our collective efforts, we shall bring pride to our Department and provide value based service to our countrymen. We shall do our duty conscientiously and act without fear or favour.

This office is thus committed to maintaining the highest level of ethics in its working towards achieving the above objective, all are requested:

- Not to pay bribe
- If anybody in this department or its offices asks for bribe : or
- If you have any information on corruption: or if you are a victim of corruption in any of our offices.

YOU MAY COMPLAIN TO:

Shri Sanjay Kumar, Joint Secretary (A&A) &
Chief Vigilance Officer,
Department of Atomic Energy,
Anushakti Bhavan, C.S.M. Marg,
Mumbai – 400 001.
Tel. No.022-22840309
Email I.D. – jsaa@dae.gov.in

YOU CAN ALSO COMPLAIN TO THE :

CENTRAL VIGILANCE COMMISSION,
Satarkta Bhavan, Block 'A',
GPO Complex, INA,
New Delhi – 110 023.
Tel. No. 011-24651084
Fax No. 011-24651010/24651186

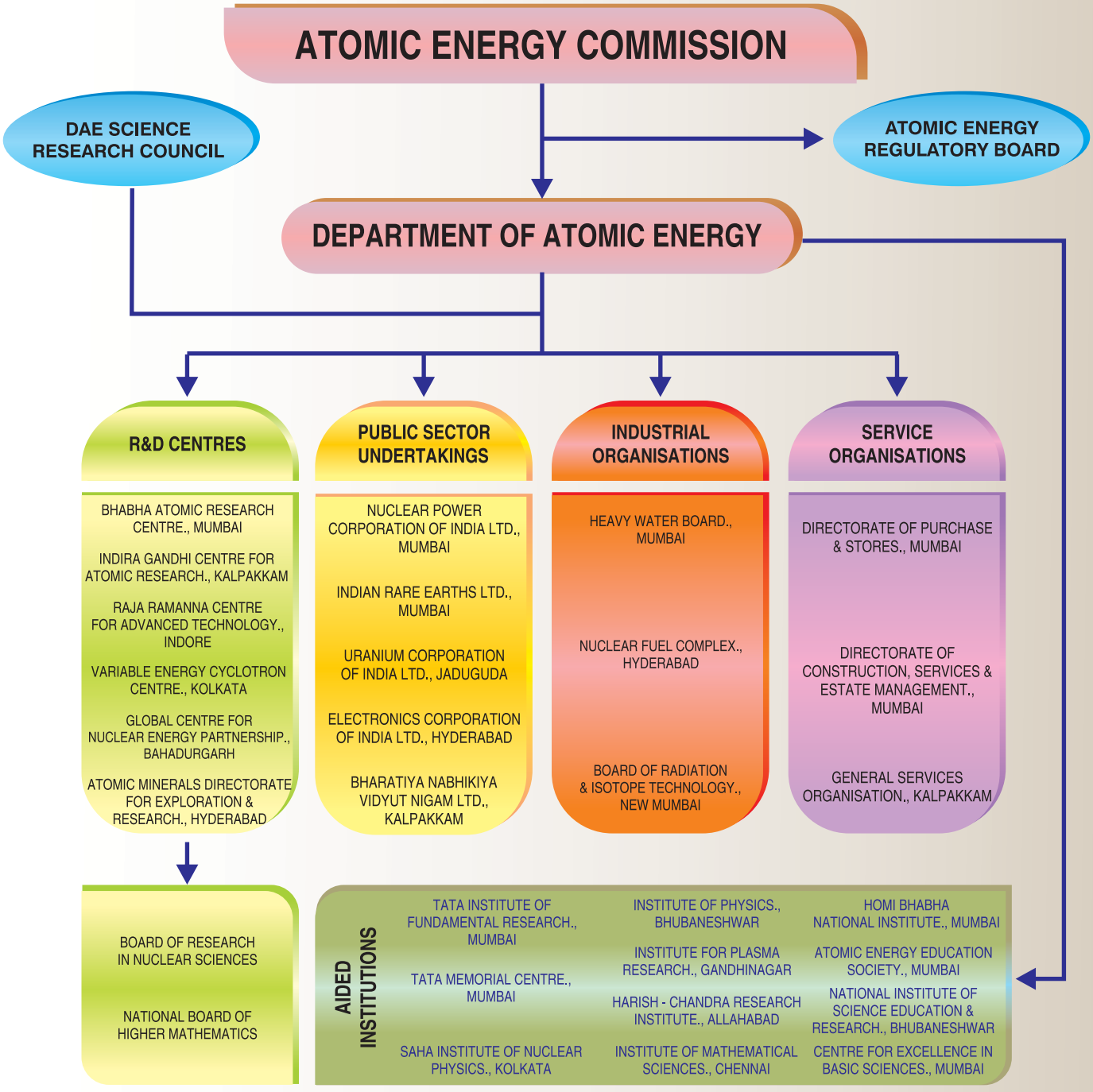
ANNEX-I

THE ORGANISATION

The Department of Atomic Energy (DAE), that came into being on August 3, 1954, has been engaged in the development of nuclear power technology, applications of radiation technologies in the fields of agriculture, medicine, industry, and basic research.

An integrated group of organizations, the Department comprises six Research Centres, three Industrial Organisations, five Public Sector Undertakings and three Service Organisations. It has under its aegis two Boards for promoting and funding extra-mural research in nuclear and allied fields, and mathematics, and a national institute (deemed university).

It also supports Ten institutes of international repute engaged in research in basic sciences, astronomy, astrophysics, cancer research and education, etc., and a society that provides educational facilities to the children of DAE employees.


ATOMIC ENERGY COMMISSION
DAE SCIENCE RESEARCH COUNCIL
ATOMIC ENERGY REGULATORY BOARD
DEPARTMENT OF ATOMIC ENERGY
R&D CENTRES
BHABHA ATOMIC RESEARCH CENTRE., MUMBAI
INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH., KALPAKKAM
RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY., INDORE
VARIABLE ENERGY CYCLOTRON CENTRE., KOLKATA
GLOBAL CENTRE FOR NUCLEAR ENERGY PARTNERSHIP., BAHADURGARH
ATOMIC MINERALS DIRECTORATE FOR EXPLORATION & RESEARCH., HYDERABAD
PUBLIC SECTOR UNDERTAKINGS
NUCLEAR POWER CORPORATION OF INDIA LTD., MUMBAI
INDIAN RARE EARTHS LTD., MUMBAI
URANIUM CORPORATION OF INDIA LTD., JADUGUDA
ELECTRONICS CORPORATION OF INDIA LTD., HYDERABAD
BHARATIYA NABHIKIYA VIDYUT NIGAM LTD., KALPAKKAM
INDUSTRIAL ORGANISATIONS
HEAVY WATER BOARD., MUMBAI
NUCLEAR FUEL COMPLEX., HYDERABAD
BOARD OF RADIATION & ISOTOPE TECHNOLOGY., NEW MUMBAI
SERVICE ORGANISATIONS
DIRECTORATE OF PURCHASE & STORES., MUMBAI
DIRECTORATE OF CONSTRUCTION, SERVICES & ESTATE MANAGEMENT., MUMBAI
GENERAL SERVICES ORGANISATION., KALPAKKAM
BOARD OF RESEARCH IN NUCLEAR SCIENCES
NATIONAL BOARD OF HIGHER MATHEMATICS
AIDED INSTITUTIONS
TATA INSTITUTE OF FUNDAMENTAL RESEARCH., MUMBAI
TATA MEMORIAL CENTRE., MUMBAI
SAHA INSTITUTE OF NUCLEAR PHYSICS., KOLKATA
INSTITUTE OF PHYSICS., BHUBANESHWAR
INSTITUTE FOR PLASMA RESEARCH., GANDHINAGAR
HARISH - CHANDRA RESEARCH INSTITUTE., ALLAHABAD
INSTITUTE OF MATHEMATICAL SCIENCES., CHENNAI
HOMI BHABHA NATIONAL INSTITUTE., MUMBAI
ATOMIC ENERGY EDUCATION SOCIETY., MUMBAI
NATIONAL INSTITUTE OF SCIENCE EDUCATION & RESEARCH., BHUBANESHWAR
CENTRE FOR EXCELLENCE IN BASIC SCIENCES., MUMBAI

ATOMIC ENERGY ESTABLISHMENTS IN INDIA



Major Programmes and Sub-Programmes

MP 1		MP 2		MP 3		MP 4		MP 5		MP 6		MP 7	
1.01	PHWR	2.01	Fast Reactors	3.01	Advanced Heavy Water Reactor	4.01	Research Reactors	5.01	Mathematics & Computational Sciences	6.01	Human Resource Development	7.01	Infrastructure
1.02	LWR	2.02	Materials	3.02	Thorium Fuel Cycle	4.02	Isotope Processing	5.02	Physics	6.02	Sponsored Research	7.02	Housing
1.03	Front End Fuel Cycle	2.03	FBR-Front End Fuel Cycle	3.03	Other Thorium Reactor Systems	4.03	Agriculture	5.03	Chemistry	6.03	Prospective Research Fund		
1.04	Back End Fuel Cycle	2.04	FBR-Back End Fuel Cycle	3.04	Accelerator Driven Sub-critical Systems	4.04	Food Processing	5.04	Biology	6.04	Homi Bhabha Centre for Science Education		
1.05	Health, Safety & Environment	2.05	Repair and Inspection Technologies	3.05	Materials	4.05	Health	5.05	Cancer	6.05	Information Technology Application Development		
1.06	Waste Management	2.06	FBR-Health, Safety & Environment	3.06	Hydrogen Energy	4.06	Water	5.06	Synchrotrons & their Utilisation				
				3.07	Fusion Reactor	4.07	Industrial Applications	5.07	Cyclotrons & their Utilisation				
						4.08	Accelerators	5.08	Fusion & Other Plasma Technologies				
						4.09	Lasers	5.09	Material Science				
						4.10	Special Materials	5.10	Interdisciplinary Areas				
						4.11	Advanced Technologies	5.11	International Research Collaborations				
						4.12	Special Programmes						

MAJOR PROGRAMMES

MP-1 : Nuclear Power Programme-Stage-1
MP-2 : Nuclear Power Programme-Stage-2
MP-3 : Nuclear Power Programme-Stage-3 and beyond
MP-4 : Advanced Technologies and Radiation Technologies and their Applications
4A : Advanced Technologies and their Applications (Includes sub-programmes 4.01, 4.08 to 4.12)
4B : Radiation Technologies and their Applications (Includes sub programme 4.02 to 4.07)
MP-5 : Basic Research
MP-6 : Research Education Linkages
MP-7 : Infrastructure & Housing

ANNEX-II

REPLIES TO AUDIT OBSERVATIONS

Report No.6 of 2020, Chapter-III: Financial Audit, Union Government

Para No.4.1 - Establishment of Medical Cyclotron Facility

Variable Energy Cyclotron Centre, Kolkata (VECC) did not prepare the site in time for installation of equipment for the proposed Medical Cyclotron facility due to which equipment costing ₹ 82.12 crore remained idle for more than eight years and the project remained incomplete for more than 15 years since sanction and after incurring an expenditure of ₹ 219.50 crore.

Action Taken:

Extract of Para is downloaded from APMS Portal on 16/12/2020 and submission of initial Action Taken Note (ATN) is under process

Para No.4.2 - Commissioning of Ion Trap System

An Ion Trap System procured by Directorate of Purchase and Stores, Mumbai for Bhabha Atomic Research Centre, Mumbai after incurring expenditure of ₹ 2.13 crore, could not be commissioned even after more than seven years due to defective parts. The organisations did not obtain adequate financial safeguards for ensuring the security of the procurement.

Action Taken:

Extract of Para is downloaded from APMS Portal on 16/12/2020 and submission of initial Action Taken Note (ATN) is under process.

Para No.4.3 - Loss due to under coverage of Medical Stock.

Tata Memorial Hospital, Mumbai did not carry out mid-term revision of the sum assured for its medical stock based on actual trend of inventory levels, which resulted in under coverage of stock and consequent loss of ₹ 1.64 crore from an insurance claim after a fire accident.

Action Taken:

Extract of Para is downloaded from APMS Portal on 16/12/2020 and submission of initial Action Taken Note (ATN) is under process.

ANNEX-III

REPRESENTATION OF SCs, STs AND OBCs

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2021 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 IN RESPECT OF **CONSTITUENT UNITS**

Groups	Representation of ST/ST/OBC (as on 01.01.2021)				Number of appointments made during the calendar year 2020									
					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	8396	622	195	1078	141	1	0	37	102	20	0	0	0	0
Group B	7129	1422	748	2353	18	2	0	10	144	26	9	6	1	1
Group C	9228	1900	883	3312	202	30	19	102	86	15	8	3	0	0
TOTAL	**24753**	**3944**	**1826**	**6743**	**361**	**33**	**19**	**149**	**332**	**61**	**17**	**9**	**1**	**1**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2021 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 IN RESPECT OF **AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2021)				Number of appointments made during the calendar year 2020									
					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	1778	123	18	182	105	3	2	7	1	0	1	0	0	0
Group B	3067	464	166	752	209	26	14	64	23	4	2	0	0	0
Group C	2504	677	165	587	42	8	4	13	0	0	0	0	0	0
TOTAL	**7349**	**1264**	**349**	**1521**	**356**	**37**	**20**	**84**	**24**	**4**	**3**	**0**	**0**	**0**

ANNUAL STATEMENT SHOWING THE REPRESENTATION OF **SCs, STs AND OBCs** AS ON 01.01.2021 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2020 IN RESPECT OF **PUBLIC SECTOR UNDERTAKINGS**

Groups	Representation of ST/ST/OBC (as on 01.01.2021)				Number of appointments made during the calendar year 2020									
					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	6953	954	350	1514	142	25	14	48	107	47	4	0	0	0
Group B	4495	794	411	1384	54	9	7	29	106	17	16	0	0	0
Group C	4048	706	566	1003	156	16	15	78	106	42	6	0	0	0
TOTAL	**15496**	**2454**	**1327**	**3901**	**352**	**50**	**36**	**155**	**319**	**106**	**26**	**0**	**0**	**0**

ACTREC	Advanced Centre for Treatment, Research and Education in Cancer
ADU	Ammonium Di-Uranate
AEC	Atomic Energy Commission
AECS	Atomic Energy Cetnral School
AEES	Atomic Energy Educational Society
AERB	Atomic Energy Regulatory Board
AFR	Away from Reactor
AFCONE	African Commission on Nuclear Energy
AgODS	Agglomeration Onset Detection System
AHWR	Advanced Heavy Water Reactor
AIP	Active Ingredient of Piper
ALIP	Annular Linear Induction Pump
AMD	Atomic Minerals Directorate for Exploration & Research
AMDER	Atomic Minerals Directorate for Exploration and Research
ANN	Artificial Neural Network
APC	Allylpyrocatechol
APAR	Annual Performance Appraisal Report
APO	Alkyl Phosphine Oxide
APMO	Asia Pacific Mathematics Olympiad
ARPF	Agricultural Radiation Processing Facility
ASIC	Application Specific Integrated Circuits
ATF	Accident Tolerant Fuel
ATI	Administrative Training Institute
ATLA	Advanced Tunable Laser Application
ATTF	AHWR Thermal Hydraulic Test Facility
AUSC	Advanced Ultra-Super Critical
BRE	Basic Research and Science Education
BAEC	Bangladesh Atomic Energy Commission
BARC	Bhabha Atomic Research Centre
BARCTS	BARC Training School
BCCP	Boron Carbide Pelletization Plant
BFP	Boiler Feed Pumps
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited
BIS	Bureau of Indian Standard
BNHS	Bombay Natural History Society
BOS	Board of Studies
BARCIS	BARC Channel Inspection System
BRIT	Board of Radiation & Isotope Technology
BRNS	Board of Research in Nuclear Sciences
BSC	BARC Safety Council
BSC	Board Sub Committee
BSD	Biennial Shutdown
BSM	Beyond the Standard Model
BSPU	Bench scale Sodium metal Purification unit
BSOI	Beach Sand and Offshore Investigations
BTA	Breakup Threshold Anomaly
BWR	Boiling Water Reactor
CARDS	Cobalt Adjuster Rod Dismantling System
CBI	Central Bureau of Investigation
CBS	Centre for Excellence in Basic Sciences
CERT	Computer Emergency Response team
CCG	Creep Crack Growth
CCE	Centre for Cancer Epidemiology
CCTF	Core Component Test Facility
CDPs	Committees on DAE Programmes
CDR	Conceptual Design Review
CFD	Computational Fluid Dynamics
CFS	Current Feeder System
CGGC	Chottanagpur Granite Gneiss Complex
CHSS	Contributory Health Service Scheme
CHTR	Compact High Temperature Reactor
CICC	Cable-in-Conduit Conductor
CISAG	Computer and Information Security Advisory Group
CISD	Computer and Information Systems Division
CMG	Crisis Management Group
CMI	Chennai Mathematical Institute
CMR	Custom Made Sources
CNT	Carbon Nanotubes
COG	CANDU Owner's Group
CORAL	Compact Reprocessing facility for Advanced fuels of Lead cells
CONSIST	Containment System Integral Simulation Test
CPS	Control And Protection System
CPT	Coherent Population Trapping
CRPs	Coordinated Research Projects
CRI	Cancer Research Institute's
CRIs	Catheter-related Infections
CSP	Core Sub-assembly Plant
CSR	Controlled Surface Rolling
CTE	Chief Technical Examiner
CTS	Cobalt Teletherapy Sources
CVC	Central Vigilance Commission
CVD	Chemical Vapor Deposition
CVL	Copper Vapour Laser
CVO	Chief Vigilance Officer
CVPS	Cryogenic Vacuum Producing System
DAC	Diamond Anvil Cell
DAE	Department of Atomic Energy
DAVA	Data Acquisition and Validation Application
DBT	Ductile to Brittle Transition
DBFFS	DAE-BRNS Fully Funded Symposia
DCS	Distributed Control System
DCSEM	Directorate of Construction Services & Estate Management
DCT	Disc Compact Tension
DDC	Dual Directional Coupler
DFRP	Demonstration Fast reactor fuel Reprocessing Plant
DGFS	DAE Graduate Fellowship Scheme
DHC	Delayed Hydride Crack
DHX	Decay Heat Exchangers
DMR	Digital Mobile Radio
DMSP	Diverse Modular Safety Platform

DNP	Delayed Neutron Precursors
DOT	Devasthal Optical Telescope
DoPT	Department of Personnel & Training
DPA	Di-picolinic acid
DPS	Directorate of Purchase & Stores
DRDO	Defence Research Development Organisation
DRT	Data Relay Transponder
DSB	Double Strand Breaks
DSC	Differential Scanning Calorimetry
DSC	Digital Signature Certificate
DST	Department of Science and Technology
DURGA	Dhruva Utilization for Research using Gamma Array
EAC	Expert appraisal Committee
ECIL	Electronic Corporation of India Limited
ECRs	Emergency Control Rooms
ECRIS	Electron Cyclotron Resonance Ion Source
EDF	Électricité de France
EFFP	Enriched Fuel Fabrication Plant
EFPD	Effective Full-Power Days
EGS	Embedded Guiding Structures
EIA	Environmental Impact Analysis
EMCCR	En-masse Coolant Channels Replacement
EMS	Environmental Management System
ELA	Energy Level Alignment
FPE	First Priority Equipment
EPR	Emergency Preparedness and Response
ERMs	Environmental Radiation Monitors
ESLs	Environmental Survey Laboratory
ESP	Environment Stewardship Programme
ESS	Environmental Stress Screening
FSTS	Full Scope Replica Operator Training Simulator
EURATOM	European Atomic Energy Community
FAIR	Facility for Antiproton and Ion Research
FAQ	Frequently Asked Question
FBTR	Fast Breeder Test Reactor
FBR	Fast Breeder Reactor
FCMSL	Forced Circulation Molten Salt Loop
FCT	Fast Current Transformer
FDG	Fluorodeoxyglucose
FET	Fluro Ethyl–L-Tyrosine
FE-SEM	Field Emission Scanning Electron Microscopy
FFLM	Failed Fuel Location Module
FFP	Fuel Fabrication Plant
FHS	Fuel Handling System
FIB-SEM	Focused Ion Beam - Scanning Electron Microscope
FMV	Fuelling Machine Vault
FOAK	First-of-a-Kind
FPC	First Pour of Concrete
FRFCF	Fast Reactor Fuel Cycle Facility
FRP	Fuel Reprocessing Plant
GANs	Generative Adversarial Networks
GBF	Great Boundary Fault
GCNEP	Global Centre for Nuclear Energy Partnership
GDR	Giant Dipole Resonance
GEM	Gas Electron Multiplier
GFRP	Glass-Fibre Reinforced Polymer
GHAVP	Gorakhpur Harayana Anu Vidyut Pariyojana
GI-XRD	Grazing-incidence x-ray diffraction
GIS	Geographical Information System
GMP	Good Manufacturing Practices
GMRT	Giant Metrewave Radio Telescope
GRAMS	Grievance Redressal and Monitoring System
GRAS	Generally Recognized As Safe
GRPF	Gamma Radiation Processing Plants
GSFL	Green Star Fertilizer Limited
GSO	General Services Organisation
HAI	Hospital-Acquired Infections
HARL	High Altitude Research Laboratory
HAZ	Heat Affected Zone
HBCH	Homi Bhabha Cancer Hospital
HBCHRC	Homi Bhabha Cancer Hospital & Research Centre
HBCSE	Homi Bhabha Centre for Science Education
HBNI	Homi Bhabha Nationa Institute
HDG	High Density Graphite
HFM	Hollow Fibre Membrane
HHFTF	High Heat Flux Testing Facility
Hi-RBS	High resolution Rutherford Backscattering Spectroscopy
HLT	Helium Leak Testing
HRDD	Human Resource Development Division
HRI	Harish-Chandra Research Institute
HTS	Horizontal Test Stand
HTUP	Heat Treated Uranium Peroxide
HSA	Human Serum Albumin
HSAR	Hydraulically Suspended Absorber Rod
HSC	Hard Steel Core
HSD	High Speed Diesel
HS&EG	Health, Safety and Environment Group
HVIF	High Vacuum Induction Furnace
HWB	Heavy Water Board
HWP	Heavy Water Plant
IAS	Isotope Application Services
ICTS	International Centre for Theoretical Sciences
ICVG	Indium doped Calcium Vanadium Garnets
IERMON	Indian Environmental Radiation Monitoring Network
ISAG	Indian Society of Applied Geochemists
ISI	In-Service Inspection
IGCAR	Indira Gandhi Centre for Atomic Research
IHX	Intermediate Heat Exchanger
IMC	Indore Municipal Corporation
IMOC	Inter-Ministerial Overseeing Committee
IMSc	Institute of Mathematical Science

IMSBR	Indian Molten Salt Breeder Reactor
INGA	Indian National Gamma Array
INMO	Indian National Mathematics Olympiad
INS	Indian Nuclear Society
INPRO	Innovative Nuclear Reactors and Fuel Cycles
INSPIRE	Innovation in Science Pursuit for Inspired Research
IOP	Institute of Physics
IOT	Inductive Output Tube
IOQM	Indian Olympiad Qualifier in Mathematics
IPR	Intellectual Property Rights
IPR	Institute for Plasma Research
IPHWR	Indian Pressurized Heavy Water Reactor
IQH	Integer Quantum Hall
IREL	Indian Rare Earths Limited
IRFEL	Infra-red Free Electron Laser
IRMA	Immunoradiometric Assay
ISC	Indian Science Congress
ISI	In-service Inspection
ISM	Induction Skull Melting
ISRO	Indian Space Research Organisation
ITER	International Thermonuclear Experimental Reactor
ITP	Integrated Test Plan
IV&V	Independent Verification and Validation
IWM	Indian Women in Mathematics
JNNSMEE	Jawaharlal Nehru National Science, Mathematics & Environmental Exhibition
KAMINI	KAlpakkam MINI Reactor
KAPP	Kakrapar Atomic Power Project
KAPS	Kakrapar Atomic Power Station
KARP	Kalpakkam Atomic Reprocessing Plant
KGS	Kaiga Generating Station
KKNPP	Kudankulam Nuclear Power Plant
KSoM	Kerala School of Mathematics
KVPY	Kishore Vaigyanik Protsahan Yojana
KYT	Know Your Trees
LBE	Lead-Bismuth Eutectic
LCF	Low Cycle Fatigue
LCTR	Large Component Test Rig
LEHIPA	Low Energy High Intensity Proton Accelerator
LIS	Laser Isotope Separation
LLCB	Lead Lithium cooled Ceramic Breeder
LLPS	Liquid Liquid Phase Separation
LMC	Long Manufacturing Cycle Equipment
LMFBR	Liquid Metal cooled Fast Breeder Reactor
LOCA	Loss of Coolant Accident
LOI	Letter of Intent
LRP	Large Rotatable Plug
LVPS	Low Voltage Power Supply
LWR	Light Water Reactor
MaskAAE	Masked Adversarial Auto-encoder
MCF	Medical Cyclotron Facility
MDU	Magnesium Di-Uranate
MFCI	Molten Fuel Coolant Interaction
MFI	Mobile Food Irradiator
MHA	Ministry of Home Affairs
MHE	Material Handling Equipment
MRI	Magnetic Resonance Imaging
MLW	Medium Level Waste
MMC	Madhava Mathematics Competition
MoEFCC	Ministry of Environment, Forest and Climate Change
MOT	Magneto-Optical Trap
MoU	Memorandum of Understanding
MOVPE	Metal Organic Vapour Phase Epitaxy
Mpro	Main Protease
MRECL	Mixed Rare Earths Chloride
MRNAs	Messenger RNAs
MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
M.Sc	Master of Science
MSR	Molten Salt Reactor
MTA	Major Turn Around
MTTS	Mathematical Training and Talent Search Programme
MWA	Murchinson Widefield Array
NAPS	Narora Atomic Power Station
NBHM	National Board of Higher Mathematics
NBI	Neutral Beam Injector
NBWL	National Board for Wildlife
NAC	National Advisory Committee
NCC	New Community Centre
NCG	National Cancer Grid
NCSM	National Council of Science Museums
NDCT	Natural Draught Cooling Tower
NDE	Non-Destructive Evaluation
NDFB	North Delhi Fold Belt
NDT	Non-Destructive Techniques
NFM	Neutron Flux Monitor
NGADU	Nuclear Grade Ammonium Di-Uranate
NISER	National Institute of Science Education & Research
NNWD	Nuclear News Web Digest
NORMS	Naturally occurring radioisotopes
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plants
NPRO	Non Planar Ring Oscillator
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
NTSE	National Talent Search
NUP	National Uranium Project
ODC	Over Dimensional Consignment
OGDHRS	Operation Grade Decay Heat Removal System
OHSMS	Occupational Health and Safety Management System
OIS	Operator Information System
OLIC	Official Language Implementation Committees

ONERS	Online Nuclear Emergency Response Decision Support System
OPF	Oxide Production Facility
PAPR	Powered Air Purifying Respirators
PAPs	Project Affected Persons
PAW	Plasma Activated Water
PBT	Profit Before Tax
PBVH	Plastic Boxes with proper Hygiene
PCP	Primary Coolant Pump
PCRD	Passive Catalytic Recombiner Devices
PCT	Patent Co-operation Treaty
PDF	Post Doc Fellowship
PES	Photo-Electron Spectroscopy
PDT	Photodynamic Therapy
PET	Positron Emitting Tomography
PFBR	Prototype Fast Breeder Reactor
PERD	Pharmaceutical Education and Research Development
PFMS	Public Financial Management System
PGMA	Polyglycidyl Methacrylate
PHT	Primary Heat Transport
PHWR	Pressurised Heavy Water Reactors
PIC	Project Implementation Committees
PIC	Particle-In-Cell
PIDS	Periphery Intrusion Detection System
PIGIS	Penning Ion Gauge Ion Source
PIE	Post Irradiation Examination
PIGE	Particle Induced Gamma-ray Emission
PLC	Programmable Logic Controller
PLF	Plant Load Factor
Plpro	Papain-Like Protease
PMFM	Permanent Magnet Flowmeter
PMJAY	Pradhan Mantri Jan Arogya Yojana
PPE	Personal Protective Equipment
PPF	Process Plant Facility
PPRDF	Pyro Process R&D Facility
PRID	Portable Radio-isotope Identifier
PRIS	Power Reactor Information System
PRTRF	Power Reactor Thoria Reprocessing Facility
PSA	Probabilistic Safety Assessment
PSA	Poison Sub-Assemblies
PSMA	Prostate Specific Membrane Antigen
PUT	Piezoelectric Ultrasonic Transducers
QIC	Quantum Information and Computation
QWR	Quarter Wave Resonator
RAL	Radioanalytical Laboratory
RAL	Radiological Assessment Laboratory
RAISE	Remote Access to IGCAR Subscribed E-resources
RAPP	Rajasthan Atomic Power Project
RAPS	Rajasthan Atomic Power Station
RCB	Reactor Containment Building
RCU	Reactivity Computation Unit
RDSP	Radar Digital Signal Processing System
RGMS	Radiation and Gas Monitoring System
RFPI	Radio Frequency Protection Interlocks
RIA	Radioimmunoassay
RMC	Radiation Medicine Centre
RMCD	Redundancy Management and Control Device
RMRE	Rare Metal and Rare Earth
RNPP	Roopper Nuclear Power Plant
ROTEX-I	Remotely Operated Tungsten shielded Exposure Device
RPC	Resistive Plate Chamber
RPS	Reactor Protection System
RPT	Radioactive Particle Tracking
RPV	Reactor Pressure Vessel
RRCAT	Raja Ramanna Centre for Advanced Technology
RSPI	Radiological Safety Performance Indicators
RSOs	Radiological Safety Officers
RSW	Radiation Shielding Windows
RTC	Room Temperature Cyclotron
RTE	Right to Education
RTI	Right to Information
RTT	Ring Tension Test
RUP	Reprocessed Uranium Oxide Plant
RWP	Radiological Work Permit
SAB	Service Auxiliary Building
SAED	Scattered Area Electron Diffraction
SAQ	Software Quality Assurance
SBS	School of Biological Sciences
SCC	Stress Corrosion Cracking
SCL	Semiconductor Laboratory
SCMF	Special Component Manufacturing Facility
SCR	Security Control Room
SCRF	Superconducting Radio Frequency
SCU	Signal Conditioning Unit
SCWR	Super Critical Water Reactor
SDK	Software Development Kit
SDS	Shutdown Systems
SEEP	Societal Enrichment and Education Programme
SEM	Scanning Electron Microscope
SETBF	Setting up of Sensor Evaluation Test Bed Facility
SFRs	Sodium cooled Fast Reactors
SGDHRS	Safety Grade Decay Heat Removal System
SGTMF	Steam Generator Tube Manufacturing Facility
SHE	Scholarship for Higher Education
SHEP	Sodium Hypochlorite Electrolyser Plant
SHIVAY	System- Sheetal Vahak Yantra
SHP	Super Hydro-Phobic

SHPS	Salt Handling & Purification System
SINP	Saha Institute of Nuclear Physics
SKA1	Square Kilometre Array
SKA	Square Kilometre Array
SOP	Standard Operating Procedure
SPE	Solid Polymer Electrolyte
SPP	Solvent Production Plant
SPV	Surface Photo-Voltage
SSNTD	Solid State Nuclear Track Detectors
SQA	Software Quality Assurance
SRC	Safety Review Committee
SRP	Small Rotatable Plugs
SSE	Structures & Equipment
SSP	Secondary Sodium Pump
SSRFPA	Solid State RF Power Amplifiers
STP	Sewage Treatment Plants
SUC	Start-up Counter
SVA	Solvent Vapour Annealing
SXP	Solvent Extraction Plant
TAPS	Tarapur Atomic Power Station
TBM	Test Blanket Module
TBP	Tributyl Phosphate
TCF	Technical Cooperation Fund
TDC	Technology Development Council
TDP	Technology Demonstration Plant
TDO	Trainee Defence Officers
TEM	Transmission Electron Microscopy
TFC	Thin Film Composite
TFS	Tritium Filled Self-luminous
THM	Total Heavy Mineral
TiAP	Tri-iso amyl phosphate
TIFR	Tata Institute of Fundamental Research
TLDs	Thermo Luminescence Dosimeters
TMC	Tata Memorial Centre
TMH	Tata Memorial Hospital
TMIS	Training Management Information System
TMS	Tarapur Maharashtra Site
TMT	Thermo Mechanical Treatment
TNAU	Tamil Nadu Agricultural University
TODGA	Tetraoctyldiglycolamide
TOF	Time of Flight
TOLIC	Town Official Language Implementation Committee
TPS	Treatment Planning System
UCIL	Uranium Corporation of India Limited
UVC	Ultraviolet C
UGP	Upgrading plant
UHRATEM	Ultra High-Resolution Analytical Transmission Electron Microscope
UHV	Ultra High Vacuum
UIS	Ultrasonic Imaging System
UNS	Uranyl Nitrate Solution
ULOF	Untripped Loss of Flow event
ULOHSA	Unprotected Loss of Heat Sink Accident
UOC	Uranium Ore Concentrate
USDA	US Department of Agriculture
VARANS	Vietnam Agency for Radiation and Nuclear Safety
VAW	Vigilance Awareness Week
VECC	Variable Energy Cyclotron Centre
VFD	Variable Frequency Drive
VPN	Virtual Private Network
VSFG	Vibrational Sum-frequency Generation
VNCH	Vietnam National Cancer Hospital
VOCs	Volatile Organic Compounds
VVPAT	Voter Verifiable Paper Audit Trail Printers
WAL	Weak Anti-Llocalization
WANO	World Association of Nuclear Operators
WEC	Westinghouse Electric Company
WHO	World Health Organization
WII	Wildlife Institute of India
WILD	Wheel Impact Load Detection
WIP	Waste Immobilization Plant
WMP	Waste Management Plant
WSN	Wireless Sensor Network
WTF	Waste Tank Farm
XANES	X-ray Absorption Near Edge Structure
XRD	X-Ray Diffraction
ZPE	Zero Point Energy

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