

# ANNUAL REPORT 2021-22



GOVERNMENT OF INDIA  
DEPARTMENT OF ATOMIC ENERGY





सत्यमेव जयते

**GOVERNMENT OF INDIA**

**DEPARTMENT OF ATOMIC ENERGY**



# **ANNUAL REPORT**

## **2021-22**

**About front and back cover:** *Bird's-eye view of the NPCIL Kakrapar Site in Gujarat, showing India's newest power reactor, KAPP-3. This maiden indigenously built 700 MW reactor is a shining example of 'Make in India' and a trailblazer among the 10 PHWRs coming up in fleet mode. KAPP-3 achieved the 'First Criticality' (controlled self-sustaining nuclear fission chain reaction for the first time) in July 2020 and was subsequently connected to the power grid in January 2021.*

# CONTENTS

<b>EXECUTIVE SUMMARY</b>	<b>I - XLII</b>
<b>Chapter-1 : Nuclear Power Programme-Stage-I</b>	<b>1 - 46</b>
<b>Chapter-2 : Nuclear Power Programme-Stage-II</b>	<b>47 - 60</b>
<b>Chapter-3 : Nuclear Power Programme-Stage-III</b>	<b>61 - 66</b>
<b>Chapter-4 : Applications of Advanced Technologies and Radiation Technologies</b>	<b>67 - 100</b>
<b>Chapter-5 : Basic and Applied Research</b>	<b>101 - 138</b>
<b>Chapter-6 : Research Education Linkages</b>	<b>139 - 154</b>
<b>Chapter-7 : Technology Transfer and Collaborative Programmes</b>	<b>155 - 164</b>
<b>Chapter-8 : Infrastructure</b>	<b>165 - 172</b>
<b>Chapter-9 : Public Sector Undertakings</b>	<b>173 - 180</b>
<b>Chapter-10 : Other Activities</b>	<b>181 - 208</b>
<b>Chapter-11 : Implementation of Persons with Disabilities (Equal Opportunities, Protection of Rights &amp; Full Participation) Act, 1995</b>	<b>209 - 212</b>
<b>Chapter-12 : Citizen's Charter</b>	<b>213 - 217</b>
<b>Annex-I : The Organisation</b>	<b>218 - 221</b>
<b>Annex-II : Replies to Audit Observations</b>	<b>222</b>
<b>Annex-III : Representation of SCs, STs and OBCs</b>	<b>223 - 225</b>
<b>Abbreviations</b>	<b>226 - 227</b>





# **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 2021-22, 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' (Highest

Safety) by CRISIL, CARE, ICRA and India Rating. NPCIL is responsible for obtaining siting consent, design, construction, commissioning, operation and upgradation of nuclear power reactors. Safety is given overriding priority during the various stages from contracting to operation of Nuclear Power Plants (NPP). At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. NPCIL is constructing eight Reactors (6800 MW) comprising of Kakrapar Atomic Power Project (KAPP) Unit-3&4 (2 x 700 MW, PHWRs), Rajasthan Atomic Power Project (RAPP) Unit-7&8 (2 x 700 MW, PHWRs), Kudankulam Nuclear Power Project (KKNPP) - 3&4 (2 x 1000 MW, LWRs) and KKNPP-5&6 (2 x 1000 MW, LWRs) these are under various stages of construction. Out of these units, KAPP Unit-3 which is the first unit of indigenously designed 700 MW PHWR, was synchronized with the Grid for the first time on January 10, 2021. In addition, First Pour of Concrete (FPC) consent is granted by AERB for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) Unit-1&2 (2 x 700 MW PHWRs) and subsequently casting of all foundation piles has been completed in both the Nuclear Building (NB) areas and preparations towards construction of nuclear building raft are in progress. For Ten 700 MW PHWRs in fleet mode, which have got Administrative Approval and Financial Sanction from the Government of India, various preparatory activities such as land acquisition and R&R, Environmental clearance, procurement activities of long delivery equipment, studies for regulatory clearances, site infrastructure development, public outreach, tendering for main plant civil works etc. are in various stages of progress. Further, in respect of new sites at Jaitapur in Maharashtra, Land Acquisition and Environment Clearance are completed. In Kovvada, Andhra Pradesh, various Pre-project activities related to land acquisition, R&R, environmental studies, Site Studies, Site infrastructure development, regulatory clearances, public outreach etc. and various techno commercial discussions for setting up large sized imported light water reactors (LWRs) based on international co-operation are in progress. In respect of Bhimpur site in Madhya Pradesh, commitment for water is to be confirmed by State Government. In respect of Mithi Viridi site in Gujarat, land acquisition process is to be re-initiated as per new land acquisition Right to Fair

Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act 2013. In respect of Haripur site in West Bengal, land acquisition is contingent to initiative by State Government. Alternate site is also under consideration by GoI. Though Covid-19 Pandemic has impacted supply chain, lockdowns, man power deployment, travel restrictions etc. affecting progress of various projects, NPCIL has put in best efforts towards resumption of normal pace of project activities and has continued safe and normal operation of its power stations.

## Power Generation

During the Calendar Year (CY) 2021, NPCIL registered total commercial power generation of 43918 Million Units (Mus). In addition, KAPP Unit-3 generated 402 MUs of non-commercial generation of power during CY 2021. In the previous CY 2020, the total commercial power generation was 44613 MUs.

During the period April - December 2021 in the Financial Year (FY) 2021-22, NPCIL registered total commercial power generation of 34837 MUs and expected total commercial generation for the FY 2021-22 is about 46000 MUs. In addition, KAPP Unit-3 has generated 139 MUs of non-commercial power during this period. In the previous FY 2020-21, the total commercial power generation was 43029 Mus.

During the FY 2021-22, the overall Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2021 for the reactors in commercial operation were 87% and 86% respectively. These figures for last FY 2020-21 were 83% and 81% respectively.

During the FY 2021-22, RAPS Unit-4 and Kaiga Generating Station (KGS) Unit-1 achieved continuous, safe and reliable operation for more than a year. RAPS-4 registered 643 days of continuous, safe and reliable operation on January 10, 2022 after which the unit was manually shut down for maintenance works. KGS Unit-1 registered 449 days of continuous, safe and reliable operation on July 12, 2021 after which the unit was manually shut down for Biennial Shutdown works. RAPS Unit-6, which registered continuous, safe and reliable operation for more than a year in the last financial year,

continued operation and registered 422 days of continuous, safe and reliable operation till its shutdown on April 28, 2021. So far, the continuous, safe and reliable operation for more than a year has been achieved 37 times by various reactors operated by NPCIL. Out of these, four reactors KGS Unit-1 (962 days), Narora Atomic Power Station (NAPS) Unit-2 (852 days), RAPS Unit-3 (777 days) and RAPS Unit-5 (765 days) have operated continuously for more than two years. The continuous, safe and reliable operation for 962 days registered by KGS Unit-1 is second longest continuous operation in world among all reactor technologies.

Nuclear power reactors in our country have registered cumulative 561 reactor years of safe operation by the end of Calendar Year 2021.

## Operating Units taken in Project mode

The Madras Atomic Power Station (MAPS) Unit-1 (220 MW PHWR) and Tarapur Atomic Power Station (TAPS) Unit-1&2 (2 x 160MW BWRs) 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 safety upgrades. TAPS Unit-1 & Unit-2 (2x160MW) have been taken in project mode since April 1, 2020 and August 1, 2020 respectively for aging management and safety upgrades. RAPS Unit-2 (200 MW PHWR), which was taken in project mode since August 15, 2020 for partial boiler hairpins replacement, resumed operation on March 10, 2021.

## Projects under construction

Currently NPCIL is constructing eight Reactors (6800 MW) comprising of KAPP Unit-3&4 (2 x 700 MW, PHWRs), RAPP Unit-7&8 (2 x 700 MW, PHWRs), KKNPP Unit-3&4 (2 x 1000 MW, LWRs) and KKNPP Unit-5&6 (2 x 1000 MW, LWRs), which are under various stages of construction.

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

First unit of indigenous 700 MW Pressurized

Heavy Water Reactor (Kakrapar Atomic Power Project Unit-3) at Kakrapar, Gujarat has been successfully synchronized with Grid for the first time on January 10, 2021. The unit has generated about 402 MUs infirm power up to December 31, 2021. In Unit-4, Feeders erection is completed. Erection of the equipment & components is in progress. The physical progress of the unit was about 96.9% as on December 31, 2021.

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

In RAPP Unit-7, erection of equipment and piping is in progress. A major project milestone i.e. "Primary Heat Transport (PHT) system Hydro Test" has been successfully completed. The physical progress of the unit is about 94.4% as on December 31, 2021. In RAPP Unit-8, civil construction and erection of equipment & components are in progress. All the coolant channels are installed and pre-stressing of Inner Containment (IC) dome is in progress. The physical progress of the unit was about 80.3% as on December 31, 2021.

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

The Civil construction and equipment erection works are in progress. Construction of Reactor Building, Reactor Auxiliary Building, Turbine Building, Tunnels, Common service Buildings, Switchyard Buildings and



**Shri S.K.Sharma, Ex-CMD, NPCIL**

Hydro- technical structures (HTS), etc. are in progress. Construction of Inner Containment (IC) up to +44m with crane rail cantilever has been completed in KKNPP-3. The physical progress of KKNPP Unit-3 and KKNPP Unit-4 was about 57.4% and 53.9% respectively as on December 31, 2021.

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

Construction of KKNPP Units-5&6 commenced with the placement of First Pour of Concrete (FPC) on June 29, 2021. Concreting of Foundation Slab of Reactor Building has been completed and construction work of walls above raft is in progress in KKNPP Unit-5. Concreting of Reactor Building foundation slab (raft) Layer-1 has been completed in KKNPP Unit-6.

### **Sanctioned Projects**

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

Casting of all foundation piles has been completed in both the Nuclear Building areas. Further activities towards obtaining regulatory clearance for casting of nuclear building raft are in progress. Excavation and ground improvement works are in progress in various other areas. Long delivery equipment manufacturing is in progress. Main plant electrical package and turbine island package are awarded. Both the end shields and first steam generator are already received at site.



**Plantation at Kudankulam Site by Shri Mukesh Singh**



**Shri B.C. Pathak, Director (Projects), NPCIL addressing on the occasion of Flag off of GHAVP 2nd Endshield from L&T Hazira**

## Ten 700 MW PHWRs in Fleet Mode

### GHAVP Unit-3&4

For GHAVP Unit-3&4, land has been made available. MoEFCC Clearance has also been made available. Siting consent from AERB has been received. EPC package for Turbine Island has been awarded. Placement of work order for Excavation and Ground Improvement is under process.

### Kaiga Unit-5&6

For Kaiga Unit-5&6, land has been made available. MoEFCC Clearance and wild life Clearance are also available. Consent to establish clearance for expansion has been accorded by Karnataka State

Pollution Control Board (KSPCB). Siting consent from AERB is received. Application for Excavation clearance is under review by AERB. EPC package for Turbine Island has been awarded. Award of work of Main Plant Excavation package is under approval.

### Mahi Banswara Rajasthan Atomic Power Project (MBRAPP) Unit-1 to 4

Land acquisition is in process. MoEFCC Clearance is under process. Construction of R&R colony is in progress.

### Chutka Madhya Pradesh Atomic Power Project (CMPAPP)-1&2

Land Possession letter has been issued for all types of land. MoEFCC Clearance is available. Stage-II Forest Clearance accorded. Construction of all 330 dwelling units for R&R colony has been completed. Infrastructure facilities of R&R colony has been completed and ready for handing over.

## 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. 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 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 constitutes a major programme segment of the Nuclear Power Programme.

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

### Heavy Water Production

For meeting the future large scale requirement of specialty materials for the front end and back end of nuclear fuel cycle and to enable DAE to successfully achieve closed fuel cycle for nuclear power production and energy security, HWB has been entrusted with design and technology development from lab scale to pilot plant scale and further scaling up to industrial production units, for the various basic synthesis processes developed by research units of DAE.

HWB has established its position as a supplier of premium quality Heavy Water in the international market. This year, for the first time HWB has participated in an international tender for supply of 16 MT of nuclear grade Heavy Water for the PHWRs of M/s. Nucleoelectrica SA, Argentina. HWB was approached for supply of 55 kg of Heavy Water for manufacturing Deuterium gas at M/s. Hyosung Chemical Corporation, South Korea. Also, M/s Iwatani Corporation, Japan requested for supply of 50 kg of Heavy Water to produce deuterium gas which will be used for optical fiber and semi-conductor applications. Both these export orders were successfully executed in this financial year.

During the challenging period of nationwide partial lockdown, amid restrictions on mobility of

employees, contract labour and large-scale disruptions in supply chain, HWB demonstrated strong resilience, strictly following all safety norms, utilized its core capabilities and stayed on course with the targets. As the restrictions eased, all projects and production targets were pursued industriously.

HWPs at Hazira, Kota and Manuguru have operated excellently. The major turn around scheduled at HWP, Hazira and Thal were successfully completed well in time. The massive work of dismantling and disposal of old Heavy Water plant structures and equipment at HWP, Talcher, commenced in November 2020 and was completed in May 2021. At HWP, Baroda, all the components of 24kA prototype cell and associated systems have been installed and tested for sodium metal production. Civil Construction of 600 MT /Annum Sodium metal plant Cell building has been completed.

Revamping and preservation of HWP, Tuticorin plant is under way for restart up. Erection work at Integrated Solvent Production Plant at HWP, Tuticorin is under progress. Work for green belt development around the plant was initiated. In order to adhere to the requirement of Tamil Nadu Pollution Control Board (TNPCB) for setting up the Solvent Extraction Plant at HWP, Tuticorin, final original CRZ map was obtained from Institute of Remote Sensing, Anna University Chennai. Borehole water samples were collected and sent for ground water radiological analysis.

### Diversification Activities

HWB continued to progress with its extended mandate on production of specialty materials. This included demonstration of Solvent Extraction technologies for nuclear hydrometallurgy, producing organo-phosphorous solvents and stable isotope products like  $^{10}\text{B}$  enriched boron carbide pellets for control & safety mechanisms in Fast Breeder Reactors; and production of nuclear grade Sodium for FBRs. HWB is also in the process of synthesizing  $^{18}\text{O}$  enriched water for medical applications for societal benefits. New initiatives taken in some of the key areas in these activities during the period are as follows:



**Reactors set up at Integrated Solvent Production Plant at HWP, Tuticorin**

### Solvent Production and Rare Material Extraction

The existing solvent production facilities at Baroda and Talcher continued to meet the demand placed by various DAE units like, NFC, BARC, IREL, KARP, IGCAR etc. for nuclear grade solvents required for extraction of various materials. For meeting the future requirements of DAE-Nuclear Power Program, an industrial scale Integrated Solvent Production (ISP) Plant is being set up at HWP, Tuticorin for production of organo-phosphorus solvents. Solvents like TiAP, D2EPHA-II, TBP, TOPO and DHOA will be produced in the facility. ISP erection and commissioning activities are in progress.

At the Technology Demonstration Plant (TDP), Mumbai, activities on indigenized sourcing of Indian phosphate rocks were taken up for extraction of rare metals. About 1500 samples from a prospecting site in Madhya Pradesh were brought to TDP. Grinding of samples in newly commissioned laboratory Hammer and Ball mill and characterization of the same is in progress.

### Boron Carbide Pellet Production

For applications in control & safety systems of fast breeder reactor program and enriched  $\text{BF}_3$  gas for neutron detector systems, HWB has taken up indigenous production of  $^{10}\text{B}$  enriched Boron and Boron Carbide pellets.

Boron Carbide Pelletization Plant (at HWP, Manuguru), has been in operation for the production of enriched Boron Carbide pellets of various isotopic purities. The  $^{10}\text{B}$  IP  $\geq 50\%$  and 90% Boron Carbide



**Boron Carbide Pellets for poison sub-assembly of FBTR being handed over to NFC**

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. Forty numbers of  $\text{B}_4\text{C}$  pellets five stacks for poison sub-assembly of FBTR were handed over on virtual platform to NFC on 22.04.2021 in presence of Chairman, AEC and senior officials of BARC, NFC & IGCAR. Another set of 80 numbers of  $\text{B}_4\text{C}$  pellets for ten stacks were inspected by IGCAR and cleared for dispatch.

### Sodium Metal

In order to achieve self-reliance of DAE in Sodium metal supply, HWB has drawn up an elaborate roadmap for operating Sodium cells at HWP, Baroda. After carrying out test operation of various configurations of 2kA electrolytic cells, adequate operational data was generated. Technology for removal of the impurities like oxides of Sodium and Calcium, Carbon, Iron, Magnesium etc. to produce nuclear grade Sodium metal was completely developed by HWB at bench scale Sodium metal purification unit. For scaling up the process, 24 kA prototype cell and sub-assemblies have been designed, procured and



**24 kA Sodium Cell at HWP, Baroda**

installed at HWP, Baroda. Concurrently, the building for the industrial scale Sodium production plant of 600 MTPA capacity at HWP, Baroda has been completed.

## 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.

During the year 2021 the exploration efforts of AMD have resulted in augmentation of 23,680 tonnes uranium oxide from the exploration areas in Andhra Pradesh, Karnataka and Jharkhand. About 2,17,731 tonnes of Rare Earth Element Oxide (REO) in Ambadungar area, Chota Udepur district, Gujarat. About 36,945 tonnes of REO (at 0.2% REO cut-off) in Bhatikhera area, Barmer district, Rajasthan.

Significant uranium anomalies were located in Uttar Pradesh; Badhera, Hamirpur district, Himachal Pradesh, Andhra Pradesh, Jharkhand, Odisha, Rajasthan and Chhattisgarh.

Geochemical surveys (7,076 sq km) have indicated anomalous concentration of Li in Arunachal Pradesh, U, V and Li in Rajasthan and U in Andhra Pradesh and Punjab.

Multi-parametric heliborne geophysical survey over 56,827 line km been carried out in Rajasthan, Haryana, Jharkhand, Uttar Pradesh, Madhya Pradesh, Chhattisgarh and Maharashtra. Three potential blocks have been identified for further exploration in Chhattisgarh.

Ground geophysical surveys (Regional: 726 sq km; detailed: 604 sq km) have delineated potential zones in Andhra Pradesh, Rajasthan and Karnataka.

A total of 2,10,714 m drilling was carried out. Significant uranium mineralised intercepts / bands have been identified in Uttar Pradesh, Himachal Pradesh, Rajasthan, Andhra Pradesh, Karnataka, Jharkhand, Maharashtra, Madhya Pradesh and in addition, reconnaissance drilling has been taken up in several

potential/significant blocks in varied geological domains.

Rare Metals and Rare Earths (RMRE) survey have been carried out in Chhattisgarh, Madhya Pradesh, Odisha, Rajasthan, Gujarat and Karnataka.

Significant zones of concentrated Total Heavy Mineral (THM) also called Beach Sand Minerals have been located in Kerala and Andhra Pradesh. Sonic drilling has been carried out along Odisha.

UCIL received 'Excellent' MOU Performance rating from DPE during FY 2019-20 for the third time in a row. UCIL has applied for NOC from Forest Department for Rohil Project in Rajasthan. Pre-project activities for setting up new mines and plants in different parts of the country are in various stages. Preparation of Techno-economic Feasibility Report (TEFR) has been completed for Rohil Project.

IREL completed 70 years of providing unstinted support to the Country. It has received "Excellent" MoU Rating for the year 2020-21 for the 4th consecutive year. The MoU Score secured by IREL (India) Limited in the year 2019-20, which was declared in October 2021, was the highest among the DAE Units and 2nd best among CPSEs all over India.

During the period April to Dec. 2021, production of minerals increased by 5.11% as compared to corresponding period of last year. Further, production of Chemicals increased by 16.09% as compared to corresponding period of last year. Production of Nuclear Grade Ammonium di-Uranate (NGADU) and Mixed Rare Earths Chloride (MRECL) stood at 17.954 tons and 3825 tons respectively.

A Memorandum of Understanding (MoU) was signed between BARC, IREL and M/s. Ashwini Rare Earths Pvt Limited for scaling up the technology developed by BARC for production of NdPr metal from indigenous NdPr Oxide produced by IREL under incubation.

In addition, another MoU was entered with Ministry of Energy & Minerals in the Sultanate of Oman in the field of mining, particularly for rare minerals.

IREL has established facilities at its RED Unit in Aluva, Kerala for production of 6N Neodymium oxide used in hi-tech LASER Glass technology. This facility can be extended to produce other Rare Earth Elements as and when required.

At BARC, a process has been developed for large-scale conversion of impure Sodium Diuranate (SDU) of Tummalapalle uranium mines to High Temperature Uranium Peroxide (HTUP).

A hydrometallurgical process has been developed for extraction of rare earths, mainly Gittensite and allanite from micro-granites of Bhatikera (Siwana Ring Complex, Rajasthan).

Through a combination of thermal and hydrometallurgical routes, high purity  $\text{Li}_2\text{CO}_3$  (assaying 15% Li) was obtained from the Lithium-bearing spodumene concentrate (assaying 2.5% Li) recovered as a by-product from Marlagalla pegmatites of Karnataka.

Studies on extraction of Magnesium occurring in ankeritic carbonatites of Amba Dongar (Gujarat) resulted in  $\text{Mg}(\text{OH})_2$  product of considerable yield and purity.

Separation of Zirconium and Hafnium from Zr frit was demonstrated using alkyl phosphine oxide based solvent extraction process.

For demonstrating direct denitration of uranyl nitrate produced in the back-end activities of nuclear fuel cycle, a new plant based on Fluidized bed thermal denitration technology has been commissioned during the year.

Strontium-selective crown ether (DTBDCH18C6) was synthesized using DTBDB18C6 precursor.

## 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 Structural (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, Steam Generator tubes and titanium half alloy products for critical and strategic applications in Nuclear Power Plants, Reprocessing Plants, Defence and Space establishments.

Some of the significant achievements of NFC during the year includes Manufacture of Modified Start-Up Counter Assembly first time at NFC and supplied to KAPS-1 & 2 site of 220 MWe PHWR; Manufacture of Inner Guide Tube Assembly (IGTA) first time at NFC on urgent basis and supplied to KAPS-3 site of 700 MWe PHWR; Development of low diameter (9m dia) Zr-2.5Nb-0.5Cu (ZNC) extrusion for wire product development for reduced process cycle; Indigenous development of Ni-Cr-Fe Alloy (UNS NO- 6690/6600) seamless pipes of different grades & sizes required for making Joule Melter / Vitrification process pot for projects of NRB/BARC at Tarapur, Maharashtra etc.

## BACK END FUEL CYCLE

### Fuel Reprocessing and Waste Management

A Special Nuclear Material (SNM) was recovered from the spent fuel of Research Reactor Dhruva through PUREX based reprocessing route implemented at the Trombay reprocessing facility.

Using a Supported Liquid Membrane (SLM) Generator, around 34 batches of 150 mCi of carrier-free radiopharmaceutical grade  $^{90}\text{Y}$  were produced from  $^{90}\text{Sr}$  solution. These batches were supplied to RMC for radiopharmaceutical applications.

A feasible process has been identified and deployed for separation of  $240\text{ }\mu\text{Ci}$  of  $^{229}\text{Th}$  from aged  $^{233}\text{U}_3\text{O}_8$  for targeted alpha therapy of cancer.

About 50,000 Ci of Cesium-137 was separated from Uranium-lean HLLW by using indigenously developed solvents, including Calyx crown.

Nuclear Recycle Group has developed Ruthenium Brachytherapy (RuBy) Plaque for affordable treatment of eye cancers. In addition to round and notched configurations of the plaque, two new configurations are being developed for pediatric applications.

Resistance brazing methodology for brazing of Ru-106 plaques of desired quality was successfully developed and established by using indigenously developed brazing machine. 11 numbers of fully-brazed Ruthenium plaques were produced in coordination with PSDD, BARC and dispatched to hospitals through BRIT.



**Resistance Brazing machine for Ruthenium Plaques**

Design and fabrication of process equipment for Decontamination Facility for recycling of contaminated water and effluent has been completed.

During the year, a total of 430 m<sup>3</sup> of radioactive solid waste had been disposed in Near Surface Disposal Facility (NSDF) in Trombay after volume reduction.

About 500,000 liters of water of low-level liquid waste origin was decontaminated and processed by employing membrane based Reverse Osmosis technique and Ion Exchange process to obtain recyclable water from the pilot-scale hybrid system installed at the Effluent Treatment Plant.

A Wet off-gas system, which is capable of reducing the temperature of exhaust gases to below 200°C from a high of 800°C, and for minimising the

toxicity of these gases to permissible levels, is under planning stage.

An engineering scale prototype of Cold Crucible Induction Melter (CCIM) for vitrification of HLW was taken up in BARC to overcome the limitations of the present vitrification melters. Around 2100 liters of simulated waste was successfully vitrified to produce approximately 170kg of glass in a five-day operation.



**Cold Crucible Induction Melter for vitrification of HLW**

## R&D OF POWER SECTOR

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

BARC has developed a new 'ZIPTAS' (Zirconium-2.5% Pressure Tube Assessment) code for assessing the service fitness of pressure tubes of Indian PHWRs.

BARC has also developed a 3D Profiler system for measuring size defects in the inner surface of pressure tubes of 540MWe Indian PHWRs, a Pressure Tube Rolled Joint Detachment (PTRJD) system for 220MWe PHWRs, and also a prototype Channel Health

Assessment System for en-masse inspection of coolant channels of 700 MWe PHWRs.

Performance of fuel bundles discharged from reactors has been assessed periodically by Post Irradiation Examination (PIE) and causes of failure, if any, were analyzed. Similarly, PIE of pressure tubes from TAPS-4 was carried out to assess the in-reactor performance of Zr-2.5% Nb pressure tubes. The results indicate that the degradation in material properties of pressure tube is well within the acceptable limit and the tubes are expected to work satisfactorily for their designed life. One calandria tube from KAPS-1 PHWR was removed from the core and subjected to post irradiation examination for the first time. The PIE results indicate good performance of calandria tube.

Failure analysis of delayed neutron monitoring tube from RAPS-2 PHWR was carried out as part of periodic surveillance. Investigations showed that the reported failure was due to transgranular stress corrosion cracking on the outer diameter of the tube.

High temperature oxidation kinetics of Zircaloy-4 and its response to thermal shock has been extended further from 1250°C to 1500°C with modifications in the test facility. The data will be utilized as input parameters for modelling and simulating the ballooning and burst behaviour of PHWR fuel cladding under Loss of Coolant Accident (LOCA) and RIA conditions.

Eddy current based non-destructive testing technique was established to detect cracks in two Control Protection Safety Absorber Rod (CPSAR) housings from KKNPP-1 during in-service inspection.

Gamma spectrometry and gamma scanning was done for identifying radionuclides in the irradiated fuel pins using a high purity germanium (HPGe) detector. The burn-up contribution observed for these pins was on expected lines.

## HEALTH SAFETY & ENVIRONMENT

A Bayesian Network model was implemented to understand the probability of human error in an

operating plant as well as to aid risk analysis studies related to OHS Management.

BARC provided services related to Radiological Safety, Surveillance and Occupational Radiation Protection for back-end fuel cycle facilities such as Reprocessing plants, Waste management facilities, MOX fuel fabrication plant, PRP, AUGF and RMP located at Tarapur, Kalpakkam and Mysuru.

The average individual dose for back-end fuel cycle facilities for the year 2020 for PREFRE-2, KARP & KARP-II was 0.73 and 0.55 mSv, respectively and collective dose was 607.7 and 571.4 mSv, respectively.

The results of the environmental surveillance carried out this year clearly indicate that the dose to the member of public at fence post of the facility is only a small fraction of regulatory limit of 1000 micro Sievert per year.

About 40 units of Environmental Radiation Monitor with Satellite Communication (ERM-SAT) have been installed at different locations throughout the country.

During the year, 8280 occupational workers were monitored for external and internal radiation exposure in the front-end of nuclear fuel cycle operations. In-plant radiological survey and radiation dose evaluations were carried out for Uranium Corporation of India Ltd (Jharkhand & Andhra Pradesh), Indian Rare Earths Ltd. (Kerala, Tamil Nadu, Odisha) and Nuclear Fuel Complex (Hyderabad) to ensure compliance with regulatory norms. The occupational radiation doses to workers in underground uranium mines and Thorium handling facilities were well within the regulatory limit of 20 mSv/y.

A reliable method based on Solid-Phase Extraction Chromatography (SPEC) has been developed and used for the separation and assay of <sup>90</sup>Sr, <sup>99</sup>Tc and <sup>239</sup>Pu from environmental sediment samples, which gives reliable and reproducible results within 24 hours.

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. NPCIL continue to maintain low radiation exposure in the public domain due to operation of nuclear power stations. Average dose received by a hypothetical person at Exclusion Zone boundary at NPP sites continue to be negligible, and for the year 2020, the value was 18  $\mu\text{Sv}$  (among all NPCIL sites) which is much lower than the regulatory limit of 1000  $\mu\text{Sv}/\text{year}$  and continues to be negligible in comparison of annual average dose to population due to natural background radiation which is about 2400  $\mu\text{Sv}/\text{year}$ .

## 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. In the 36 years of operation so far, 29 irradiation campaigns have been successfully completed. It is planned to raise reactor to its rated power of 40 MWt for the first time.

#### Prototype Fast Breeder Reactor

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. The plant is located 500 m south of the existing Madras Atomic Power Station. After completion of construction, manufacture & erection of all the systems / components of PFBR, commissioning of the individual system and the integrated commissioning are under progress. The major activities that have been completed during the reporting period includes refurbishment of Small Rotatable Plug bearing by indigenously developed and manufactured spacer balls; Increasing the labyrinth clearances of the primary and secondary sodium pump; Testing of in-service inspection vehicle (DISHA) at room temperature and Commissioning works of Fuel Handling equipment.

IGCAR is continuing to provide necessary support for the 500 MWe Prototype Fast Breeder Reactor (PFBR) which is in the advanced stage of integrated commissioning; with successive milestones like filling up of sodium in main vessel, commissioning of Safety Grade Decay Heat Removal (SGDHR) purification circuit-1, installation of inspection technologies for various components and inaccessible systems etc., are progressing at expected schedules. Fissile Zone Identification System deploying cadmium zinc telluride detectors and handing over of in-house manufactured four 170 m<sup>3</sup>/hour capacity Annual Linear Induction Pumps of modified design overcoming many challenges, resulting in substantial savings in both time and cost are some of the significant milestones that have been completed. A significant number of employees from various disciplines in IGCAR have been deployed to BHAVINI to coordinate and closely interact with the

colleagues there, towards expediting the commissioning activities.

## FBR Fuels

As a part of the quality control, X-ray Gamma Autoradiography (XGAR) is being performed routinely to check the loading sequence of internal components inside a fuel pin during FBTR fuel pin fabrication with the help of a Computed radiography scanner system based at RMD.

Work on design, fabrication and assembly of two machines for axial gamma scanning of fuel bundles of Fast Reactor has been completed. Integrated testing of the machine with source was completed and the machines are now ready for scanning experiments.

## 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 with required recovery and decontamination factors. Sixty reprocessing campaigns have been successfully completed till Dec 2021. Demonstration Fast Reactor Fuel Reprocessing (DFRP) Plant: Second stage of commissioning, viz. Acid-TBP run has commenced and Inter-cell Transfer Trolley Systems have been commissioned.

## FBR Related Technologies

The Research and Development activities for the fast reactors fuel cycle included Studies on Performance of Active Magnetic Bearing; Indigenization of Sodium service Frozen seal Gate Valves and Upgradation of Distributed Digital Control System (DDCS) in Steam Generator Test Facility (SGTF).

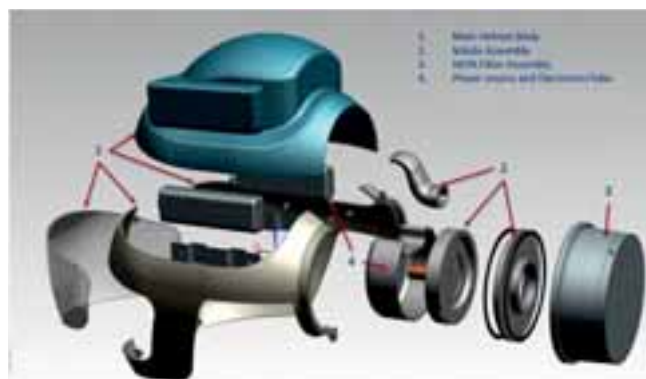
## Future FBRs

The design of FBR 1&2 has been improved by incorporating the experiences from design, R&D, safety review, construction and commissioning of PFBR.

Review of conceptual design of future FBRs was done with the objective of making essential design changes with respect to PFBR to meet the revised safety criteria. Physics design of 500 MWe core was carried out by incorporating the additional safety provision of Hydraulically Suspended Absorber Rods (HSAR).

## Health, Safety & Environment

The Health Physics units in all radioactive facilities of IGCAR provided uninterrupted radiological surveillance round the clock. About 1200 radiation workers were monitored for radiation exposures (in-vivo and in-vitro). Industrial & Fire safety inspections and physical hazard surveillance for maintaining safe work environment was carried out on regular basis in all facilities at IGCAR. To ensure high levels of operational health safety among workers handling nuclear materials in various facilities of DAE, a prototype Powered Air Purifying Respirator and an Optimised Respirator was developed by BARC using 3-D printing technology. The respirators can also be deployed in the operations of healthcare, chemicals and pharmaceuticals industries.



*Powered Air Purifying Respirator  
developed by BARC*

## NUCLEAR POWER PROGRAMME: STAGE 3

## THORIUM BASED REACTORS

Nuclear power employing closed fuel cycle is the only sustainable option for meeting a major part of the world energy demand. World resources of thorium are larger than those of uranium. Thorium, therefore is, widely viewed as the 'fuel of the future'. The Indian

Nuclear Power Programme Stage-3 aims at using thorium as fuel for power generation on a commercial scale. In the thorium fuel cycle, thorium-232 is transmuted into the fissile isotope uranium-233 which is a nuclear fuel. As a part of this programme, BARC has been developing a 300 MWe Advanced Heavy Water Reactor (AHWR). Fuelled by thorium and using light water as coolant and heavy water as moderator, this reactor will have several advanced passive safety features.

## Advanced Heavy Water Reactor

The critical power for Advanced Heavy Water Reactor (AHWR) has been experimentally demonstrated under the operating conditions to establish design safety margins. Experiments were performed to study voiding effects in thorium based (Th-1%Pu) Mixed Oxide fuel cluster. The measurements recorded as part of this were compared with the design simulations of AHWR. An improved method for predicting load bearing capacity of dissimilar metal welds joining the Concrete Frames of AHWR was proposed and the effect of corrosion on load carrying capacity of the Frames was also quantified.

Pre-experimental analyses to assess the reactivity effects of introducing a Molten Salt Fuel Tube (MSFT) were carried out in BARC Critical Facility.

## Kalpakkam MINI (KAMINI) Reactor

The U-233 based Kalpakkam Mini Reactor (KAMINI) was available till October 2021 for neutron activation analysis, neutron radiography and testing of indigenously developed neutron detectors. During inspection of fuel subassemblies in October 2021, de-bonding of fuel plates was observed in some of the fuel subassemblies. This could be the main reason for increase in reactor water activity and release of FPNGs which was observed earlier. Since presence of any solid fission products in reactor water has not been noticed so far, the de-bonded subassemblies can be considered equivalent to gas leaker fuel subassemblies. Accordingly, a proposal for continuing KAMINI reactor operation with de-bonded fuel plates has been submitted for regulatory review and approval.

## Research Reactors

The Apsara-U Research Reactor is a 2 MWth swimming pool reactor with composite core loaded with Low Enriched Uranium fuel, light water as coolant and moderator, and Beryllium Oxide Reflector. Apsara-U reactor achieved its full rated power operation of 2 MWth on October 8, 2021. The reactor was operated with high level of safety standards with an availability factor of 90% during the year. Total 44 irradiated cans comprising of various isotopes were delivered during the year.

Dhruva reactor operated at 70% availability factor during the year and produced radioisotopes for various applications, including 500 irradiated cans delivered to various users.

## 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

At RRCAT, a preliminary baseline magnetic lattice of a 6 GeV, 200 mA electron storage ring with beam emittance 150 pm.rad, has been designed to produce high brightness photon beam in the energy range up to 200 keV. This facility will open the door for science beyond Indus-2 synchrotron radiation source. The field strengths of 224 dipoles, 512 quadrupoles, 192 sextupole and 64 octupoles are optimized to achieve the desired goal in circumference of ~ 900 m.

A five cell 650 MHz beta 0.92 niobium superconducting RF cavity has been successfully processed and tested for its performance qualification at



2 K using in-house developed facilities. Various cavity processing steps include electro-polishing, ultrasonic rinsing, high temperature annealing, tuning, high pressure rinsing, cleanroom assembly and vacuum evacuation. The cavity achieved final accelerating gradient of 29 MV/m with low field quality factor of  $5 \times 10^{10}$  at 2 K temperature.

The development of superconducting RF cavities are being continued under IIFC collaboration with Fermilab, USA and as a part of R&D phase deliverables, RRCAT has developed related superconducting technologies and successfully delivered three qualified high beta ( $\beta=0.92$ ) 5-cell 650 MHz niobium SCRF bare cavities along with dressing components to Fermilab. At Fermilab, these cavities were processed, tested, dressed and qualified for rated performance. Now these cavities will be part of PIP-II cryomodule. The dressing activity was carried out by virtual presence of RRCAT's team continuously as part of collaborative efforts.



A large magnetron sputtering deposition system, for catering to the need of thin film coatings of accelerator vacuum chambers, has been indigenously developed and deployed in ultra-high vacuum (UHV) lab. Vacuum chambers upto length of 3500 mm and cross-section dimension upto 290 mm can be coated using this system. This is unique facility in the country and deposition of range of metals in elemental, alloy and compound form can be carried out using this system. Thin film deposition of Ti and Ti-Zr-V alloys has been successfully carried out using this system. Recently, thin layer deposition of Titanium and Ti-Zr-V alloys respectively to the ceramic and aluminium chamber for Indus-2, have been successfully done using this system.

A 25 kV, 6.5 A high frequency switched Capacitor Charging Power Supply (CCPS) for the linear charging of PFN capacitors of 130 kV, 100 A, 300 Hz pulsed modulator has been designed, developed and



qualified. The modulator is also integrated and tested with 6.0 MW S-Band klystron amplifier. An average RF power 20 kW has been extracted from the klystron-based microwave system. This development will pave the way for indigenous development of the crucial microwave technology.

At BARC, a new 10 MeV, 5 kW RF electron Linac has been installed at EBC Kharghar for irradiation of various industrial products. The subsystems of the accelerator such as electron gun, accelerating cavity, klystron-based RF source, electromagnets, vacuum system, beam extraction system have been fabricated and are ready for beam trials. Neutron fluxes of the order of  $10^6$  was measured. The capture cross section of Mo-98 was measured in this set-up which is useful for production of Mo-99 through the accelerator route.

A 6 MeV standing wave linac (XBL) system was designed in BARC for medical applications. X-Band low energy accelerators are preferred over S and C band linac in medical accelerator because of its compact size, light weight, higher accelerating gradient and higher shunt impedance.

A 6/4 MeV dual energy linac was developed for the first time for cargo scanning applications. The Linac was tested and integrated with all sub systems.

In-house development of two number of  $\pm 5A$ ,  $\pm 20V$  current-regulated, true-bipolar, 100ppm stability class power supplies have been done at VECC and it has been installed and commissioned for the steering magnets for the e-LINAC system of RIB Facility. In-house development of a state-of-art soft-switching based continually variable 0-20kV / 5mA max, dc-regulated power supply to operate in Constant-Voltage Constant-Current (CV/CC) mode, has been done and further installed and commissioned for the extractor system of RIB ion source. Radioactive Ion Beam (RIB) of Carbon-11 has been produced for the first time at VECC. Carbon-11 is a PET radio-isotope with the half-life of about 20 minutes and is a potential candidate for next generation hadron therapy using radioactive carbon beams. Measured Carbon-11 intensity at exit of isotope separator is about 5000 particles per second for beam energy of 10 kilo-electron volts. With this experiment the

indigenously developed 2.45 GHz gas-jet ECR ion source has been commissioned for production of RIB.

## Laser Technology Development and Applications

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

A laser micro-welding workstation for welding of high dose rate (10 Curie) Ir-192 radioactive source in capsule of size having 1 mm diameter and 200 m wall thickness in hot cell has been developed for BRIT. This workstation has been equipped with rotary stage, CCD camera based viewing system, interlocks for laser operation, gas purging and controller for laser operation. These brachytherapy assemblies will be used for cancer treatment of internal body organs.

An engineered 500 W of an all-fiber single transverse mode Yb-doped CW fiber laser was developed and integrated with galvano-scanner, powder spreader and vertical actuators for the development of powder bed fusion based Laser Additive Manufacturing (LAM) system. The developed system has been used to build structures with build accuracy within 50 microns.



**In-house developed 500 W Continuous Wave (CW) fiber laser system**

The engineered version of 'Agni-Rakshak'- a Raman scattering optical fiber based distributed fire detection system has been developed. The system is

capable of detecting onset of fire along with marking the spatial location of hot zone. The system has been successfully demonstrated in a 'Fire Drill Tower', detecting multiple fire zones, on the 1st and 2nd floor of fire drill tower. The developed system is being put up for technology transfer.

A machine vision based metrology system using non-contact shadowgraph technique has been designed and developed for automated dimension measurement of end caps of PHWR fuel elements. This system has field of view of 45 mm x 35 mm and optical resolution of better than 10 micron. It measures eleven dimensions of each end caps with accuracy of  $\pm 10$  micron and repeatability of better than 10 micron. Overall throughput of system is 12 end caps / minute. System has been qualified and will be deployed at NFC.

The CO<sub>2</sub> lasers, owing to high absorption of its wavelength in glass, are best processing tool for glass. An automated CO<sub>2</sub>-laser based system has been developed for cutting and sealing of glass tubes. The system is being developed for BRIT, Mumbai for the fabrication of tritium-filled self-illuminated glass tubes.



**Glass tube cutting and sealing system**

The other Laser Technologies developed at RRCAT for various applications includes development of Hybrid Laser-Arc Welding (HLAW) System and demonstration of welding of 10 mm thick SS304L plates.

## Electronics & Instrumentation

BARC has developed USB based hardware device called AnuNishta to ward off security threats on portable computing devices like Laptops.

A compact, low noise standalone Integrated HPGe readout system comprising of Spectroscopy amplifier (Shaper), Multichannel Analyzer (MCA),  $\pm 5$  kV High Voltage (HV) Supply and low voltage (LV) in a single unit has been developed in BARC.



**Integrated high resolution multi-channel analyzer**

BARC has developed Antenna Control Unit and Supervisory Gateway Controller of the 18-meter Indigenous Deep Space Network (IDSN) antenna facility of ISRO for deep space programs. Installation, commissioning and system acceptance test have been completed at IDSN site.

## 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. Six crop varieties three in mustard, one in groundnut and two in rice have been released and notified for commercial cultivation by the Ministry of Agriculture and Farmers Welfare, Govt. of India. For popularization and supply of quality seeds to farmers, breeder seed multiplication was taken up in Trombay groundnut, pulses and rice varieties. 303 quintals of groundnut varieties, 65 quintals of pulses, and 80 quintals of rice varieties were distributed to various National and State Seed Corporations. In biotechnological approach for crop improvement, a rapid, reproducible and sustainable micropropagation protocol was developed for ginger. This offers a disease-free good quality planting material throughout the year. In tobacco, transgenic lines harbouring PMusaCHI-1-GUS which guard the cells of leaves against negative effects arising due to drought, salinity and cold were developed.



**New mustard variety - Trombay Him  
Palam Mustard 1**

## Food Technology

Radiation processing alone or in combination with other treatments, including chemicals or heat was



**Radiation processed onion after 7 months**

used for improving the shelf life of potato, onion, wheat and pulses. Premium plums wrapped with PVA-pectin films developed in BARC improves the shelf life of plums to 15 days as against the normal 7 days for other types of packaging. Radiation processing technique was employed to derive preservative free and long shelf-life products from seasonally occurring jamun fruits. The same technique was applied to obtain candy rolls out of strawberries. Low doses of gamma radiation were applied to improve the shelf life of foodstuffs, including milk-based sweets made by Amul India, flesh balls made out of Tilapia fish variety, mashed potato, etc. The spoiling effect of 'Salmonella Typhimurium' cells on Beetle leaves was eliminated without affecting its sensory attributes. In the area of basic research, molecular dynamic simulation approach was applied in identifying A-cadinol as a potent inhibitor of ACE enzyme (-50 kJ/mol) in bean extract and the results showed that it had greater efficacy compared to captopril (-25 kJ/mol). The microbial diversity of fruits and vegetable surfaces upon radiation processing was elucidated through metagenomics studies. A demonstration facility for radiation processing of food grains using Cesium-137 source is being established in BARC.

## Nuclear Medicine and Healthcare

Production & supply of medical radioisotopes and ready-to-use radiopharmaceuticals to Nuclear Medicine (NM) centres all over India continued during the reported year 2021-22, even during the various periods of lockdown in the country due to the COVID-19 pandemic.

Alumina column based Coltech ( $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ ) Generators (Product Code:TCM-1) using high specific activity  $^{99}\text{Mo}$ -sodium molybdate were produced and supplied to various hospitals in India. Demand for

Coltech generators saw an upward trend during this period. 1073 generators were supplied in 2021-22 as compared to 492 in 2020-21. In addition, low specific activity  $^{99}\text{Mo}$  in the form of sodium molybdate solution was also supplied for Solvent Extraction Generators (Product code:TCM-2) to avail Technetium-99m at the hospital end, as per demand.

Technetium-99m cold kits (19 Products; BRIT Code: TCK) for diagnostic imaging of diseases in various organs of the body were supplied to nuclear medicine centres in India. Two new cold kits were introduced during this period for formulation of  $^{99\text{m}}\text{Tc}$  based diagnostic radiopharmaceuticals viz. HYNIC-TATE for early diagnosis of neuroendocrine tumors and HYNIC-RGD kit for imaging angiogenesis.

Two ready to use radiopharmaceutical products were launched by BRIT for the management of joint disorders viz. Yttrium-90 labeled hydroxyapatite ( $^{90}\text{Y}$ -HA) and Lutetium-177 labeled Hydroxyapatite ( $^{177}\text{Lu}$ -HA). These products serve as indigenous alternatives to the  $^{90}\text{Y}$  products which are being imported into the country for the purpose. Till date, 20 treatment doses of these therapeutic products were supplied to nuclear medicine centres in India.

Supply of Iodine-131 based products in the form of  $^{131}\text{I}$ -sodium iodide oral solution and capsules for the management of thyroid disorders was continued. Production and supply of  $^{131}\text{I}$  labelled mIBG for diagnosis and therapy of Neuro Endocrine Tumors (NET) was also continued, during the reported period.

There was significant increase in the demand for  $^{177}\text{Lu}$  based products namely  $^{177}\text{Lu}$ -DOTA-TATE for treatment of neuroendocrine tumors and  $^{177}\text{Lu}$ -PSMA-617 for treatment of prostate cancers. 650 patient doses of these products were supplied to hospitals in this period (as compared to 253 patient doses for the same period in 2020-21).

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

Around 412 batches of radiopharmaceutical samples (which includes TCK kits, ready-to-use radiopharmaceuticals injections and oral solution and capsules) and 48 batches of  $^{99}\text{Mo}$ - $^{99\text{m}}\text{Tc}$  COLTECH Generators were routinely analysed and certified 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 301 batches of TCK cold kits, ready-to-use radiopharmaceuticals injections, oral radiopharmaceuticals. This also includes radiopharmaceuticals based on  $\text{Lu-177}$ ,  $\text{Ga-68}$  and  $^{99}\text{Mo}$ - $^{99\text{m}}\text{Tc}$  COLTECH Generators.

The Medical Cyclotron Facility (MCF) of BRIT continued the synthesis and supply of Positron Emitting Tomography (PET) radiotracers, the maximum being  $[\text{F-18}]\text{-FDG}$ . Other PET radiopharmaceuticals include  $[\text{F-18}]\text{-NaF}$ , and  $[\text{F-18}]\text{-FET}$ , which are produced in smaller scales. So far  $\sim 125$  Ci of  $[\text{F-18}]\text{FDG}$  have been supplied to various hospitals in Mumbai for PET imaging. More than 15000 patients are benefitted with PET investigations in the reported year 2021-22.

RC, Kolkata, BRIT, has also introduced another important F-18 product, namely, Sodium Fluoride [ $^{18}\text{F}$ ]-NaF, in the market. This product is a valuable imaging modality of the skeleton. This radiopharmaceutical was supplied to Command Hospital, Kolkata, for clinical trials.

Thallium-201 chloride (TI-201) has been produced (first time in India) for cardiac imaging studies towards the diagnosis of heart ailments and supplied to NH Rabindranath Tagore International Institute of Cardiac Sciences, Kolkata.

Custom synthesis and supply of radiolabelled compounds, mainly, C-14 based compounds to research institutes was carried out by BRIT. These find extensive applications as tracers in the field of biology.

During the Year 2021-22, more than 12000 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.

Infrastructure development for setting up of tritium gas facility at CIRUS reactor building, BARC, Trombay, is in the advanced stage of completion.

At BARC, numerous Positron Emission Tomography (PET) based imaging agents used for diagnosis of prostate cancers and bone metastasis; anti-hypertensive –sartan drugs, which are not readily available in the country were synthesised in-house, including PSMA-11 ligand for preparation of  $^{68}\text{Ga}$ -PSMA-11; PSMA-617, ligand for preparation of  $^{77}\text{Lu}$ -PSMA-617;  $^{64}\text{Cu}$  based theranostic and Cu (MIBI)  $\text{BF}_4$  for preparation of  $^{99\text{m}}\text{Tc}$ -sestamibi.

In the area of nuclear medicine imaging, PET Scatter and PET Sensitivity phantoms were fabricated as per National Electrical Manufacturers Association (NEMA) standards. Testing of these systems will be carried out at imaging facilities of RMC, BARC and TMC, Mumbai. Phantoms are equipped to evaluate various image quality parameters such as reconstructed uniformity, spatial resolution, low contrast resolution, pixel size, slice width etc. of the SPECT/PET system. They provide accurate information on physiological processes in the human body in the form of 3D images.

A computer-based Thyroid Uptake Measurement System based on gamma radiation probe has been developed in BARC. The system was clinically-verified and commissioned at RMC Mumbai.

A prototype Deep Brain Stimulator was developed for treating neurological conditions in deep areas of brain in a precise manner. The system was developed under an MoU between BARC and SCTIMST, Thiruvananthapuram.

At VECC, a 30 MeV, 350  $\mu\text{A}$  Medical cyclotron facility along 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, has been made operational. It produces FDG (Fluoro-deoxyglucose) radiopharmaceutical which is used in Positron Emission Tomography (PET) for diagnostics of tumor/cancer. The cyclotron is also used for the production of gamma emitting radioisotopes such as Gallium-67, Gallium-68, Thallium-201, etc. and related radiopharmaceuticals, are used with a gamma camera for Single Photon Emission Computed Tomography (SPECT). So far ~53.89 Ci of [F-18] FDG, in 150 batches, have been supplied by BRIT to various hospitals in and around Kolkata for PET imaging.

## Alternative Applications of Heavy Water

In order to extend DAE's contribution towards societal benefits, HWB is synthesizing  $^{18}\text{O}$  enriched water required for PET scanning. This is a high value material and is the precursor for generation of radiopharmaceutical  $^{18}\text{F}$ -FDG in cyclotron which provides the images of PET scanning by radioactive decay with emission of positron. Nuclear grade Heavy Water is used as raw material in first indigenously developed  $^{18}\text{O}$  production plant at HWP, Manuguru. The unit remained under steady operation during the year. In the enrichment columns, the targeted  $^{18}\text{O}$  concentration of 95.5% a/a was achieved on 29.12.2021.



**Electrolyser and Recombination unit to produce  $\text{H}_2^{18}\text{O}$  from  $\text{D}_2^{18}\text{O}$  at HWP, Manuguru**

Installation and commissioning of two new ultra-pure  $\text{H}_2$  Gas generators was completed on

02.06.2021.  $^{18}\text{O}$  enriched water of 10% enrichment is useful in metabolic studies. First drop of  $\text{H}_2^{18}\text{O}$  with  $^{18}\text{O}$  IP 12.5% was produced on 23.09.2021. Purified sample of the product meeting all specifications was handed over to BARC for characterization.

## Cancer Diagnostics & Treatment Services

With its motto of providing affordable care to all irrespective of socio-economic strata, the Tata Memorial Centre (TMC) attended over 1 lakh patients at its hospitals across the country.

The organisation “ImPaCCT Foundation” (Improving Paediatric Cancer Care and Treatment Foundation), which is closely associated with TMC mobilised more than 35 crores worth of funds and extended educational, financial, nutritional and psycho-social support to scores of children and their families, effecting a significant reduction in treatment refusal and abandonment.

This year, the Brain Tumor Foundation (BTF) of India that was established with a mission to help and support patients with tumors of the brain and central nervous system, added another feather to its cap by featuring in the International Brain Tumor Alliance (IBTA) News Magazine and also got recognised as member of the Asia-Pacific Brain Tumor Alliance (APBTA).

The Department of Preventive Oncology an integral part of TMC, reached out to 2000 plus



**Screening camps conducted by  
Tata Memorial Centre**

participants across 32 institutions (schools, colleges, etc.). It conducted screening camps for high-risk populations such as slum dwellers, factory workers and employees of 'Solid Waste Management Department' of Brihanmumbai Municipal Corporation. The Department was also involved in COVID-19 vaccination duties at TMH Vaccination Centre for general public.

Women's Cancer Initiative– Tata Memorial Hospital (WCI-TMH), a non-profit NGO provided financial support of more than ₹ 7.75 lakhs to several underprivileged patients suffering from breast and gynecological cancer in the past year.

## Industrial Applications of Radioisotopes & Radiation

BRIT continued the tasks related with the safe supply of Cobalt-60 sealed sources such as Cancer treatment Cobalt-60 Teletherapy Sources & Multi-Purpose Gamma irradiator sources.

BRIT-RAPPCOF continued the tasks related with the safe supply of Cobalt-60 sealed sources, such as Cancer treatment Cobalt-60 Teletherapy Sources & Multi Purpose Gamma irradiator sources.

Processed 4244 kCi of Cobalt-60 activity and fabricated Two hundred and Sixty-Five (265) Multi-Purpose Gamma Irradiator Sources which includes One hundred and Seventy-Six (176) number of BC-188 type and Eighty-Nine (89) number of W-91 type sealed sources. Supplied a total 4792 kCi of Cobalt-60 sealed sources in Forty-Eight (48) number of consignments which include Eleven Cobalt-60 Teletherapy sources (CTS) and Two hundred and Ninety-Seven (297) Multi-Purpose Gamma Irradiator Sources consisting of Two hundred (200) number of BC-188 type and Ninety-Seven (97) number of W-91 type sealed sources. Exported total of Seventy-Two (72) BC-188 type Multi-Purpose Gamma Irradiator Sources amounting to total activity of 750 kCi to Sri Lanka & Malaysia. Source loading operation were carried out in Seventeen (17) Multi-Purpose Gamma Irradiators in the country.

Co-60 CMR sources of 32 nos. with total activity 2996.04 mCi were fabricated (34 nos. with total activity

3178.26 mCi were supplied) up to December 2021. Ir-192 Radiography sources of 533 nos. with total activity 21003.27 Ci were fabricated & supplied up to December 2021. Another 150 sources with activity 6000 Ci are expected to be fabricated & supplied up to March 2022. Co-60 radiography sources of 2 nos. of source with 93.3 Ci were supplied.

The devices including neutron sources from 5 institutes are to be collected, source is to be removed from devices for repatriation to USA after revalidation of contract next year. Out of 5, the devices lying at NTPC, Korba, is verified and some suggestions were made and devices are to be transported to BRIT, Vashi, after getting confirmation from NTPC. Remaining institutes will be visited after getting confirmation from them.

Nine nos. of Neutron sources were removed at IFRT, Vashi and transported to BARC for safe management. Remaining devices (5 nos.) will be handled during Jan to Mar 2022. Around 152 nos. of sources were verified from the devices at RSMS, BARC for safe management and same will be removed as per suitability and requirement.

BRIT launched the Indegionously developed Cobalt-60 based Industrial Radiography Device (COCAM-120) along with New Lightweight Remote Controlled Cranking Device, to the NDT industry, during the reported year 2021-22. Conceptualization and design of Indegionous Cobalt-60 based Industrial Gamma Radiography Device, COCAM-A, with improved features. BRIT has designed Mobile Food Irradiator and preparation of Security Plan. BRIT has developed user-friendly Hand-held Cranking Unit for the remote operation of indigenous Co-60 industrial irradiator, COCAM-120. BRIT has designed Cobalt Export Flask, which is Type B (U) transportation flask, and this package can carry 30 kCi of Co-60 safely across the country.

## Radiation Processing

BRIT signed two MoU's 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 2021-22.

These are namely M/s Accumax Lab Devices Pvt. Ltd. for setting up plant at Mehsana, Gujarat, and M/s Advanced Micro-devices Pvt. Ltd., for setting up plant at Ambala, Haryana. Apart from these MoU's, Gamma radiation processing plant of M/s Solas Industries, Noida, & M/s AV Gamma Tech, Mumbai, was commissioned during the reported period.

Gamma Radiation Processing Plant at ISOMED, BRIT, is being revamped and is under renovation. 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, is under construction. Radiation Processing Plant, Vashi has provided gamma radiation processing services for spices and allied products to various exporters from all over the country. Twenty new customers were registered during the current year. Main products processed were spices (whole & ground both), pet feed, ayurvedic raw materials & healthcare products. Industrial samples like induction motor, armoured cable, transmitter etc. were received from NPCIL vendors & exposed with desired doses of gamma radiation as per qualification test criterion. During the current financial year, 2021-22, 4400 MT of spices, Ayurvedic raw material, healthcare products and other products were processed. Surveillance audits for ISO 9001:2015, 22000:2018 and ISO 13485:2016 were got carried out by certifying agency and found in full compliance with the Standard's requirement.

Dosimetry services during the commissioning of two 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 five radiation processing plants. Dose rate certification was provided to three Cs-based blood irradiators and one Gamma Chamber-5000. ISO 9001:2015 Certification was obtained for Dosimetry Production Laboratory. Production and supply of 2.0 Lakhs Ceric-Cerous dosimeters was made for various gamma irradiators in the country to measure the absorbed doses. Another 5000 Nos. of these dosimeters & 15 Nos. of irradiated standard dosimeters were exported to Atomic Energy Regulatory Board, Sri Lanka.

## Radiation Technology based Equipment & Services

BRIT supplied 28 numbers of Radiography Cameras, ROLI series and 2 nos. of recently launched COCAM-120 radiography device were supplied to various NDT users within India upto December 2021. Expected supply of radiography cameras upto March 2022 is ~15 nos. Inspection and services were provided for 615 numbers of BRIT and imported radiography cameras. Expected servicing for ~204 radiography cameras (both imported and domestic) would be provided upto March 2022. Two Blood Irradiators-2000 units with Cs-137 source have been supplied to hospitals in India during April 2021 to December 2021 and supply of 02 units of BI-2000 is expected to be supplied upto March 2022. One old BI-2000 unit was decommissioned while services was provided for 6 units. Two units of Gamma Chamber (GC)-5000 with Co-60 source are expected to be supplied upto March 2022, while one unit of GC-4000A & GC-900 were decommissioned during the reported year 2021-22. Inspection & servicing was provided for one unit of GC-5000. Replenishment of source for one of the units of GC-5000 and decommissioning of another unit of GC-5000 is expected to be taken up in another 2 months time.

## Water Purification, Water Desalination & Isotope Hydrology

BARC has developed a precipitation-assisted membrane-based technique for treating radioactivity present in effluents discharged during the processing of rare earth minerals.

An adsorptive gel material has been developed for production of Uranium-free water (<30 ppb U), in community scale, from contaminated ground water.

An Advanced Effluent Water Treatment Plant (AEWTP) of 500 LPH capacity was installed by BARC for treating water contaminated with oil and dyes.

Under the DAE Project "Deployment of water purification technologies in 50 villages in India", 400 point-of-use arsenic decontamination devices of 24

litres per day capacity were deployed for providing arsenic-free safe drinking water at a remote village in Bihar.

A 2000 litres per hour capacity plant was installed for providing drinking water free from fluoride to 4 villages of a remote district in Odisha. The plant was established based on the technology developed in BARC. The Nuclear Desalination Demonstration Plant at Kalpakkam was operated by BARC to produce 145,204 m<sup>3</sup> of water.

## BASIC & APPLIED RESEARCH

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

### Mathematics & Computational Sciences

At SINP, a new class of open, translationally invariant spin chains with long-range interactions, which includes the well-known Haldane-Shastry chain as a particular degenerate case, has been introduced.

At BARC, a 2D CFD model has been developed for separation of Hydrogen from Hydrogen – Helium mixture in a Proton Exchange Membrane (PEM) based electro-chemical reactor. The current density versus cell voltage was predicted with reasonable accuracy. A single phase, laminar flow Computational Fluid Dynamics (CFD) model has been developed to study electrolyte distribution inside flow channels with different geometries. A two phase CFD model of electrolyte flow channel geometry was also developed to study the influence of feed flow rate and current density on gas hold-up distribution inside the flow channel. Design and size specifications of cryogenic distillation column for Liquid Oxygen (LOX) or Liquid Nitrogen (LN) production was carried out using commercial process simulation software and in-house thermodynamics model library. The operating

conditions, hydraulic performance and other related parameters for the distillation column were optimized and heat duties for the condenser and re-boiler were determined. Molecular dynamics simulation approach was employed to elucidate energetic heterogeneity arising from well-defined surface structure of atomistic C-60.

At HRI, the main themes of research of the mathematics remained in the areas of Finite Group theory, Algebraic Geometry, Differential Geometry, Harmonic Analysis, Lie Algebras, and Number theory.

At TIFR, work was carried out on several questions and problems in Geometric Group Theory, Probability Theory, Complex Analysis, Conformal Dynamics, and Reflection Groups, Geometry and Topology, Lie Groups, Arithmetic Groups and Algebraic Geometry.

The Institute of Mathematical Sciences (IMSc) continued to work in the areas of Computational Biology, Mathematics, Theoretical Physics and Theoretical Computer Science.

## Physics

At BARC, the MACE (Major Atmospheric Cherenkov Experiment) telescope has been successfully commissioned after performing rigorous trial runs for more than 350 hours at Hanle, Ladakh. Several active galactic nuclei and pulsars of particular interest would be explored during January-March 2022 spell.

Operando structural studies were carried out on electrode materials of Li-ion batteries with synchrotron radiation to understand cyclic instability of the batteries during the charging/discharging processes and for identifying short-lived intermittent species.

A cryogen-free low temperature set-up was deployed for testing quantum components (RF cavity, cold amplifier) at 1K-2K, as part of superconductivity experiments. The set-up is presently being used for testing aluminum and Niobium superconducting cavities for their RF performance.



***A cryogen-free low temperature set-up has been deployed by BARC for testing quantum components***

Evolutionary crystal structure searches in combination with ab-initio calculations have led to the prediction of an unusual trigonal phase of superconducting  $\text{LaH}_{10}$  seen stable at high pressures 250-425 GPa at 0 K. The new phase contains three units of  $\text{LaH}_{10}$  in its primitive cell, and is expected to become superconducting at a critical temperature of about 175 K.

A large area plastic scintillator (PS) detector set-up ISMRAN (Indian Scintillator Matrix for Reactor Anti-Neutrinos) has been installed at the Dhruva research reactor facility. The decay products of cosmic muons located inside the detector matrix as well as those passing through its full geometry have been measured. ISMRAN consists of 90 plastic scintillator bars each 1m long in the 9 x 10 matrix and has a weight of 19.4 Tons together with its shielding components.

Mechanistic understanding of DFNS formation and growth process has been achieved by time-resolved SAXS measurements during the synthesis of DFNS, which unveils the evolution of two levels of bicontinuous microemulsion (approximately 5 nm, and 50 nm) responsible for their intricate structure. SAXS beamline at Indus-2 synchrotron and Medium resolution Small Angle Neutron Scattering facility at Dhruva reactor were used for probing of powder DFNS samples.

A specialised supermirror neutron guide is being established as part of upgradation of neutron scattering facilities at Dhruva reactor.

Guide alignment procedure was experimentally explored using two units of supermirror neutron guide elements of 0.5 m and 1 m simultaneously. Successful demonstration of an indigenously developed HPGe detector from procured HPGe single crystal has been completed. The resolution of the acquired spectra is found to be 0.3% at 662keV with a line width of the  $^{137}\text{Cs}$  peak around  $\sim 2\text{keV}$  as compared to 1.5keV with commercial detectors.

Efforts were made for developing super-capacitors using hybrid electrode materials such as nanocomposites of poly (3,4-ethylenedioxythiophene)-poly (styrene sulfonate) (PEDOT:PSS) and  $\text{V}_2\text{O}_5$ . Coin cells of capacitance 1F were fabricated which offered gravimetric energy density of 7 Wh/kg and gravimetric power density of 1kW/kg.

In Astronomy and Astrophysics, the researchers at TIFR presented the abundance analyses of seven Carbon Enhanced Metal-Poor (CEMP) stars to understand the origin of carbon in them. The TIFR Balloon Facility, Hyderabad extended its support to national and international user scientists for conducting balloon flights for space research. The Pelletron LINAC facility operations at TIFR continued through the pandemic, complying with Covid safety regulations. The LINAC user cycle started in February, 2021, continued till mid-April, 2021 and 8 experiments were completed successfully. The Pelletron operated from mid-July to end-October, 2021 as per user requirements, wherein a total of 18 experiments were carried out.

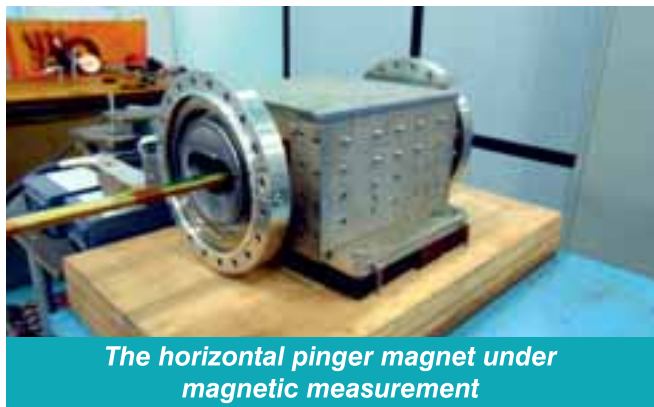
In Astrophysics at HRI, works on accretion physics around astrophysical black holes, analogue gravity phenomena, non commutative fluids, nonlinearity and chaotic behaviours of the light curves from compact objects, and on various other aspects of gravitation and field theory were carried out. The Quantum Information and Computation (QIC) group of HRI conducted fundamental and application-oriented research from a wide range of topics that included physics, mathematics and computer science. Studies were carried out in string field theory to gain understanding of non-perturbative aspects of the theory.

The Theoretical Nuclear Physics (TNP) Group at IoP remained actively involved in various areas of front-line research work. They studied the structure of neutron star along with their merger to estimate the Gravitational Wave Strain. The group continued to work on the development of a low-to-medium energy ion beam facility. The low energy 3 MV Pelletron accelerator of IoP was used by different external users to carry out their research.

At SINP, in String Theory and Holography, one of the activities involved exploring how quantum aspects of black holes can teach us qualitative universal physics at strong coupling and vice-versa. The ideas of quantum complexity, entanglement entropy, entanglement thermodynamics within the context of quantum field theory, gravity and black holes were also being explored.

## Synchrotrons and their Applications

At RRCAT, both the synchrotron radiation sources (SRS), Indus-1 and Indus-2 were operated as national facility for the synchrotron radiation (SR) user community in round-the-clock mode for 189 days during the period April to December 2021. The Indus synchrotron radiation sources, Indus-1 and Indus-2, constituting a national facility, are operating in round-the-clock mode for more than a decade. Design and development of a high stability current controlled orbit correction power supply for microtron in Indus facility has been developed. The existing power converters for LS2Q2F magnet in Indus-2, developed about 20 years ago, is replaced with the upgraded new power converters. A VME based three-layered modular test and simulation setup for Indus control system, has been developed to test software as well as hardware for various sub-systems of Indus-1 & Indus-2 control system. A horizontal pinger magnet, which is a beam diagnostic tool for measuring various beam dynamical parameters of particle accelerator, was designed, developed and characterized and has been installed in Indus-2. Upgraded BPIs have been developed, and installed in Indus-2 for the measurement of electron beam position at 56 locations. An electron beam radiation processing facility ARPF (Agricultural Radiation Processing Facility) has been set up by DAE at



**The horizontal pinger magnet under magnetic measurement**

Indore. The facility is based on indigenously developed 10 MeV, 6 kW electron linacs. RRCAT has developed 9.5 MeV electron Linac with beam power of 10 kW for food irradiation applications.

The Experimental Chamber for matrix isolation (MI) spectroscopy set-up at Photo-physics beamline at Indus-1 was replaced with a UHV Chamber having eight ports CF flanges and compatible rotary feedthroughs for deriving large sets of quality data. A 2 Tesla compact electromagnet has been commissioned at BL-09 of INDUS-II.

## Cyclotrons & their utilisations

At VECC, the K130 room temperature cyclotron has been operating round the clock and delivering light and heavy ion beams for various types of experiments. The K130 cyclotron has two ion sources (internal PIGIS and external ECRIS) to produce light and heavy ions. Presently PIGIS is in use to produce light ion beams like proton and alpha for conducting the research program. Alpha beams having energy 26 to 52.4 MeV have been provided to the users and as a special requirement alpha beam in the energy range 5.5 to 6.5 MeV have also been delivered using higher harmonic mode of operation. Proton beams in the range 7 to 14 MeV are also delivered regularly for physics experiment.

A 30 MeV, 350  $\mu$ A Medical Cyclotron facility along 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, has been operational. Since June, 2020, commercial production and delivery of Fluorodeoxyglucose (FDG) to various hospitals and

nuclear medicine centres in and around Kolkata, has been continued on regular basis.

Some of the major activities and achievements of the indigenous Compact Medical Cyclotron (MC18) project includes Development and testing of ion source and injection beam line components; Development and testing of Beam Viewer for injection beam line; Engineering design of stripper driving system and Design, fabrication of 1 kW Solid-State driver RF amplifier at 65 MHz

## Fusion and Other Plasma Technologies

A new accelerator-based 14 MeV D-T fusion neutron facility has been commissioned at IPR. During early testing, it has already yielded  $7 \times 10^{11}$  n/sec, which will go up to  $5 \times 10^{12}$  n/sec during full operation. An In-Vessel Inspection System, comprising a 6-DOF articulated arm with reach up to 4 m, has been developed to perform remote inspection inside a tokamak, compatible with ultrahigh vacuum and high temperature. Vacuum Barriers for RF technologies using Alumina brazed with metal have been developed and tested successfully.

As a contribution to Atmanirbhar Bharat, an indigenous ECR plasma source, yielding performance on par with imported sources, has been developed and integrated with the Spacecraft Plasma Interaction eXperiment (SPIX) facility. A low-cost apparatus developed by IPR for production of atmospheric-pressure plasma using microwaves has been granted an Indian Patent. A joint study with an external agency has shown that Plasma Activated Water can significantly reduce microbial load in containers used in certain food-processing applications. A helicon plasma thruster developed at IPR, operating with argon gas, has yielded 70-80 mN thrust in routine runs at 5 kW RF input, and further optimization is in progress. Under an MoU with VSSC, a specially set-up low-energy ion beam facility at IPR was used to measure erosion of ceramic anode liner material developed by VSSC for Stationary Plasma Thrusters (SPT), the feedback helping to improve the material for deployment.

IPR-developed Deep Learning software DeepCXR is now at the heart of a national programme coordinated by ICMR, and involving 20 institutions all over the country, aimed at the automated high-speed detection of TB and other lung ailments from chest X-rays. A state-of-the-art computer code suite for nuclear activation analysis, called ACTYS, which is faster than existing codes, has been validated against internationally-available benchmarks and approved by ITER for nuclear activation calculations. Externally-funded projects, involving a range of 2-D and 3-D simulations for electromagnetic macro-particle acceleration and deflagration-to-detonation transition, have been completed on IPR's HPC facility ANTYA, and codes have been developed for modelling of plasma-assisted coal and diesel combustion.

Experiments done with DC glow discharge argon plasma have shown that clusters of charged dust particles form a Hexagonal symmetric structure by self-organization.

A new 8-channel Thomson Scattering diagnostic system has been installed and calibrated on the SST-1 tokamak, and yielded first results for electron density and temperature profiles with a spatial resolution of 10 mm and time resolution of 5/33 msec. A 100 GHz heterodyne interferometer has been indigenously developed and commissioned on the Aditya-U tokamak for real-time electron density measurement. A double-null divertor configuration has been tested for the first time on Aditya-U.

## Chemistry

At BARC, standard materials for buffer and conductivity measurements were developed as per the ISO protocols for in-house applications. Analytical services encompassing more than 4000 samples of wide varieties of matrices were provided to various units of DAE and other institutes. Analytical support was provided to various R&D activities, operating plant and demonstration facilities. These included isotopic analysis and elemental analysis (ppm, trace and ultra-trace levels). Physico-chemical properties such as heat capacity, thermal conductivity, water absorption-desorption and crush strength of the sintered red-mud

bricks have been evaluated for application as a sacrificial core catcher material. A stable crystalline complex phosphate has been prepared by an optimized solid reaction method which can hold  $\text{Cs}^+$  (36 wt. %) up to its melting point. Structure and stability of IPG matrices containing Sb and Te have been evaluated for their superior glass forming ability.

Phase behavior of binary alloys in zirconium-iron (Zr-Fe) system and Zircaloy-steel system has been investigated to develop metallic matrix for immobilization of zirconium-based metallic nuclear waste originating from thermal nuclear reactors. Protein conjugated magnetic nanoparticles were developed for hyperthermia treatment of cancer cells. The developed nanoparticles show superior cellular internalization and heating efficacy under AC magnetic fields. A lanthanide doped nanocomposite material with super bright red emission under near infrared excitation has been developed for bio-imaging applications. Functionalization of the particles with folic acid leads to selective targeting of the bio-imaging agent to tumor cells.

Multi-scale simulations that have been carried out provide detailed insights of solvation dynamics which can offer solutions and opportunities in bio-speciation of actinides. A dissolved oxygen (DO) monitor with linear dynamic range of 1 ppb ( $\mu\text{g L}^{-1}$ ) to 20 ppm ( $\text{mg L}^{-1}$ ) was developed. Studies on development of modified SS electrodes showed promising results enabling its utilization as cost effective electrodes in alkaline and anion exchange membrane based commercial electrolyzers. Due to effective bactericidal and biofilm prevention activities, imidazolium ionic liquids with -dodecyl to hexadecyl alkyl group on the cation were found to be promising for antimicrobial formulations. Clinical grade oral formulation of DSePA has been developed using FDA-approved excipients lactose monohydrate and magnesium stearate. Deuteration can be a novel strategy to improve the biological safety of DSePA.

Colorimetric and Raman studies on chlorpyrifos adsorbed on silver and gold particles revealed that the nanoprobe serves as a platform for the sensing of traces

of pesticide in fruits and vegetables. A sensitive and selective fluorescence based assay has been designed for the detection of Alkaline Phosphatase (ALP), which is an important biomarker. R&D work on design and development of novel materials for isotope separation, storage and permeation of hydrogen isotopes, waste water purification through adsorptive separation, and radioactive waste immobilization in glass was done under Molecular chemical engineering based on atomistic simulations.

At TIFR, the researchers synthesized peptides - mini-versions of a protein (azurin) from soil-dwelling bacteria that are important for nitrogen fixation. It was found that these small peptides exhibit novel metal-binding properties. These peptides provide a platform for studying metal-induced structural and spectroscopic properties using transition-metal ions.

## Biology

At BARC, a Protein Sequence Analyzer software has been developed to calculate physico-chemical properties of proteins at the computation facility of BL21 in Indus-2. The co-evolving sites of SARS-CoV-2 protein were identified using this software. The enzyme RNase H1 was shown to exist in membrane-less organelles in human cells. A new eukaryotic-type DNA damage response/cell cycle regulation was discovered in the radioresistant bacterium *Deinococcus radiodurans*. Studies showed that the damage response of DNA repair genes and survivability of the cell was regulated by guanine quadruplex DNA (G4 DNA) - a non-canonical structure of DNA. Genes that enhance bio-remediation potential of cyanobacterial exopolysaccharides were identified. The plant bromodomain homologs from rice and arabidopsis were analyzed in silico. Novel agents were synthesized for detection and mitigation of intracellular iron in human bodies.

SINP remained focused on rational design of 'artificial enzymes' for applications in energy, healthcare and environmental sectors. Works on the two most efficient artificial enzymes, namely Ir(Me)-PIX-Cyp119-Max and de novo retro-aldoleses to understand the underlying reasons for their remarkable efficiency were continued.

At TIFR, a study uncovered hitherto unknown mechanisms that regulate robustness of information flow through insulin signaling. In addition to highlighting the importance of normal insulin cycles (during feeding and fasting), it identified components that could perturb the signaling cascade under situations of hyper-insulinemia as in diabetes and clinical insulin administration. The study also raised the possibility of re-evaluation of insulin dosing (amounts and frequency) to ascertain its impact on molecular components that protect tissues from damage, beyond maintenance of blood glucose levels.

## Materials Science

Infra-red Free Electron Laser (IR-FEL) has been developed earlier at RRCAT, Indore. This year the continuous wave average power output achieved from the IR-FEL was  $\sim 19$  mW, which corresponds to peak power of  $\sim 5$  MW. Wavelength tuning over a range 12.5 to 40  $\mu$ m has been achieved. The IR-FEL radiation has been transported up to the user area over a distance of around 45 m and an experimental facility for the utilization has been established using a custom-built experimental set-up for doing frequency domain spectroscopy in transmission and reflection modes.



**Set-up for doing frequency domain spectroscopy at low temperatures (5- 300 K) and high magnetic fields (up to 7 T) using FEL and laboratory based sources**

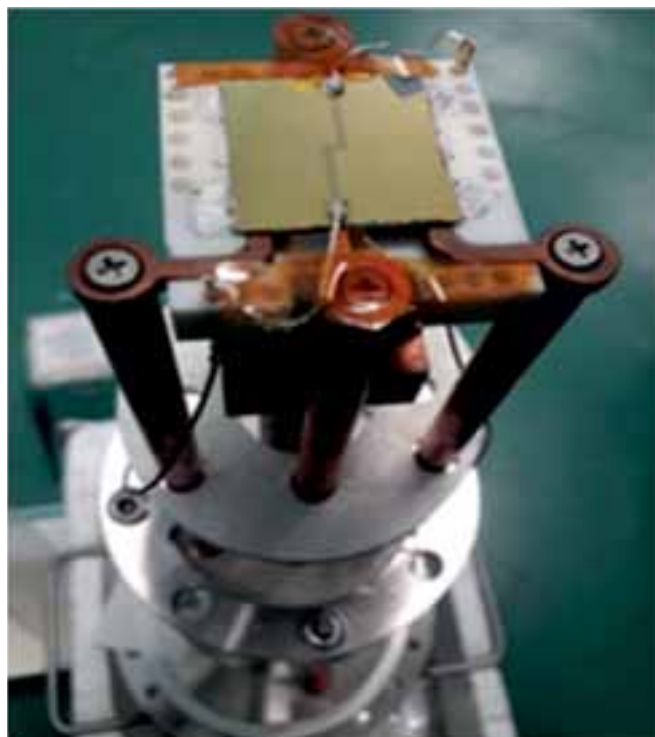
Prototype scintillator CsI (TI) coupled GaAs PIN junction-based radiation detectors have been developed for  $\gamma$ -ray detection at room temperature. The

developed detector along with custom made preamplifier can also be used in  $\gamma$ -ray and x-ray spectroscopy and also for the detection of high-energy charged particles.

Au nanoparticles and Si nanowire-based Surface Enhanced Raman Scattering (SERS) substrates were prepared using a cost-effective chemical synthesis for trace detection of Methylene Blue (MB) dye, Thiram and Thiabendazole (ThB) pesticides up to 100 nano molar (100 ppb).

Cerium doped YAG ceramic disc of diameter 20 to 30 mm and thickness 0.5 to 1.5 mm were fabricated by nano-powder technology and vacuum sintering technique and one of these ceramic discs (diameter: 30 mm; thickness: 0.5 mm) was used as a scintillator screen to characterize the hydrogen negative ion beam at Ion Source Development & Diagnostics Section, RRCAT and also to detect electron beam.

An atom-chip with around  $4 \times 10^6$   $^{87}\text{Rb}$  atoms trapped at a height of  $\sim 550$   $\mu\text{m}$  from the surface in an Ioffe-Pritchard trap has been demonstrated. The estimated life-time of atoms in micro-trap is found to be  $\sim 60$  ms.



*In-house developed atom-chip  
fixed on chip mount*

At BARC, a novel Nickel based alloy with Mo, Cr and Ti as the principal alloying elements has been developed in-house as a candidate structural material for the Indian Molten Salt Breeder Reactor (IMSBR). A unique glove box coupled Molten Salt Corrosion Test Facility (MSCTF) was developed and commissioned with FLiNaK salt. Results of the studies obtained from this facility indicated that the presence of Cr is not desirable from the fluoride ion point of view. Detailed characterization of oxide layer of Ni-based super alloy, Hastelloy, was done to show the formation of multi-layer oxide film on it. Phase separation tendencies in ferritic/martensitic steels and ODS alloys have been determined up to atomic level resolution for their applications in nuclear reactors. SiC fibre matrix composite was made using the input materials developed in-house. Ab-initio simulations were carried out to assess the potential of Fe-Zr alloy based intermetallic to incorporate s-, p- and d-block fission metals. Hydroxyapatite/bioglass composites were prepared and characterized for their bio-mechanical properties towards potential applications in human bone deformities. Graphene oxide-cement composite concrete with a better compressive strength over pristine M30 concrete was developed.  $\text{Cr}_2\text{AlC}$  MAX-phase is one of the potential candidate materials for oxidation resistant coating on Zr-based Accident Tolerant Fuel (ATF) clad tubes because of its greater stability and oxidation resistance at  $1550^\circ\text{C}$  and  $1400^\circ\text{C}$ , respectively. Optimum hot working condition for Titan-24 alloy has been determined by constructing a detailed processing route map. Split Hopkinson Pressure Bar is used to carry out mechanical testing at high strain rates  $\sim 1000 \text{ s}^{-1}$  at a dedicated facility. Fracture and Fatigue crack growth behavior of the UFG steel was determined for grain refinement in metastable austenitic steels.

In order to bench-mark the newly developed indigenous materials, a program was carried out to compare the irradiation response of these materials with respect to the imported material of equivalent grade using the proton beam from the Variable Energy Cyclotron. The microstructural evolution and corresponding changes in mechanical properties of proton irradiated Nb-1Zr-0.1C alloy have been studied as a function of irradiation dose. Different XRD line profile analyses (XRD/LPA) have been carried out using

synchrotron XRD data to evaluate the microstructural parameters.

## Cancer Research

At BARC, characterisation studies were done on Topoisomerase-1 enzyme to understand the role of kinases during phosphorylation towards applications in targeted cancer therapy. Studies on DNA repair in homologous proficient breast cancer were done with pharmacological drugs made from naturally available sources as well as those from synthesized route. The presence of neuroendocrine tumors in humans was ascertained by selectively analyzing 30 genes in their blood samples.

At SINP, the research is on-going which aims at the understanding of the cell biological phenomena that govern extensive cellular dysfunction and death in late-on set neurodegenerative diseases. Investigations are carried out to understand the rationale behind the involvement of several membrane proteins like Receptor Tyrosine Kinases (RTKs), Water Channels etc. in neurodegenerative signalling, which are otherwise highly implicated in cancer.

## International Research Collaborations

Based on the design, guidance and supervision from RRCAT, the first-of-series prototype of a four-quadrant power converter for HB.C2 magnet for FAIR, Germany, which is rated for  $\pm 400$  A,  $\pm 90$  V maximum, was developed at ECIL, Hyderabad, and has qualified the factory acceptance test. Series production of 45 such power converters is in the advanced stage.

The Experimental High Energy Physics & Applications (EHEP&A) group of VECC has been working in the field of instrumentation and performing experiments in the field of high energy heavy ion collisions for creation and characterization of the Quark Gluon Plasma (QGP), a de-confined phase of the strongly interacting matter. VECC is involved in the areas of creation of such media at high temperature at LHC-CERN and at high density at the upcoming FAIR facility at Darmstadt, Germany.

The CMS group at IoP contributed to the measurement of CP structure of the Yukawa coupling between the Higgs boson and tau leptons in proton-proton collisions at centre-of-mass energy of 13 TeV using the data recorded by the CMS experiment at LHC.

SINP is responsible for the fabrication, maintenance and upgradation of the 2nd Muon Tracking station of ALICE. During the RUN-III of Large-Hadron Collider (LHC), the luminosity of the beams will increase substantially. The expected trigger rate in Pb-Pb collision will be 50 kHz. In order to handle this huge rate, both the High Voltage and the Readout chain of the Muon chambers have been upgraded on a surface laboratory at CERN. The SINP-CMS group has made significant contributions in Higgs and BSM physics analyses using the 135 fb<sup>-1</sup> of proton-proton collision data collected by the CMS experiment during Run-II of LHC.

Adv-LIGO is presently operational with two second generation ground-based detectors at Hanford, WA and Livingston, LA in the USA. The third Adv-LIGO detector of similar capability has been planned (with in-principal approval from the Govt. of India) to be built at Aundha in Maharashtra, India. Several members of the LIGO-India community with different expertise and specializations studied the scientific rationale of LIGO-India as the third detector. In this context, a fully (Bayesian) numerical simulations of GW signals of inspiralling binary neutron star systems were performed. It was demonstrated that the addition of the LIGO-India detector at Aundha, Maharashtra will significantly enhance the ability to constrain the neutron star EOS.

## ITER-Project

India has been ensuring timely supply of all components/sub-systems required for first plasma in International Thermonuclear Experimental Reactor (ITER), including the cryostat, cooling water system, in-wall shields and Cryolines and cryodistribution. The top lid segments, which were dispatched last year, marked the end of cryostat manufacturing in India. The successful delivery of approximately 4 km of Cryolines, first-of-a-kind product in Cryogenics at par with the best in the world, are also a good illustration of Atmanirbhar

Bharat. Various components of the cooling water system, capable of dissipating 510 MW of heat on average and 1.5 GW at peak load, generated during ITER machine operations, have also been supplied to the machine site.

## 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 extramural research, DAE-UGC consortium for scientific research and others.

Indus-1 and Indus-2 are national facilities with 17 beamlines in Indus-2 and 7 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. However, due to issues related to the Covid-19 related lockdown, there has been a significant reduction in the number of user experiments.

## 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 16 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 18th position in the Universities category, in the 2021 NIRF exercise. During the period January to December 2021, HBNI awarded 79 MD degrees, 24 DM and 25 MCh degrees, contributing significantly to the number of specialists in medical oncology in the country. Till December 2021, HBNI has

awarded 1972 PhD degrees in a variety of disciplines. HBNI has launched “HBNI Research scholar Forum” on January 14, 2021 in order to advance/promote academic links between the research scholars of HBNI and to provide them a platform to grow their skills in communication, management and organizational domains. As part of a MoU entered into with INSTN, France, a joint course was organized on Corrosion Degradation in Light Water Reactors from December 6 to December 10, 2021 at HBNI, Mumbai. HBNI also organized a course on Nuclear Law and policies for professionals of AERB and for professionals of various units of DAE such as BARC, IGCAR, HWB NFC, BRIT and TISS. In addition, HBNI also organized several value-added courses on online platform such as Nuclear Science and Technology; Design of multiphase Reactors/Contactors; Advanced Materials Chemistry and Emerging Trends in Biophysics.

### Training

Human Resources Development Division (HRDD) of BARC provides highly skilled human resources to DAE through two flagship programs, OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). A total of 91 graduating TSOs of 64th batch of OCES/DGFS-2020 (57 engineering + 14 physics + 7 chemistry + 7 biosciences + 6 RSE), after successful completion of training, were placed in various units of DAE. There were 8 Trainee Defence Officers, as compared to 6 last year, who passed out with this batch and were assigned to different Divisions/Units for undertaking project for M.tech.

Human Resources Development activities at RRCAT revolve around imparting training to Ph.D. Scholars and M.Tech. Students from various Indian institutes. At present 14 Ph.D. Scholars are registered. The stipendiary programme for CAT-I and CAT-II is conducted for the Scientific Assistants and Technicians. The 13 TSO's were graduated in the OCES programme on October 30, 2021.

BARC Training School AMD Campus, Hyderabad continued its activity wherein 16 (Geology) Trainee Scientific Officers (TSO) of the 11th batch

(OCES-2020) completed induction training on 31st October 2021.

At IGCAR, 30 young trained scientists and engineers (OCES-2020, 15th Batch) have successfully completed their orientation programme at BARC Training School at IGCAR and have been placed in various units of DAE.

NPCIL has strong and dedicated workforce of 10823 employees as on December 31, 2021 consisting of Engineers, Technicians and Supervisors etc.

## SPONSORED RESEARCH

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

Board of Research in Nuclear Sciences (BRNS) is an extra mural funding agency of DAE which has been funding universities and research centres of the country for pursuing various research projects and for organising several scientific events of relevance to DAE. 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.

During the financial year 2021-22, 58 new regular research projects were sanctioned and a grant of ₹ 8.9 Crore was released to initiate these new projects. A sum of ₹ 26.36 Crore has been disbursed for all ongoing and new projects, symposium, Olympiad funding. All the projects entering in the final year or requiring extensions were reviewed and graded by committees of BRNS. To accomplish these tasks, 37 Technical Programme Discussion Meetings (TPDMs) of the Committees on DAE Programme (CDPs) were organized. Apart from reviewing, evaluating and recommending new projects, CDPs were also engaged in monitoring activities of ongoing projects and suggesting mid-course corrections.



**Development of technology for large sized Nd-doped phosphate LASER glass blocks and discs**

To deal with COVID-19 issues, 63 new research proposals were received at BRNS and after rigorous review, 9 projects were approved for funding. Towards new Coordinated research Project (CRP) scheme, BRNS had received 57 nos. of projects/sub-projects proposals submitted by PIs from various non-DAE academic institutes across India. Around 136 publications originating from the basic science projects were analysed in terms of “impact factor”. Most of the publications were in the peer-reviewed journals having 2 to 4 impact factors. Some of these were also published in very high impact journals (>5) which is considered to be a reasonably good outcome. Six patents were filed from the works originating from the BRNS research projects. Four ongoing MoUs were reviewed by respective committees of BRNS. 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.

### 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 schemes/activities of NBHM that were continued during the year includes Financial Support to Mathematical Institutions; Travel Grant, Conference Support and Research Project Grant; Conduct Mathematical Olympiad/Madhava Mathematics Competition (MMC); Mathematical Training and Talent Search Programme (MTTS); Provide Undergraduate/Postgraduate/PhD Scholarships, PD(F) Fellowship; Support to Indian Women in Mathematics (IWM) and Financial Support to Libraries & Book Distribution Schemes. Apart from this, it also supported various centres of Mathematics such as Chennai Mathematical Institute (CMI), Chennai; Kerala School of Mathematics (KSoM), Kozhikode; National Centre for Mathematics (NCM), IIT-Bombay Campus, Mumbai; Bhaskaracharya Pratishthan (BP), Pune; Institute of Mathematics & Applications (IM&A), Bhubaneswar and National Centre for Mathematics (NCM), IIT-Bombay Campus, Mumbai.

## 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 frequent interaction taken place 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 and they are Tata Institute of Fundamental Research (TIFR), Mumbai; Tata Memorial Centre (TMC), Mumbai; National Institute of Science, Education & Research (NISER), Bhubaneswar; Institute of Physics (IoP), Bhubaneswar; Saha Institute of Nuclear Physics (SINP), Kolkata; Harish-Chandra Research Institute (HRI), Allahabad; Institute of Mathematical Sciences (IMSc), Chennai; Institute of Plasma Research (IPR), Gandhinagar; Atomic Energy Education Society (AEES), Mumbai; Homi Bhabha

National Institute (HBNI), Mumbai and University of Mumbai – Department of Atomic Energy–Centre for Excellence in Basic Sciences (UM-DAE-CBS), Mumbai.

Out of total Budget Provision of ₹ 3115 Crore in the year 2021-22 an amount of ₹ 2645.58 Crore has been released as on January 2022 for Aided Institutes towards salaries, creation of assets etc.

### Olympiad Programme

India secured 1 Silver Medal and 1 Honourable Mention at the 10th European Girls' Mathematical Olympiad (EGMO) 2021, organized by Georgia, held online during April 9-15, 2021. India secured 1 Gold, 1 Silver and 3 Bronze Medals at the 62nd International Mathematical Olympiad (IMO) 2021 hosted by Saint Petersburg, Russia, held online during 14-24 July, 2021. India secured 3 Silver and 1 Bronze medals at the 32nd International Biology Olympiad (IBO), (named as IBO Challenge II) held online and hosted by Portugal from July 18 to 23, 2021. The Indian team of five students secured four Gold and one Silver medal in the 14th International Olympiad on Astronomy & Astrophysics (IOAA), organized by Colombia, which was held online from 14 to 21 November 2021. The Indian team also bagged the second prize in the Team Competition. In the country-wise medals tally, India was placed in the top position, jointly with Thailand and Russia.

## INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The various IT related activities that have taken place at RRCAT includes the design, development and deployment of scientific computing resources; Design, development and deployment of network, electronic security and Collaboration tools / systems and Design, development and deployment of information management tools/systems.

A new Cloud Computing system known as MEGH-3 has been developed at BARC. Internet based document sharing system, AnuDocs, was developed as an alternative to third party cloud-based storage systems for ensuring better information security in BARC.

The IPR-developed Deep Learning software DeepCXR is now at the heart of a national programme coordinated by ICMR, and involving 20 institutions all over the country, aimed at the automated high-speed detection of pulmonary TB and other lung ailments from chest X-rays. To facilitate the conversion of X-ray films to digital images, IPR has also developed a low-cost X-ray digitizer and pre-processing software.

A private cloud solution is deployed for IGCAR to provide a reliable, flexible and secure hosting platform for providing service delivery models of Infrastructure as Service (IaaS) and Platform as Service (PaaS) using Openstack over Intranet. IGCAR had laid ITU G.657A1 standard 24-core single mode Optical Fiber Cable for the Fault-tolerant campus network for connecting all the buildings in the campus for about 26 km. USB Access control and monitoring software is developed in-house to secure the user desktops (personal computers & thin-clients) from unauthorized access of USB devices and monitor/control their usage. A collaborative project, sponsored by Office of the Principal Scientific Advisor to Govt. of India, has been initiated by IGCAR with DGRE (Defense Geoinformatics Research Establishment), DRDO, Chandigarh with the prime objective to design indigenous Wireless Sensor Network (WSN) nodes and to deploy WSN for measurement and dissemination of snow and meteorological parameters from a mountain slope in the avalanche prone areas.

At VECC, an enhanced version of Handheld RFID (Radio Frequency Identifier) reader, designed and developed in-house has been deployed at VECC main gate for attendance recording. Border Gateway Protocol (BGP) (one of the key protocols for achieving Internet connection redundancy) has been implemented at VECC internet gateways. VECC is connected to two different Internet service provider's ISPs (NKN and BSNL) over BGP routing. A Network Intrusion Detection System (NIDS) has been implemented using open-source software SNORT. The system has been deployed outside VECC perimeter to inspect entire incoming and outgoing network traffic of VECC and generate alert against any malicious event based on the defined rule sets. Network traffic monitoring and analysis are two key aspects of cyber

threat management in any organisation. In view of these, a monitoring and analysis system for network traffic of VECC has been implemented using open-source software tools Ntopng and ELK. With the upsurge in the number of web meetings, webinars and video conferences, particularly in the aftermath of the COVID-19 pandemic, there is a substantial increase in the demand from users for accessing the facilities for holding such meetings and conferences. To streamline the arrangement of concurrent meetings at different rooms by different users, a meeting room booking portal has been implemented based on open-source software.

## TECHNOLOGY TRANSFER

BARC is offering a one-time concession in license fee charged by it in return for transferring of technologies to interested parties. A 75% concession in license fee is being offered for most of its technologies during the period up to August 2022 under the Azadi Ka Amrit Mahotsav drive to celebrate 75th year of Indian Independence.

Thirty One new technologies were introduced into public domain during the year by BARC. These relate to agriculture & bioscience, radiation technology, medical, engineering, environment and chemical domains.

Several COVID-19 related technologies developed in BARC were released for public benefit. These include, a portable device called BARC-CRISPR-



**BARC-CRISPR-CUBE unit for COVID-19 testing**

CUBE for CRISPR-based detection of COVID-19, Sodium Hypochlorite Plant, Kit for detecting Alcohol content, UV sanitizer- Neelbhasmi and Taapdarshak.

Licenses for technologies that were renewed during the period are Inductively Coupled Plasma Mass Spectrometer, Fluoride Detection Kit for ground water (FDK) and Nitrogen oxides releasing wound dressing.

At RRCAT, technologies of unipolar (15 A, 50 V max.) and bipolar power converters ( $\pm 15$  A,  $\pm 50$  V max.), both having output current stability of  $\pm 100$  ppm, were made available to transfer to the industry through TT&CD, BARC and transferred to M/s Electronics Corporation of India Limited, Hyderabad.

A technology knowhow and license agreement was signed between IPR and M/s Persapien Innovations Pvt. Ltd. for a prototype system to generate Plasma Activated Water, which is found to have anti-microbial properties.



**Unipolar power converter on 6U printed circuit board**



**Bipolar power converter on 6U printed circuit board**

## COLLABORATIVE PROGRAMMES

BARC has launched a dedicated technology incubation program to boost entrepreneurship activities using technologies it has developed in-house. An MoU was inked for incubation of “Development of Carbon Nanotube-Boron Carbide (CNT-B<sub>4</sub>C) composite tiles by hot pressing and “Strong Motion Seismic Instrumentation system for Nuclear Power Plants” technologies. Further, it has advertised for potential partners in the incubation of “Handheld Gamma Spectrometer based on Cesium Iodide (CsI) Single Crystal” technology.

## SOCIETAL INITIATIVES

RRCAT has developed an indigenous technology for refrigerated transportation of Fruits and Vegetables of Farmers. SHIVAY (Sheetal Vahak Yantra) uses Liquid Nitrogen as a source of refrigeration. After successful road trials of more than 3000 kms, the technology has been shared with M/s Tata Motors Ltd. At present in India, diesel-powered and chloro fluoro carbon based Reefers are used, which are operationally expensive, maintenance prone and not eco-friendly. SHIVAY technology solves these issues and a system which is more suited to Indian conditions has been built. Liquid Nitrogen is a by-product of oxygen generation plants with large excess capacity in the country. SHIVAY is a standalone system with multimodal features i.e it can be mounted on a truck or a railway wagon.



**20 feet refrigerated container SHIVAY**

Twelve agreements were signed with different organisations and individuals to promote rural

entrepreneurship using BARC technologies under Advanced Knowledge & Rural Technology Implementation (AKRUTI) Tech Pack. Training programs were organized for 26 interested entrepreneurs from various parts of India. A new BARC Outreach Centre was inaugurated at Utkal University, Bhubaneswar under AKRUTI Programme.

## 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 this period, six DAE-IPR cell meetings were held, where fourteen new patent proposals were reviewed. A total of eleven patent applications have been filed in the current reporting period. This includes six in India, two each in USA & Europe and one application was filed under the Patent Cooperation Treaty (PCT). During this period, thirteen of the previously filed patents were granted to the Department. These includes nine in India, three in USA and one in Japan.

## PUBLIC SECTOR UNDERTAKINGS (FINANCIAL PERFORMANCE)

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

### NUCLEAR POWER CORPORATION OF INDIA LTD.

The provisional profit after tax (Total Comprehensive Income) up to end December 2021 in current FY 2021-22 is ₹ 4390 crore and the estimated profit for FY 2021-22 is around ₹ 5200 crore. The net

profit after tax (Total Comprehensive Income) for previous FY 2020-21 was ₹ 4374 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 2020-21 were ₹ 2,352.90 Cr and ₹ 623.20 Cr as against ₹ 2,419.60 Cr and ₹ 596.83 Cr respectively during the previous year.

### INDIAN RARE EARTHS LTD.

During the financial year 2020-21, Despite Pandemic COVID-19, the company achieved sales turnover of ₹ 974.13 as against ₹1040.63 crore during previous year. The company achieved highest ever Profit Before Tax (PBT) of ₹ 415.11 crore registering growth of 3% as compared to corresponding previous year.

During the period from April to December 2021, the company has achieved Sales Turnover of ₹ 1019.06 crore as against ₹ 689.82 crore achieved during the corresponding period of previous year, registering growth of 48%. The Company achieved Profit Before Tax (PBT) of ₹ 451.12 crore during the period April to Dec, 2021 as against ₹ 253.30 crore during the corresponding period in previous year.

IREL paid dividend amounting of ₹ 94.71 crore for the year 2020-21. The total amount of dividend paid by IREL surpassed the equity infused into the Company, multifold. IREL issued 100% equity bonus shares amounting to ₹ 86.36 Crore to the Government of India.

### ELECTRONICS CORPORATION OF INDIA LTD.

ECIL recorded revenue from operations of ₹ 1504 Crores in the Financial Year 2020-21 with a PBT of ₹ 152.37 Crore. DPE has set a target of ₹ 2700 crore for the year 2021-22. Against the set target, ECIL has achieved an income of ₹ 934.84 crores till end December 2021.

## 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 & 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 & 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 comprising of Director, BARC, Chairman, AERB & Joint Secretary (ER) to the IAEA 65<sup>th</sup> General Conference which was held at Vienna, Austria from 20-24 September, 2021. In addition to this, the Ambassador & officials from Indian Permanent Mission in Vienna also participated in the event.

On the sidelines of the 65<sup>th</sup> General Conference, Chairman, AEC had bilateral meetings with DG, IAEA & delegations from USA, USA, Westinghouse, U.K., OECD-NEA, Russia, AFCONE, EU, CEA, France, INVAP Argentina, Ghana, Kazakhstan, CNEA Argentina & Bangladesh.

An Inter-Governmental Agreement (IGA) was signed between India & Ghana regarding cooperation for peaceful uses of Nuclear Energy on 22.09.2021. Memorandum of Understanding (MoU) between Global Centre for Nuclear Energy Partnership (GCNEP), India & Ghana Atomic Energy Commission (GAEC), Ghana was signed on 02.07.2021. MoU between GCNEP, India & National Nuclear Centre (NNC), Kazakhstan was signed on 20.09.2021. An Arrangement between AERB, India & Nuclear Safety Authority (ASN), France was signed on 21.09.2021.

Despite the 2nd wave of Covid-19 pandemic, construction & facility augmentation process at GCNEP continued uninterrupted. All essential services and construction progressed in accordance with Government guidelines. During April to December 2021, GCNEP conducted online "Indo-US-UK technical exchange on Security By Design (SBD) for devices and facilities that use radioactive materials" and "Indo US Workshop on Modelling & Simulation of PPS". Follow up & review meetings for on-going activities with other countries were carried out using virtual platform. The Centre also expanded its activities for experiments on mutated seed for wheat & mustard with the help of NA&BTD, BARC.

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. Since August 2021, WANO has started a six month training programme on Leadership Effectiveness which is being conducted for four hours every month. In various virtual programmes many persons from NPCIL stations and HQ participated including senior Plant Managers and young generation from NPCIL plant sites. During this year, COG conducted a Candu Chemistry Workshop (virtual) to present and discuss experiences and issues with regard to plant chemistry. NPCIL participated in this information exchange programme of COG. 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, 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 2021, more than 200 meetings of BSC were held.

## CRISIS MANAGEMENT

The Crisis Management Group (CMG) is the standing Committee of senior officials of the Department of Atomic Energy (DAE) which 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. CMG continued to carry out its functions. 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 2021-22, up to December 2021, India participated in four numbers (projected figure for FY 2021-22 is five 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 carried out variety of emergency exercises. CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Narora, Tarapur, Kudankulam as well as Kaiga 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. As per the directives of Central

Vigilance Commission, "Vigilance Awareness Week" is observed every year. Accordingly, "Vigilance Awareness Week 2021" was observed in DAE during October 26th to November 1st, 2021 on the theme of "Independent India @ 75: Self Reliance with Integrity"; "स्वतंत्र भारत @ 75: सत्यनिष्ठा से आत्मनिर्भरता". The week commenced with administering integrity pledge by Joint Secretary (A&A) and Director (Vigilance) to the all employees of DAE Secretariat on 26.10.2021. Various competitions such as Slogan writing, Quiz competition and Role play were held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Smt. Ity Pandey, Chief Commercial Manager, IRTS delivered a talk on 01.11.2021. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 01.11.2021. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

Vigilance Directorate of NPCIL continued to promote integrity, spread awareness and to sensitize employees against malpractices and corruption to achieve organizational goals. NPCIL carried out many activities and events to achieve this during the period April - December 2021.

## 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 published a book titled "Non Power Applications of Nuclear Technologies" in 2021. The book comprises of 19 articles, which highlight R&D activities in BARC in development of nuclear technologies having widespread industrial applications.

The mobile-friendly version of BARC official website with latest Content Management System based technology features was launched for providing better site navigation and rich experience for internet users. Fresh apex project, “Digital Resources for R&D Support” was approved for implementation of new and advanced digital information resource platforms through acquisition of new servers and network devices. Access to knowledge resources of BARC Library digitally was made easy with the launch of Saraswati portal 3.0 Version in November this year. BARC Newsletter on various themes, including Nuclear Reactor Technology, Research in Physics, Atomistic Modelling and Simulations, and Nuclear Reprocessing were published online. Key R&D outcomes of BARC have been presented in the form of articles catering to both technical and general audience. During the year, 31 Internal, 23 External and 05 Restricted reports based on scientific outcomes of R&D activities were published to meet specific requirements of BARC. Three issues of in-house magazine, Pulse, of BARC Hospital were also published. BARC has carried out translation of scientific documents from French, German and Russian into English as well as interpretation routinely to cater to the specific requirements of various groups of BARC and the constituent units of DAE. The International Nuclear Information Service (INIS) of IAEA in India has been augmented with journal articles, conferences and reports totalling 4000 in nuclear energy domain published by multiple scientific agencies within the country. To ensure scholarly work of BARC scientists reflects originality, similarity check was performed and reports generated for 700 articles and 100 Ph.D theses during the year. To ensure uninterrupted running of academic program for 2020-21 batch of Trainee Scientific Officers of BARC Training School, Mumbai and to ensure compliance to guidelines in view of COVID-19 pandemic situation, lectures by BARC Training School faculty were recorded and streamed to the TSOs through a suitable online channel.

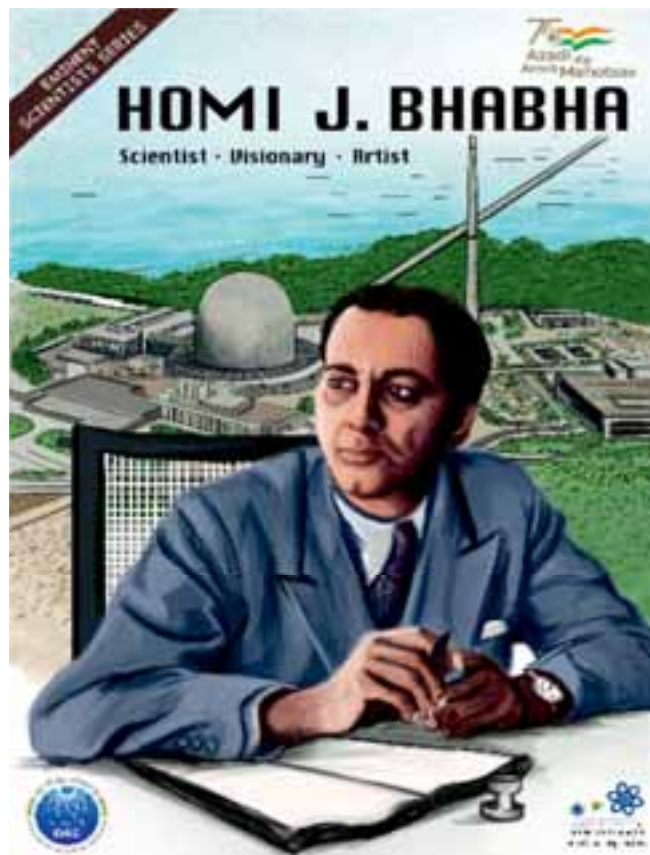
## PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of Public Awareness programmes in order to alleviate unwarranted fears, misconceptions

and apprehensions harboured against nuclear energy. To keep the public abreast of the latest developments and contributions of atomic energy towards societal welfare, DAE 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 the exhibition, “Alluring Rajasthan 2021” at Udaipur, Rajasthan organised during August 4-6, 2021. DAE put up a pavilion in “Make in Uttarakhand – 2021” held at Ramnagar, Uttarakhand during September 16-17, 2021. DAE along with a team from Global Centre for Nuclear Energy Partnership (GCNEP) participated in this two-day event. DAE participated in the 8th Rajasthan Science Congress IIS University, Rajasthan exhibition held at Jaipur, Rajasthan during October 20-22, 2021.

DAE celebrated the 112th birth anniversary of Dr. Homi J. Bhabha. On this occasion the Public Awareness Division of DAE released an illustrated picture book on the life and scientific contributions of Dr. Bhabha.





**Release of illustrated picture book on "Homi J. Bhabha" by Dr. R. Chidambaram, former Chairman, AEC and former Secretary, DAE**

DAE organized the 33rd DAE All India Online Essay Contest. Three topics were given to the students for participation. The notification was put on DAE website for giving wide publicity. Around 400 essays were received and out of which 30 students (10 students from each topic) were selected as winners and the winners were awarded with winners' certificates and cash awards of ₹ 10,000/- each. All other participants were given participation certificates.

The 24th National Science Exhibition was held at Kolkata on the occasion of 75 years of India's Independence during October 28-31, 2021. DAE participated in the exhibition along with VECC and exhibited DAE technologies.

India International Science Festival - 2021 (IISF-2021) was organised by Ministry of Science and Technology, Ministry of Earth Sciences and Vijnana Bharti at Panaji, Goa during 10-13 December 2021. DAE



**Hon'ble Minister of State Dr. Jitendra Singh during his visit at DAE pavilion at the India International Science Festival, 2021 held at Panaji, Goa**

participated in the science festival by putting up an exhibition along with BARC, BRIT, HWB etc. The event was well received by the students and the general public. Large no. of students visited the DAE pavilion.

DAE published an article titled as "Department of Atomic Energy: A Technology Powerhouse" in the anniversary issue of the Outlook magazine on January 2022. The article highlighted high end technologies at a glance for betterment of society.

DAE contributed an article titled as "Novel Pathways in Healthcare" in The Week magazine during celebration of Science Week (February 22-28, 2022).

DAE participated in the 8th Indian National Exhibition-cum-fair 2022 on the focal theme of "Science & Technology for sustainable development of India" at Kolkata Metropolitan Development Authority (KMDA) ground, Patuli, Kolkata during February 24-28, 2022.

The Public Awareness Division of DAE brought out another picture book "The Noble Curies", the second in the Eminent Scientists Series, depicting the life and contributions of the Curie family (Marie Curie, Pierre Curie, Irene Curie and Frederick Joliot Curie). The book was released at BARC on International Women's Day (8th March, 2022).

DAE participated in the exhibition "Shining Maharashtra, 2022" at Phaltan, Maharashtra. DAE had put up a mega exhibition in Phaltan held during March 25-27, 2022.

Various public outreach activities were organized by RRCAT as part of 'Azadi Ka Amrit Mahotsav' including a two-day camp for screening of oral cavity using OncoDignoscope developed at RRCAT.

The Public Awareness activities are being carried out by NPCIL to address the myths and the apprehensions in the minds of the people regarding various aspects of nuclear power. The cumulative outreach activity of NPCIL from April to December, 2021 has reached around six lakhs and forty-six thousand people. NPCIL has fabricated Halls of Nuclear Power as permanent nuclear galleries at Science Centres located in Mumbai, New Delhi and Chennai and miniature

nuclear galleries at Kavar, Mangalore, Hyderabad and Vijayawada. Also, as India is celebrating the Azadi Ka Amrit Mahotsava, NPCIL has taken up many special public awareness drives under its aegis to make the people aware of the saga of DAE in general and NPCIL in specific and the development of the nuclear power program in India. During the year 2021-22 (upto December-2021), NPCIL has reached out to the public mostly on the digital platform. In all, a total of about 235 activities were carried out in the aforementioned period which includes around 170 site visits and around 60 lectures, 2 exhibitions and few other special programs such as interviews of Chairman and Managing Director of NPCIL etc.

As part of the year-long Azadi Ka Amrit Mahotsav celebration in DAE to mark 75 years of Indian Independence, BARC published new scientific documents and books in bi-lingual form, organise farmer-scientist interactions, student seminars and lectures both online and offline, new short films to highlight significant achievements of the Centre to general public.

## 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 under developed areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme. During the FY 2021-22, the Company allocated an amount of ₹ 101.90 Crore for implementation of CSR programme. It is a matter of satisfaction that for the last five 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

Swachhta Pakhwada was introduced in all the Central Government Ministries & Departments on the directives of the Hon'ble Prime Minister as a part of the Swachh Bharat Mission. Swachhta Pakhwada was observed in DAE headquarters from 16th February – 28th February, 2022 on the occasion of the World Science Day on 28th February, 2022. The programme comprised of Swachh Section Competition, Quiz Contest, Essay Contest, Poster Contest and Slogan contest. All the events were held as per the schedule which was circulated in advance. In all these contests, the staff members of DAE participated wholeheartedly. The results of these contests were announced on 28th February, 2022. Prizes were distributed to the winners of the various contests held and employees were felicitated for their contribution to maintain cleanliness.

Indore Municipal Corporation (IMC) has chosen RRCAT colony for the “Swachhta Champion Award” for the record fourth time in the category of “Cleanest Colony of Indore” as part of the Swachh Survekshan - 2021. A "Certificate of Appreciation" and a trophy of “Swachhta Champion – 2021” was awarded to RRCAT in an award ceremony (स्वच्छता चैम्पियन सम्मान समारोह) organized by IMC on 2nd October 2021.

## EMPLOYEES' WELFARE

The Contributory Health Service Scheme (CHSS) which was introduced in the Department in the year 1962 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. National Safety Council (Maharashtra Chapter) awarded plaques (2 Nos.) to Tarapur Atomic Power Stations (TAPS) -1&2 for "Factories Working over One Million Man-Hours under Scheme-I - Lowest Accident Frequency Rate for the year 2020 and Scheme-II - Longest Accident-Free Period for the year 2020. Madras Atomic Power Stations



**CMD, NPCIL with Technology Development Board's National Award – 2020**

(MAPS)-1&2 received “PRASHANSA PATRA” from National Safety Council of India under the Manufacturing Sector in Group-C category of Power Generation for the assessment period of 2017 to 2019 for the award year of 2020. The Narora Atomic Power Stations (NAPS)-1&2 NAPS won AERB's Industrial Safety Award 2020. The Kakrapar Atomic Power Stations (KAPS)-1&2 won AERB Fire Safety Award for the year 2020 in category-I. KAPS-3&4 bagged Industrial Safety Award 2020 (Construction Units) and Fire Safety Award 2020 from AERB (Category-II). The Kaiga Generating Stations (KGS) -1&2 has been awarded the Certificate of Appreciation from National Safety Council, India for the year-2020. KGS-1&2 has bagged “Unnatha Suraksha Puraskara-2021” award from National Safety Council, Karnataka Chapter. KGS-3&4 received “Sarva Shreshtha Suraksha Puraskar” (Golden Trophy) from National Safety Council, India for the year 2020. KGS-3&4 bagged the prestigious Safety Award “Unnatha Suraksha Puraskara” from National Safety Council, Karnataka Chapter for the year 2021. NPCIL was conferred prestigious 'National Award – 2020' by Technology Development Board, Department of Science and Technology, for 'Development of Technology for Production of Low Alloy Steel Heavy Forgings for 700 MWe Nuclear Power Plant Steam Generators and Bleed Condensers (BCD), commercialized by M/s L&T Special Steel and Heavy Forgings Pvt. Ltd.'

During the year, IREL won many awards these includes best CMD Corporate Management Innovative Leadership Excellence Award during the 21st Annual Geominetech International Symposium; CEO of the year; Implementation of official language by Mumbai

PSUs TOLIC for the year 2020-21 (3rd Prize); Leading Director Award 2021 in the Leading Directors' Conclave conducted by Greentech Foundation and Carpet Swachh Bharat Mission & Covid-19 Management Excellence Award.

AERB's Industrial Safety Award-2019 was presented to HWP, Tuticorin in the category of "R&D and Other Low Risk Units" during this period. HWP, Talcher was conferred with AERB's Industrial Safety Award-2020 in the category of "R&D and Other Low Risk Units" during this period.





*Site View of Rajasthan Atomic  
Power Project -7&8*

# **CHAPTER 1**

## **NUCLEAR POWER PROGRAMME STAGE-I**



***Departmental drilling unit in field area  
of Southern Region, Bengaluru***

## 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' (Highest Safety) by CRISIL, CARE, ICRA and India Rating. NPCIL is responsible for obtaining siting consent, design, construction, commissioning, operation and upgradation of nuclear power reactors. Safety is given overriding priority in all facets of nuclear power reactors. At present, NPCIL operates 22 nuclear power reactors with an installed capacity of 6780 MW. Currently NPCIL is constructing eight Reactors (6800 MW) comprising of Kakrapar Atomic Power Project (KAPP) Unit-3&4 (2 x 700 MW, PHWRs), Rajasthan Atomic Power Project (RAPP) Unit-7&8 (2 x 700 MW, PHWRs), KKNPP-3&4 (2 x 1000 MW, LWRs) and KKNPP-5&6 (2 x 1000 MW, LWRs) which are under various stages of construction. Out of these units, KAPP Unit-3 which is first unit of indigenously designed 700 MW PHWR, was synchronized with the Grid for the first time on January 10, 2021. In addition, First Pour of Concrete (FPC) consent is granted by AERB for Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP) Unit-1&2 (2 x 700 MW PHWRs) and subsequently casting of all foundation piles has been completed in both the Nuclear Building (NB) areas and preparations towards construction of nuclear building raft are in progress. For Ten fleet mode 700 MW PHWRs, having Administrative Approval and Financial Sanction of the GoI, various preparatory activities such as land acquisition and Rehabilitation & Resettlement (R&R), Environmental clearance, procurement activities of long delivery equipment, studies for regulatory clearances, site infrastructure development, public outreach, tendering for main plant civil works etc. are in various stages of progress towards launching of these projects. In spite of Covid-19 Pandemic which impacted the supply chain, man power deployment, travel restrictions etc. affecting progress of various projects, NPCIL was able to put best efforts towards resumption of normal pace of project activities

and managed to continue safe and normal operation of its power stations.

## Operating Performance

At present, NPCIL operates 22 nuclear power reactors (including RAPS-1, 100 MW PHWR, owned by DAE and managed by NPCIL, which is under long shutdown) 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

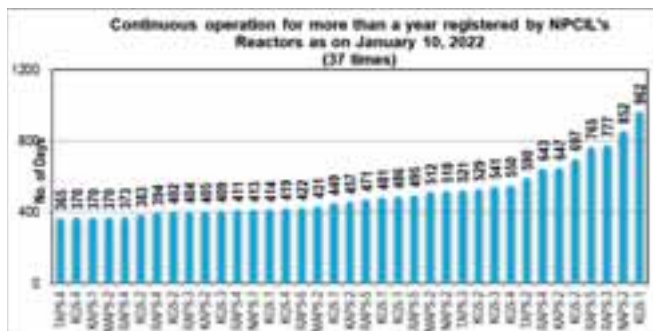
During the Calendar Year (CY) 2021, NPCIL registered total commercial power generation of 43918 Million Units (Mus). In addition, KAPP Unit-3 has generated 402 MUs of infirm power (non-commercial generation) during CY 2021. In the previous CY 2020, the total commercial power generation was 44613 MUs.

During the period April - December 2021 in the Financial Year (FY) 2021-22, NPCIL registered total commercial power generation of 34837 MUs and expected total commercial generation for the FY 2021-22 is about 46000 MUs. In addition, KAPP Unit-3 has generated 139 MUs of infirm power (non-commercial generation) during the period April - December 2021 in the FY 2021-22. In the previous FY 2020-21, the total commercial power generation was 43029 MUs. In addition, KAPP Unit-3 has generated 263 MUs of infirm power (non-commercial generation) during the period January - December 2021 in the FY 2021-22.

During the FY 2021-22, the overall Availability Factor (AF) and Plant Load Factor (PLF) till December 31, 2021 for the reactors in commercial operation were 87% and 86% respectively. These figures for last FY 2020-21 were 83% and 81% respectively

## Continuous Operation for more than a year

During the FY 2021-22, RAPS Unit-4 and Kaiga Generating Station (KGS) Unit-1 achieved continuous, safe and reliable operation for more than a year. RAPS-4 registered 643 days of continuous, safe and reliable



operation on January 10, 2022 after which the unit was manually shut down for maintenance works. KGS Unit-1 registered 449 days of continuous, safe and reliable operation on July 12, 2021 after which the unit was manually shut down for Biennial Shutdown works. RAPS Unit-6, which registered continuous, safe and reliable operation for more than a year in the last financial year, continued operation and registered 422 days of continuous, safe and reliable operation till its shutdown on April 28, 2021. So far, the continuous, safe and reliable operation for more than a year has been achieved 37 times by various reactors operated by NPCIL. Out of these, four reactors KGS Unit-1 (962 days), Narora Atomic Power Station (NAPS) Unit-2 (852 days), RAPS Unit-3 (777 days) and RAPS Unit-5 (765 days) have operated continuously for more than two years. The continuous, safe and reliable operation for 962 days registered by KGS Unit-1 is second longest continuous operation in world achieved by any reactor.

## Reactor Years of operation

Our Nuclear power reactors have registered 561 cumulative reactor years of safe operation by the end of CY 2021.

## Operating Units taken in Project mode

Madras Atomic Power Station (MAPS) Unit-1 (220 MW PHWR) and Tarapur Atomic Power Station (TAPS) Unit-1&2 (2 x 160MW BWRs) 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 safety upgrades. TAPS Unit-1 & Unit-2 (2x160MW) have been taken in project mode since April 1, 2020 and August 1, 2020 respectively, for aging management and safety upgrades. RAPS Unit-2 (200 MW PHWR), which was taken in project mode since

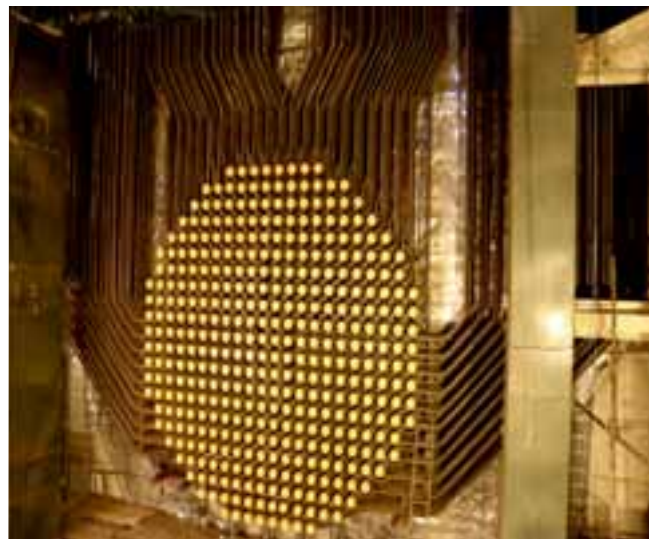
August 15, 2020 for partial boiler hairpins replacement, resumed operation on March 10, 2021.

## Projects under Construction

Currently NPCIL is constructing eight Reactors (6800 MW) comprising of KAPP Unit-3&4 (2 x 700 MW, PHWRs), RAPP Unit-7&8 (2 x 700 MW, PHWRs), KKNPP Unit-3&4 (2 x 1000 MW, LWRs) and KKNPP Unit-5&6 (2 x 1000 MW, LWRs), which are under various stages of construction.

### Kakrapar Atomic Power Project (KAPP)-3&4

These units are the first pair of indigenously designed 700 MW Pressurized Heavy Water Reactors. First unit (KAPP Unit-3) has been successfully synchronized with Grid for the first time on January 10, 2021. The unit has generated about 402 Mus of infirm power up to December 31, 2021.



Feeder installation at KAPP-4

KAPP-4 achieved significant progress despite the challenges of second wave of COVID-19 pandemic and the major milestone of "Completion of feeder installation" was achieved in October 2021. Major Primary Piping equipment viz. Primary Coolant Pumps (PCPs), Bleed Condenser (BCD), Regenerative heat exchanger, Pressurizer, Emergency Core Cooling System (ECCS) tank, PHT storage tank etc. have been erected. Various activities towards PHT hydro test are in

progress. Turbine Generator pre-box up activities have been completed. Civil works of KAPP-4 including Main Plant Civil work have been completed and preparation for Integrated Leak Rate Test (ILRT) are under way. The physical progress of the unit was about 96.9% as on December 31, 2021.

## Rajasthan Atomic Power Project (RAPP)-7&8

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

In Unit-7, erection of equipment and piping is in progress. Primary Heat Transport (PHT) system Hydro Test has been completed. Preparatory jobs pertaining to Reactor Building Proof Test and Integrated Leak Rate Test, emergency Diesel Generator no. 4 commissioning, etc. are in progress. Balance works on Induced Draft Cooling Towers (IDCTs) and Natural Draft Cooling Towers (NDCTs) are underway. The physical progress of the unit was about 94.4% as on December 31, 2021.



Site View of RAPP-7&8

In Unit-8, civil construction and erection of equipment & components are in progress. Complete coolant channels have been installed and pre-stressing of Inner Containment (IC) dome is in progress. Balance works on IDCTs and NDCTs are underway. The physical progress of the unit was about 80.3% as on December 31, 2021.

## Kudankulam Nuclear Power Project (KKNPP)-3&4

Kudankulam Nuclear Power Project Units - 3&4 located at Kudankulam in Tirunelveli district of Tamil

Nadu, where two units of 1,000 MWe (KKNPP Units-1&2) are already operating, are under construction in co-operation with Russian Organizations within the framework of the Inter-Governmental Agreement (IGA) signed between the Governments of Russian Federation (RF) & Republic of India in December 2008 and General Framework Agreement (GFA) signed in April 2014 between Joint Stock Company Atomstroyexport (ASE) and Nuclear Power Corporation of India Limited (NPCIL).

Construction of Reactor Buildings (RB), Reactor Auxiliary Buildings (RAB), Turbine Buildings (TB), Tunnels, Common service Buildings, Switchyard Buildings, Hydro- technical structures (HTS) etc. is in advanced stage in Unit-3.

In Unit-3, construction of Inner containment (IC) wall up to +43.9 meter elevation has been completed. Erection of liner of Inner Containment Dome (part -1) and concreting of first lift (out of three lifts) has been completed. Erection of Support ring of Reactor Pressure Vessel (RPV) completed in Unit-3 and preparatory work for lowering of RPV in reactor cavity using heavy duty crane is under progress. In Unit-4, construction of IC wall up to 34.7 meter elevation has been completed.

Project cargo in 6 break bulk shipments and 4 container shipments containing major equipment and materials have been delivered / dispatched from Russian Federation and Third Countries to Kudankulam NPP Site. Manufacture and delivery of Long Manufacturing Cycle Equipment is in progress. Manufacture and delivery of indigenous items / equipment, under various Packages in NPCIL scope of supply, is also in progress. Development of Working Documentation (WD) is in progress.

Work Order for "Erection of Ventilation & Air conditioning, Chilled water & Firefighting systems equipment & piping of Main plant buildings package" has been awarded and equipment erection has commenced. The physical progress of KKNPP-3 and KKNPP-4 were 57.4% and 53.9% respectively as on December 31, 2021.

## Kudankulam Nuclear Power Project (KKNPP)-5&6

Kudankulam Nuclear Power Project Units -5&6 are under implementation at Kudankulam in Tirunelveli district of Tamil Nadu in pursuance of Inter-Governmental Agreement (IGA) of December 2008 signed between the Governments of Russian Federation (RF) & Republic of India and General Framework Agreement (GFA) of June 2017 signed between Joint Stock Company Atomstroyexport (ASE) and NPCIL.

Consent for First Pour of Concrete (FPC) from AERB has been received in May 2021 and the construction of KKNPP Units-5&6 has commenced with the placement of FPC on June 29, 2021. Concreting of Foundation Slab of Reactor Building is completed and construction work of walls above raft is in progress in KKNPP-5. Concreting of Reactor Building foundation slab (raft) Layer-1 is completed in KKNPP-6.

Development of Working Documentation (WD) is in progress. About 3,000 Freight Ton project cargo in two break bulk shipments has been delivered / dispatched from Russian Federation to Kudankulam NPP Site. Manufacture of Long Manufacturing Cycle Equipment; Reactor pressure vessel and Internals, Steam generator, Condenser, Turbo generator etc. is in progress.

## Sanctioned Projects

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

Consent for First Pour of Concrete (FPC) was granted by AERB on 18.11.2020. Casting of all foundation piles has been completed in both the Nuclear Building (NB) areas. Further activities towards obtaining regulatory clearance for casting of nuclear building raft are in progress. Excavation and ground improvement works are in progress in various other areas. Long delivery equipment manufacturing is in progress. Main plant electrical package and turbine



*First Steam Generator for GHAVP-1&2*

island package have been awarded. Both the endshields and first steam generator have been already received at site.

Purchase Orders for major equipment / components like Steam Generators, Calandria, End-shields, Reactor Headers, Primary Coolant Pump Motor Unit, D2O Heat exchangers, Moderator Heat Exchangers, Bleed Condenser, Pressurizer, Zircalloy components, PDHRS condensers, Shielding Plug assemblies, Seal Discs Installation Rigs Accessories & Spares, manual Installation Rigs, Compressors and Vacuum Pumps, Standpipe Thimble, Passive Decay Heat Removal System etc. have already been placed and manufacturing of many of these equipment is in progress. EPC contract for main plant Electrical System & Switchyard and Turbine Island package have also awarded.

## Ten 700 MW PHWRs in Fleet Mode

### GHAVP Unit-3&4

Siting consent from AERB has been received. EPC package for Turbine Island has been awarded. Placement of work order for Excavation and Ground Improvement is under process.

### Kaiga Unit-5&6

Consent to establish clearance for expansion has been accorded by Karnataka State Pollution Control Board (KSPCB). Siting consent from AERB has been received. Application for Excavation clearance is under review by AERB. EPC package for Turbine Island has been awarded. Award of work of Main Plant Excavation package is under approval.

## **Mahi Banswara Rajasthan Atomic Power Project (MBRAPP) Unit-1 to 4**

Land acquisition and MoEFCC clearance is in process. Construction of R&R colony is in progress. Forest clearance is to be expedited by State Government.

## **Chutka Madhya Pradesh Atomic Power Project (CMPAPP)-1&2**

Land Possession letter has been issued for all types of land. MoEFCC Clearance is available. Stage-II Forest Clearance accorded. Construction of all 330 dwelling units for R&R colony have been completed. Infrastructure facilities of R&R colony have been completed and ready for handing over. Field investigations will be taken up after availability of access to site.

## **New Projects / Sites**

### **Light Water Reactor (LWR) Projects**

In respect of new sites at Jaitapur in Maharashtra (Land Acquisition and Environment Clearance are completed) and Kovvada in Andhra Pradesh, various Pre-project activities related to land acquisition, R&R, environmental studies, Site Studies, Site infrastructure development, regulatory clearances, public outreach etc. and various techno commercial discussions for setting up large sized imported light water reactors (LWRs) based on international co-operation are in progress. In respect of Mithi Virdi site in Gujarat, land acquisition process is to be re-initiated as per new land acquisition Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act 2013. In respect of Haripur site in West Bengal, land acquisition is contingent to initiative by State Government. Alternate site is also under consideration by Government of India (Gol).

### **Pressurized Heavy Water Reactor (PHWR) Projects**

In respect of Bhimpur site in Madhya Pradesh,

commitment for water is to be confirmed by State Government.

## **Make in India Initiative**

Highest ever (around ₹10,800 crores) Purchase Orders for the Turbine Island package for GHAVP-1&2, Kaiga-1&2 and GHAVP-3&4 (total 6 units) have been issued, which is conceptualized in line with the “Make in India” initiative of Gol to establish manufacturing facility in India for 700 MWe Reactors. Also, Purchase Order placed for Steam Generators (28 nos) for fleet mode reactors.

## **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 have been carried out as per the Projects/ Stations schedules. NPCIL has continued to provide QA consultancy services to BARC and BHAVINI/ NFC. SQA activities such as Independent Verification and Validation (IV&V) activities for 700 MWe and 1000 MWe Projects are carried out stage wise. Verifications & Validations after up-gradations of software systems at various operating stations are completed as per the program. Quality Management System Audits are carried out at NPCIL Project Sites and at manufacturing location of major equipment suppliers. Pre-Service and In-Service Inspection Audits are carried at operating plants of NPCIL.

## **Safety Performance of Reactors**

NPCIL is responsible for performing the safety analysis including deterministic and probabilistic safety assessment of nuclear power plants for design, siting, commissioning of new projects, safe operation, extension of operating license/life management of operating plants and obtaining regulatory clearance for

the projects and operating stations. Some of the major contributions of NPCIL related to RSA are as follows:

A computer-based operator support tool for online monitoring of critical heat flux ratio for 700 MWe PHWR was developed and tested successfully on plant simulator. Another tool for events identification was also developed and tested in collaboration with Reactor Safety Division, BARC.

Level 2 Probabilistic Safety Assessment (PSA) for KAPS Unit-1&2 representing all 220MWe PHWRs was revised based on the latest methodology adopted for release estimation. Flow Performance inside Feed Water Box of KAPS Unit-1&2 Steam Generator under existing and Modified Design Configuration during normal operation using Computational Fluid Dynamics (CFD) technique has been completed.

Protection Strategy has been developed for each site-specific Emergency action levels/Initiating conditions (EALs/ICs). The developed strategy will be integral part of off-site Emergency Preparedness and Response plan (EPR) manual of the respective NPP sites.

NPCIL has recorded about 561 reactor years of safe operation of nuclear reactors by the end of December 2021.

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. NPCIL continue to maintain low radiation exposure in the public domain due to operation of nuclear power stations. Average dose received by a hypothetical person at Exclusion Zone boundary at NPP sites continue to be negligible, and for the year 2020, the value was  $18 \mu\text{Sv}$  (among all NPCIL sites) which is much lower than the regulatory limit of  $1000 \mu\text{Sv}/\text{year}$  and continues to be negligible in comparison of annual average dose to population due to natural background radiation which is about  $2400 \mu\text{Sv}/\text{year}$ .

At operating stations of NPCIL, certified Environmental Management System (EMS) as per IS/ISO-14001 and Occupational Health and Safety Management System (OHSMS) as per IS-18001/ ISO-45001 are maintained and regular audits are carried out for continual improvement. NPCIL obtained Clearance for AAFR for RR Site from Rajasthan Wild Life Department. Various activities related obtaining Environmental clearance/ extensions for NPCIL projects from MoEFCC and monitoring their compliances continued during the year.

NPCIL continued its mission to implement robust Industrial and Fire Safety standards in Operating Stations and Construction Projects. The Management Team is committed to convey NPCIL's safety values to employees to instill robust safety culture. Industrial and Fire Safety aspects are being ensured through implementation of Safety Management System at work locations. NPCIL takes responsibility for maintaining safe workplace by minimizing the risk of injury, fire and exposure to ill health for all employees and contractors.

Operating Stations and Construction Projects of NPCIL bagged prestigious National Awards from Atomic Energy Regulatory Board, National Safety Council of India and Ministry of Labour & Employment.

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 villagers, 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).

## 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 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.

For meeting the future large scale requirement of specialty materials for the front end and back end of nuclear fuel cycle and to enable DAE to achieve closed fuel cycle for energy security, HWB has been entrusted with design and technology development from lab scale to pilot plant scale and further scaling up to industrial production units, for the various basic synthesis processes developed by research units of DAE.

During the challenging period of nationwide partial lockdown, amid restrictions on mobility of employees, contract labor and large-scale disruptions in supply chain, HWB demonstrated strong resilience, strictly following all safety norms, utilized its core capabilities and stayed on course with the targets. As the restrictions eased, all projects and production targets were pursued industriously.

HWPs at Hazira, Kota and Manuguru have operated excellently. The Major Turn Around scheduled at HWP, Hazira and Thal were successfully completed well in time. The massive work at HWP, Talcher, of dismantling and disposal of old Heavy Water plant structures and equipment commenced in November 2020 and was completed in all respects by beginning of May 2021. At HWP, Baroda, all the components of 24kA prototype cell and associated systems have been installed and tested for sodium metal production. Civil Construction of 600 MT /Annum Sodium metal plant Cell building has been completed.

Revamping and preservation of HWP, Tuticorin plant is under way for restart up. Erection work at

Integrated Solvent Production Plant at HWP, Tuticorin is under progress. Work for green belt developmental around the plant was initiated. As part of TNPCB requirement for setting up Solvent Extraction Plant at HWP, Tuticorin, final original CRZ map was obtained from Institute of Remote Sensing, Anna University Chennai. Borehole water samples were collected and sent for ground water radiological analysis.

### Heavy Water Plant, Manuguru

The plant achieved safe and efficient operation producing targeted nuclear grade Heavy Water with optimum energy consumption, enriched Boron Carbide pellets and  $^{18}\text{O}$  enriched water.

At Boron Carbide Pelletization Plant, subsequent to supply of 40 pellets of IP  $^{10}\text{B} \geq 50\%$  to NFC on 22.04.2021, the remaining batch of 80 nos. of  $\text{B}_4\text{C}$  pellets of IP  $^{10}\text{B} \geq 50\%$  equivalent to 10 stacks of poison sub-assembly have been inspected and accepted by IGCAR. Enriched  $\text{B}_4\text{C}$  powder of IP  $^{10}\text{B} \geq 90\%$  was got micronized for further processing and production of  $\text{B}_4\text{C}$  pellets and meeting the demand of FBTR. Expansion of the boron facility at HWP, Manuguru has been taken up and procurement and other related activities are under progress.

At  $^{18}\text{O}$  water Plant, subsequent to installation and commissioning of two new ultra-pure  $\text{H}_2$  Gas generators, first drop of  $\text{H}_2^{18}\text{O}$  with  $^{18}\text{O}$  IP 12.5 % was produced on 23.09.2021. In the enrichment columns, the targeted  $^{18}\text{O}$  concentration of 95.5% a/a was achieved on 29.12.2021.



*Manuguru Seismic Station being inaugurated at HWP, Manuguru*

Manuguru Seismic Station was inaugurated on 17.09.2021 by Shri P. P. Marathe, Director, E&I Group, BARC to study and monitor seismic activity in the region.

### Heavy Water Plant, Kota

The plant operated excellently during the period to meet the production target for Heavy Water. The export consignments for M/s. Hyosung Chemical Corporation, S. Korea and M/s. Iwatani Corporation, Japan were prepared by HWP, Kota meeting all specifications required by the parties and were sent to Mumbai for further transport to the consignees.

Sodium Sulphate Crystallizer unit continued to operate to produce saleable quality of sodium sulphate crystals. Two Sale Orders of 100 MT each were issued, against which 165 MT has been lifted by parties.

### Heavy Water Plant, Hazira

The plant continued to be in smooth and regular operation. Both the streams were taken under shutdown in November – December 2021 for Major Turn Around (MTA) activities.

The plant has safely and successfully completed MTA 2021. The major activities included hydro-test and ISI activities of pressure vessel, Boiler

inspection, critical valves maintenance, maintenance of MOVs, replacement of 12E4B heat exchanger, hydro-jet and water cleaning of heat exchanger, PSV maintenance, testing and calibration, cooling tower sump cleaning, maintenance and calibration of control valves, level trolls and others instruments, maintenance of electrical motors, circuit breakers and transformers.

### Heavy Water Plant, Thal

Ammonia Cracker is used for cracking enriched deuterated ammonia to synthesis gas. The equipment operates under high temperature up to 700°C and pressure of 140 Kg/cm<sup>2</sup>. MOC of different equipment in the cracker are Inconel 625 and Incoloy 800H. These critical equipment have completed their stipulated service life of 1,20,000 hours and were due for replacement. In the process of revamping of Main Cracker of Stream B in July 2021, these components were replaced with used components after re-solution annealing. This has resulted in significant cost saving of the expensive components. Components replaced include 70 numbers of Inconel 625 cracker tubes, Super heater, inlet and outlet headers, hairpins, pigtails.

HWP, Thal worked out a plan for tube length extension with meticulous measurement of length. Required tubes extension ranged from 11 mm to 35 mm.



*Stage internals of 12TI exchange tower at HWP, Hazira*



*Main Cracker B Super heater replacement in progress at HWP, Thal*



*Heat treatment of new weld joints after cracker tube extension at HWP, Thal*



*Lifting of individual stage of exchange towers in progress at HWP, Thal*

Extension was done by cutting and welding a piece of tube followed by heat treatment of the weld joint at 1160 °C and soaking time of 130 minutes. This was followed by hardness test, hydro-test at 320 Kg/cm<sup>2</sup> pressure and microstructure test.

Annual Turn Around of Stream B was taken up during November - December 2021. Statutory testing like Hydro-testing of HP & MP loops; pneumatic testing of 14 unit, 17 unit & Refrigeration unit; Boiler hydro-test and inspection; ISI activities-III Cycle; revamping Exchange tower; Main Cracker A/B bottom component and catalyst replacement were carried out.

## Heavy Water Plant, Baroda

The Plant has achieved its annual target of Potassium metal production in 2021-22. The operation of TBP plant was affected due to the challenges faced with procurement of raw material (Phosphorous Oxy-chloride) on account of shortage of industrial oxygen during second wave of Covid-19 pandemic.

The plant synthesized the targeted quantities of d-labeled compounds of desired purity viz., deuterated Chloroform, deuterated Benzene and deuterated Methyl iodide.

Based on the operational data generated from operation of 2kA sodium cells of various configurations, higher capacity 24kA prototype sodium cell is being installed at HWP, Baroda. All the components of 24kA prototype cell have been procured, assembled and tested. Five numbers of 2 m<sup>3</sup> capacity dump tanks required for evacuation, ten numbers of 1 m<sup>3</sup> sodium storage tanks, one 10 m<sup>3</sup> capacity sodium storage tank required for the plant have been procured, installed and tested. 24/36 kA Rectifier system has been procured, erected, installed and tested. Erection, installation, testing, mechanical completion and pre-commissioning of Scrubber unit has been completed. Parallely, civil construction of cell building of 600 MTPA capacity Sodium plant has been completed.

Purification of impure sodium produced from 2kA test cell was carried out in the Sodium Purification Unit to produce 5.611 MT of Nuclear Grade Sodium out of which 3.085 MT have been supplied to IGCAR till date.

## Heavy Water Plant, Tuticorin

Solvent production plant is being set up at HWP, Tuticorin to produce 150 MTPA of TBP and 20-30 MTPA of D2EPHA II(PC88A), TiAP and DHOA. Civil construction of reactor building, ETP and utility building have been completed and construction of raw material storage, bulk storage area and elevated solar evaporation pan is in progress. Major mechanical items like Glass lined reactors, glass lined and SS receiver erection work completed. Utility systems like vacuum system, chilled water system, steam generation system

is completed. Erection of electrical panel, DG and Transformers are completed. Erection of pipe line and cable tray work is in progress. The project erection work is likely to be completed by September 2022 and trial production will be followed. After commissioning of the plant depending on the demands received from other DAE units the plant will produce solvents like TiAP, D2EHFA-II(PC-88A), DHOA, TOPO and TBP.

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, a nearby Fertilizer plant. Work Order for Detailed Engineering & Project Management Consultancy work has been placed on M/s MECON. At present, base documents such as DBRs, PFDs and P&ID of main process units and plot plan have been approved. Unit-wise equipment layout is being finalized. Pre-construction HAZOP study is being carried out. Technical evaluation of bids received against tender enquiry floated for civil work for SXP- GSFL/ HWP, Tuticorin interconnection pipe rack, is in progress. Tender Preparation for balance works, STP & WPA tanks is in advanced stage. The detailed engineering of subsequent packages is being carried out by M/s MECON. Applications for obtaining Consent to Construction & Consent to Establishment have been submitted to AERB & TNPCB respectively for their review.



**New SXP lab inaugurated by Shri Jitendra Srivastava, Chief Executive, HWB**

## Heavy Water Plant, Talcher

Dismantling & disposal of old Heavy Water Plant was a major activity during the year. Physical activity of dismantling commenced in Oct. 2020 and was completed in May 2021. Detailed planning and supervision was required for dismantling work and preparation of Safety Work Permit, ensuring proper decontamination, execution of Order To Operate (OTO) etc. and also keeping surveillance of the dismantling unit in RTC for ensuring safety (risk of fire due to presence of Potassium Amide etc.).

Calix Crown-6 (CC-6) is being utilized at Waste Immobilization Plant (WIP), BARC for solvent extraction of Cs-137 from aqueous solutions of Medium Level Waste (MLW) and 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 this commercially available material, HWB took up the task of in-house production of CC-6.

The synthesis of CC-6 was taken up at HWP, Talcher. Successful synthesis of the compound was achieved with yield as high as 80% and excellent purity in spite of very little literature available on the novel compound CC-6.



**Pilot plant set-up for synthesis of calix Crown-6 at HWP, Talcher**

CC-6 production is a multistep process. However by utilizing the already easily available Calix-3 in the market, process was optimized to only two steps. After optimization of the process, quantities of solvent & reagents and better temperature control during both the reactions, the yield was considerably improved. It is aimed to have a zero effluent strategy by recovering the solvents under reduced pressure and monitoring their quality through GC analysis post recovery. HWP Talcher has supplied around 2.5 kgs of the material to BARC, Mumbai.

The overall cost to the department in procurement of CC-6 from other sellers is around Rs.30 lakh per kg. Being able to provide it to BARC, Mumbai, at a much cheaper rate is indeed an achievement for HWP, Talcher.

## New Initiatives

HWB has now ventured in to new technology demonstration initiatives viz. recovery/ production of Gallium and Cobalt. 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 is as below:

### Extraction of Gallium

Gallium, a strategic metal, has vital application in the computers, transistors, aerospace, photovoltaic cells, specific electronics, medical science, defense systems etc. In medical field Gallium is used in nuclear medicine as radio contrast agent for medical imaging, in medical thermometers, certain pharmaceuticals etc. Strategic applications include use in nuclear industry, radar and heat transfer medium in high-temperature engines.

There is no primary source of Gallium in India. Gallium usually occurs as trace component in Zinc and bauxite ores. Bayer's liquor (sodium aluminate) obtained during alumina production from bauxite is the most important source of Gallium. Bauxite ores contain 20 to 80 ppm Gallium.

During ore processing, nearly 70% of Gallium is leached out in Bayer's liquor and accumulates in the

liquor due to several successive circulations, reaching a concentration of 100 to 300 mg/L. In few countries, Gallium is also recovered from residues obtained during Zinc processing. HWB, in collaboration with BARC, has ventured into technology development for Gallium recovery from Bayer liquor. BARC has developed an ion exchange resin for adsorption of Gallium from Bayer liquor.

After receiving technological input from Radiation & Photochemistry Division, BARC, HWB has set up a pilot scale plant for development of technology for Gallium recovery from Bayer liquor at TDP, Mumbai. Based on the data generated from pilot scale operation, HWB has carried out basic engineering design of industrial scale plant to be set up at NALCO, Damanjodi, to produce Gallium for meeting the in-house requirement of DAE.



Gallium recovery unit at TDP, Mumbai

### Recovery of Cobalt

At present, the demand of Cobalt is totally met with imports by MIDHANI, (Mishra Dhatu Nigam Limited), a public sector enterprise engaged in development, manufacture and supply of critical alloys and products of national security and strategic importance. MIDHANI generates about 200 to 300 tonne/annum of maraging steel alloy scrap (Grade MDN 150 to 350). These special alloy scraps could be a rich secondary resource for Cobalt, Nickel, molybdenum and titanium. This scrap alloy contains 8 to 12% Cobalt and 18 to 20% Nickel.

HWB has taken up the task of demonstrating technology for recycling steel alloy scrap for recovery of Cobalt and Nickel, reducing import load and foreign



**Bench scale mixer settler setup for Cobalt-Nickel separation at TDP, Mumbai**

exchange burden for the country. The process know-how was developed at Materials Processing & Corrosion Engineering Division, BARC. It involves hydro-metallurgical process of leaching of metals from scrap, removal of impurities by precipitation, solvent extraction, etc.

HWB has prepared an exhaustive plan to carry out recycling of this scrap material for recovery of Cobalt and Nickel at existing solvent extraction facility at TDP, Chembur. The process developed by BARC was tested at pilot scale plant and optimization of process was carried out. Based on bench scale data and operational experience, basic engineering for industrial scale plant to process 1 ton/day of MDN scrap was carried out.

## 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.

The Atomic Minerals Directorate for Exploration and Research (AMD) with a major mandate to identify and evaluate mineral resources of uranium, thorium, niobium, tantalum, beryllium, lithium, zirconium, titanium and rare earths containing uranium and

thorium, has carried out integrated multi-disciplinary exploration in various geological domains in the country.

During the Annual Programme 2020-21 (November 2020 to October 2021) substantial inputs of radiometric, geological, ground & heliborne geophysical, geochemical surveys and drilling (Departmental and Contract) were deployed for exploration of U, Th, REE, Nb - Ta, Li, Be and Zr.

Uranium investigations have been continued in the thrust areas for establishing Proterozoic unconformity, granite-related, carbonate, metamorphite, Palaeo-QPC and metasomatite type uranium deposits in Proterozoic basins and sandstone and surficial types in Phanerozoic basins. Similarly, substantial exploration inputs were deployed for augmentation of Rare Metal and Rare Earth resources (in pegmatite belts of Chhattisgarh, Odisha and Karnataka and in hard rock terrains such as Ambadungar Carbonatite Complex, Gujarat and Siwana Ring Complex, Rajasthan) and heavy mineral deposits in coastal beach placers in parts of Kerala, Tamil Nadu, Odisha, Andhra Pradesh, Maharashtra and Gujarat and in the inland placers in parts of Jharkhand, West Bengal and Tamil Nadu. In addition, collection of columbite – tantalite (Nb-Ta mineral) and xenotime (REE mineral) bearing poly-mineral concentrate was continued in the units established in Odisha, Karnataka and Chhattisgarh.

All the laboratories in 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.

## Uranium Investigations

### Geological and radiometric surveys

Reconnaissance (6,853 sq km) and detailed (364.75 sq km) surveys helped in locating the following promising new uranium anomalies/extension of known occurrences in various geological environs:

**Kanwan-Vishundhari**, Sonbhadra district, Uttar Pradesh hosted in pegmatoidal leucosome & migmatite

of Chhotanagpur Granite Gneiss Complex (CGGC) [up to 0.21%  $U_3O_8$ ].

**Badhera**, Hamirpur district, Himachal Pradesh, hosted in feldspathic lithic arenite of Siwalik Group [up to 0.26%  $U_3O_8$ ].

**Bhatrajugaripalle**, [upto 0.071%  $U_3O_8$ ], **Katamayakunta** [upto 0.150%  $U_3O_8$ ], **Kotakadapalle** [upto 0.049%  $U_3O_8$ ], **Pasapulavandalapalle** [upto 0.14%  $U_3O_8$ ], **Pujalavandlapalle** [upto 0.10%  $U_3O_8$ ] in basement fractures [mylonite and granite mylonite], Kadapa district, Andhra Pradesh.

**Khejurdari**, East Singhbhum district, Jharkhand, hosted in biotite rich magnetite bearing quartzite in Singhbhum Shear Zone (SSZ) [upto 3.60%  $U_3O_8$ ].

**Telendih**, Sundergarh district, Odisha hosted in basement granite [upto 0.89%  $U_3O_8$ ].

**Rumgang**, West Siang district, Arunachal Pradesh hosted in ferruginous phyllite of Khetabari Formation [upto 0.27 %  $U_3O_8$ ].

**Kundala**, Sikar district, Rajasthan, hosted in albitite of Khetri sub basin in North Delhi Fold Belt (NDFB) [upto 0.12%  $U_3O_8$ ].

**Namdarpura** [upto 0.24%  $U_3O_8$ ] hosted in brecciated quartzite and **Shri Ramgopalpura** [upto 0.57%  $U_3O_8$ ] hosted in magnetite bearing impure dolomite of Dogeta Formation (Raialo Group) in Alwar sub basin of North Delhi Fold Belt (NDFB).

**Chiknipali and Nagarda** in Chhattisgarh Basin, Korba and Janjgir-Champa districts, Chhattisgarh hosted in fractured basement granite and sediments of Chandrapur Formation of Chhattisgarh Basin [upto 0.20%  $U_3O_8$ ].

## Geochemical Surveys

Geochemical surveys (7,076 sq km) have indicated anomalous concentration of lithium in hot water springs of Karkha area, West Kameng district and Grenkhar area Tawang district, Arunachal Pradesh. High concentrations of U (up to 224ppb) and V (138 ppb) have been recorded in groundwater samples

along palaeo-channel course of Saraswati River in Pilani–Rajgarh–Mandawa–Bussau tract, Jhunjhunu and Churu districts, Rajasthan. Anomalous concentration of uranium in ground water samples has been recorded with values up to 765 ppb U in Indanoor, Mehboobnagar district, Telangana; 2,214 ppb U in Kotakadapalle, Anantapur district, Andhra Pradesh and 1,167ppb U around Bathinda, Punjab.

## Ground Geophysical surveys

Ground geophysical surveys (Regional: 726 sq km; Detailed: 604.40 sq km) have delineated potential high chargeability and low resistivity zones in Sarangapalli area, Guntur district, Andhra Pradesh; NNE-SSW trending high chargeability-low resistivity zone to the east of Ashakala Ki Dhani, Sardarpura sector, Jhunjhunu district, Rajasthan and depth persistency of low resistivity- high chargeability zones associated with fracture zones (up to 312m depth) in Hulkal block, Yadgir district, Karnataka.

## Airborne survey and Remote Sensing

Heliborne geophysical (TDEM, magnetic and Gamma-ray spectrometric) survey has been carried out over 56,826.72 line km in parts of North Delhi Fold Belt, Rajasthan & Haryana and Chhotanagpur Granite Gneiss Complex, Jharkhand, Uttar Pradesh, Madhya Pradesh and Chhattisgarh and Dongargarh-Kotri Belt, Chhattisgarh and Maharashtra.

Three (03) potential blocks have been identified in Bodal-Mungadih in Kotri-Dongargarh Belt for ground validation and targets zones have been delineated for



*Preparation of heliborne geophysical survey with VTEM plus system, Kota helibase, Sonbhadra district, Uttar Pradesh*

further exploration in CGGC near Ucherua area, Balrampur district, Chhattisgarh.

### Exploration by Drilling

A total of 2,10,714.05m (Departmental: 92,454.85m and Contract: 1,18,259.20m) 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 new promising areas.



*Departmental drilling unit in field area of Southern Region, Bengaluru*

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

**Anjangira and Kudar**, Sonbhadra district, Uttar Pradesh: Associated with pegmatoidal leucosome of Chhotanagpur Granite Gneiss Complex (CGGC).

**Rajpura-Nari-Maslana-Parah, Una district and Loharkar-Galot**, Hamirpur district, Himachal Pradesh: In sandstone along the Middle and Upper Siwalik transition zone.

**Jamalpur-Mukhota area**, Jhunjhunu district, Rajasthan: Associated with quartzo-feldspathic and albitised calc silicate of Delhi Supergroup.

**Motnupalalle, Kanampalle & Tummalapalle Blocks**, Kadapa district, Andhra Pradesh: In Vempalle Dolostone of Cuddapah Basin.

**Rachakuntapalle, Velmvaripalle and Kumarampalle Blocks**, Kadapa district, Andhra Pradesh: In Vempalle Dolostone of Cuddapah Basin.

**Sarangapalli**, Guntur district, Andhra Pradesh: Associated with basement granite / Banaganapalle Quartzite of Kurnool Group in Palnad Sub-basin (Cuddapah Basin).

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



*Spodumene bearing pegmatite, Mangalur Schist Belt, Yadgir district, Karnataka*

**Gujanal - Ankalgi**, Belagavi district, Karnataka: Associated with feldspathic arenite of Badami Group, adjacent to the unconformity contact.

**Jaduguda North**, East Singhbhum district, Jharkhand: Associated with conglomerate and sericite chlorite quartz schist in Singhbhum Shear Zone (SSZ).

**Baglasai-Mechua (Bhatin-Tirukocha Link)**, East Singhbhum district, Jharkhand: Associated with serpentinised peridotite in Singhbhum Shear Zone (SSZ).

**Kudada**, East Singhbhum district, Jharkhand: Associated with serpentinite in Singhbhum Shear Zone (SSZ).

**Bagjata**, East Singhbhum district, Jharkhand: Hosted in silicified chlorite-biotite-quartz schist / feldspathic schist, in Singhbhum Shear Zone (SSZ).

**Rohil West, Narsinghpuri, Jahaz, Bagholi, Sefraguwar - Chinchroli, Hurra Ki Dhani and Geratiyon ki Dhani**, Sikar & Jhunjhunu districts, Rajasthan: Associated with albitite zones in North Delhi Fold Belt (NDFB).



*Rohil Exploratory Mine decline,  
Sikar District, Rajasthan*

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

**Bijepar**, Gondia district, Maharashtra: Associated with rhyolitic conglomerate/ porphyritic rhyolite (Bijli Rhyolite) in Dongargarh-Kotri Belt of Central India.

**Jhapar**, Sonbhadra district, Uttar Pradesh: Associated with pegmatoidal leucosome of Chhotanagpur Granite Gneiss Complex (CGGC).

**Dharangmau-Kachhar**, Betul and Hoshangabad districts, Madhya Pradesh: Associated with feldspathic sandstone of lower Gondwana in Satpura-Gondwana basin.

In addition to the above, the potential/ significant blocks have also been taken up for sub-surface exploration in Sonbhadra district, Uttar Pradesh; Una district, Himachal Pradesh; Belagavi district, Karnataka; Kadapa and Chittoor district, Andhra Pradesh; East Singhbhum and Singhbhum district, Jharkhand; Dausa, Bhilwara and Chittaurgarh districts, Rajasthan; Balrampur district, Chhattisgarh;

Hoshangabad districts, Madhya Pradesh and at Guntur district, Andhra Pradesh.

## Rare Metal and Rare Earths (RMRE) investigations

Reconnaissance (805 sq km) and detailed (8 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. This has resulted in establishing additional resource of 1,157 kg of columbite-tantalite in pegmatites near Marlagalla, Mandya district, Karnataka (494 kg) and in extension areas of Pandikimal-Jangapara, Jharsuguda district, Odisha (663 kg).

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

A total of 17,596.30 m (Departmental: 2,076.30m and Contract: 15,520m) drilling has been carried out for RMRE in Allapatna-Marlagalla sector, Mandya district, Karnataka; Ambadungar, Chhota Udepur district, Gujarat and Siwana Ring Complex, Barmer district, Rajasthan.

A total of 293.28m length of pegmatite bodies in 37 boreholes and spodumene mineralisation of 59.68m in 31 boreholes have been established in Marlagalla-Allapatna sector, Srirangapatna, Mandya district, Karnataka. In Ramaniya block of Siwana Ring Complex, strike continuity of REE-Nb mineralised peralkaline granitoid has been established for 900m strike length and 185m width.

## Beach Sand and Offshore Investigations

Survey (Reconnaissance: 403.57 sq km and Detailed: 10.24 sq km) and prospecting (drilling, sampling and evaluation) were continued along the coastal tracts of Kerala, Andhra Pradesh and Odisha to establish additional beach sand mineral resources.

## Exploration/Evaluation

Conrad bunka (135 boreholes) and Sonic drilling (43 boreholes) have been carried out with a cumulative meterage of 9,587.40m and 7,063 samples have been generated.

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

Alappuzha-Cherthala-Aroor (up to 20%),  
Alappuzha district, Kerala

Mela Ganguvada-Rampuram (up to 68%),  
Srikakulam district, Andhra Pradesh

Boddu Gurayyapeta-Tippavalasa,  
Vizianagaram district, Andhra Pradesh (up to 48%)

Red sediments of Ravivalasa - Bhimunipatnam  
(up to 19%), 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 35% THM content.

## Mining & Mineral Processing

Mining and processing of uranium ore in India is done by the Uranium Corporation of India Ltd. (UCIL). The corporation operates in Jharkhand state with seven mines at Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, Banduhurang, Mohuldih and two processing plants at Jaduguda and Turamdih. One opencast mine and three mills located in Jharkhand (in East Singhbhum and Seraikela-Kharsawan districts) and Andhra Pradesh (in YSR district). 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.

For the Financial Year 2019-20, UCIL received 'Excellent' MoU rating with a score of 96.67 from the Department of Public Enterprises, Ministry of Finance, Government of India. During Financial Year 2020-21, UCIL has once again met all parameters for achieving 'Excellent' rating in MoU performance.

In the 'R&D, Innovation and Technology Upgradation' front, studies on percentage reduction of excess (residual) hydrogen peroxide in Jaduguda mill has been carried out in laboratory as well as pilot scale. Based on the studies, it was observed that by elevating temperature, the excess hydrogen peroxide in the supernatant solution obtained after product precipitation got reduced by 95%.

At Jaduguda Mill, the installation of Horizontal Belt Filters to replace the drum filters for better Uranium recovery from the leached slurry has been completed and commissioning is underway.

In order to sustain present level of production for next five years in trackless underground mines in Jharkhand, upgradation and adoption of latest available mechanization / technology through procurement of new equipment as well as overhauling of existing equipments has been undertaken. The overhauling of 10 Nos. of mining equipment has been completed at total cost of about ₹ 16 crores. For development of the lower horizons of Bagjata mines, a tender has been floated for the work of sinking of vertical shaft (₹ 20.5 Crores). Further, contract has been awarded for mine development and operation of Bhatin mine (₹ 89 crores). Besides, for improving vehicle management and safety, a tender has been floated for the work of installation of advanced vehicle & employee tagging and tracking system as well as CCTV surveillance system in Narwapahar underground mine.

For achieving the 'Vision 2031-32 Self Sufficiency in Uranium Production' and attaining sustainable long-term energy security of the country the Atomic Energy Commission (AEC) has accorded in-principal approval for 13 new projects in different parts

of the country. 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. UCIL has applied for “No Objection Certificate” from Forest Department for Rohil Project in Rajasthan. Geological Report in respect of Banadungri project (Jharkhand) has been submitted to Director, Department of Mines & Geology, Govt. of Jharkhand.

UCIL continues to maintain the ISO 9001:2015 certifications for Quality Assurance, ISO 14001:2015 certification for Environmental Management System. UCIL also continues to maintain IS-18001:2007 certification for Occupational Health and Safety Management System.

Andhra Pradesh Pollution Control Board (APPCB) had entrusted IIT (Chennai) for carrying out detailed scientific studies (Hydro-geological investigations) due to the allegations of contamination of tailing pond by the local villagers. The scientific study report concludes that, there is no discernable plume of uranium emanating from the Tailings pond from the water quality measurements performed in the downstream of the Tailings pond suggesting that the dam has not caused any ground water contamination in the adjoining villages.

However, as per the directives of APPCB, lining of tailing pond with HDPE has been started along with heightening of tailing pond (2nd Stage).

Besides, pilot scale construction of near surface trench disposal of uranium tailings at Tummalapalle (Andhra Pradesh), which is a unique method of uranium tailings management in the world has been completed and has been tested successfully.

IREL completed 70 years of providing unstinted support to the Country. It received “Excellent” MoU Rating for the year 2020-21 for the 4th consecutive year.

The MoU Score secured by IREL (India) Limited in the year 2019-20, which was declared in October 2021, was the highest among the DAE Units and 2nd best among CPSEs all over India.

During the period April to Dec. 2021, production of minerals increased by 5.11% as compared to corresponding period of last year. Further production of Chemicals increased by 16.09% as compared to corresponding period of last year. Production of Nuclear Grade Ammonium di-Uranate (NGADU) and Mixed Rare Earths Chloride (MRECL) stood at 17.954 tons and 3825 tons respectively.

Memorandum of Understanding (MoU) was entered between BARC, IREL and M/s. Ashwini Rare Earths Pvt Limited for scaling up the technology developed by BARC for production of NdPr metal from indigenous NdPr Oxide produced by IREL under incubation.

In addition, another MoU was entered with Ministry of Energy & Minerals in the Sultanate of Oman in the field of mining, particularly for rare minerals.

IREL has established facilities at its RED Unit in Aluva, Kerala for production of 6N Neodymium oxide used in hi-tech LASER Glass technology. This facility can be extended to produce other Rare Earth Elements as and when required.



*Virtual inauguration of Ion-Exchange facility at IREL*

At BARC, a new process scheme has been implemented for yellow cake obtained through conversion of crude sodium diuranate (SDU) to high temperature uranium peroxide (HTUP) in which impurities such as Zr, Mo, Si and C present in yellow

cake have been removed to a large extent. As a result of this, purity of TUP improved to 95% from 90%.

A flowsheet was developed for the recovery of around 92% of Lithium with 82% purity from the spodumene mineral concentrate of Marlagalla Karnataka site.

Around 70% of the identified Rare Earths values were extracted through pug-cure roasting – aqueous leaching – ion exchange separation and precipitation process route on a new found hard rock resource - Bhatikera micro-granites of Siwana Ring Complex in Rajasthan.

Studies were undertaken to recover Magnesium by-product from the REE-depleted liquor stream through lime precipitation. The  $Mg(OH)_2$  product obtained is of 80% purity with quantitative stage-recovery.

Mapping of Gallium in select samples of fly ash (coal) was completed using both neutron activation and chemical analysis. The Ga content in lignite origin coal flyash was 25 ppm. About 60% of it was leached in alkaline attack and further work on purification and separation of Ga values is in progress.

To develop a fundamental understanding of nuclear chemical processes and equipment, a single-phase Computational Fluid Dynamics (CFD) modelling of flow in a single compartment of the leaching reactor of UCIL Tumallapalle was carried out. A virtual tracer study was also done using CFD to understand the residence time distribution in the compartment.

The effect of the shape of the droplet on mass transfer to/from a droplet has been studied as part of efforts to address empiricism in CFD models of solvent extraction equipment. The results show that the shape of the droplet (spherical/symmetric ellipsoidal/asymmetric ellipsoidal) changes internal circulation pattern and hence the mass transfer rate considerably.

Nuclear chemical processes simulator - ANUSIM - has been augmented with several new modules, including Alkyl Phosphine Oxide (APO) based solvent extraction processes to separate Zr-Hf from

various feed streams; solvent extraction processes involving U, Pu and nitric acid carried out in a cascade of stage-wise contactors; mixer-settler design module; and a thermosyphon reboiler design module.

Real-time tracking of liquid-liquid interface within an accuracy of 1mm is carried out at the newly installed sensor-based Two-Phase Interface Detection System (TPIDS v1.0). The system comprises of self-calibrating ultrasonic sensor and COTS hardware with Ethernet interface.

A Proton Exchange Membrane (PEM) based electrolyser-cum-fuel cell system has been installed. It successfully demonstrates the close loop Electrolysis-cum-Fuel Cell process for treating low radioactivity liquid effluents.



*Proton Exchange Membrane (PEM) based Fuel cell system for CEFC process*

A process was developed for production of nuclear grade  $ZrO_2$  and  $HfO_2$  from dissolver solution using Alkyl Phosphine Oxide (APO) solvent. The process was demonstrated at 10 litres per hour (feed) using a mixer-settler cascade. To reduce the process footprint, a Miniaturized Pulsed Stirred Column (MPSC) contactor was also explored and the initial results were found to be positive.



*99.99% pure  $ZrO_2$  (on the left), Miniaturized Pulsed Stirred Column (on the right)*

Microreactor technology was employed for producing imidazolium-based ionic liquids for in-house R&D activities of the Department. The microreactor set-up was customized for producing ionic liquid at 7 kg/day capacity in a solvent-free continuous mode.

About 1.2 tons of uranium was recovered through leaching of 20 tons of  $MgF_2$  obtained as a by-product of MTR process.

A demonstration plant is being set up for Direct thermal denitration of uranyl nitrate solution generated in spent fuel reprocessing. It paves way for avoiding the use of ammonia and recovery of nitric acid. Several plant related works, including installation of equipment, instrumentation control panel, pneumatic pressure testing, metering pump and external mix type twin fluid nozzle have been completed.



*Fluidized bed reactor system inside enclosure (left) and Instrumentation control panel in Direct Denitration Demonstration Plant (right)*

5 kg of crude DTBDB18C6, the precursor of DTBDCH18C6, was synthesized in the upgraded bench scale plant using recycled solvent fractions. 95% pure



*20 L rotary evaporator for recovery of solvent (on the left) and 95% pure DTBDB18C6 product (on the right)*

DTBDB18C6 was recovered as a white powder. It was hydrogenated to DTBDCH18C6 which gave encouraging results upon evaluation for recovery of Sr from synthetic nitrate solution.

## 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 Structural (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.

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 achieved production of 614 MT of PHWR fuel bundles and 211 MT of pellet packing in addition to bundle production in the financial year till December, 2021.

## PHWR fuel

### The Uranium Oxide Plant (UOP)

In UOP, all the process parameters were controlled in a narrow band with stringent process control to produce sinterable grade  $UO_2$  powder of acceptable quality.  $UO_2$  powder produced has exhibited excellent sintering and visual recoveries.

Successfully completed the erection and commissioning of Automatic Integrated End Cap welding & Element Machining Unit-2. One end cap welding head in this unit is qualified. The addition of the unit is a step towards establishment of fully automatic PHWR fuel assembly production line with increased productivity, quality & safety.

Step less eccentricity correction mechanism for end cap welding machines developed in house has been successfully installed and commissioned in four end cap welding machines and has been under regular production with satisfactory performance with respect to improving quality & recovery.

Consequent to the adoption of modified process of 'Direct reduction of ADU to  $UO_2$ ' in reduction furnace, two Calcination furnaces (CF-I & II) available in the plant were not used for production activities. Hence, one of the calcinations furnace has been converted into Reduction Furnace-III which is used as stand-by equipment. This has resulted in increased availability of Direct reduction furnace to meet the production requirements.

Natural Uranium Oxide Fabrication Plant – Oxide (NUOFP-O) has successfully produced 16.3 MT of  $DDUO_2$  powder in Sept-Oct 2021 as a part of special requirement by AFFF, Tarapur for PFBR Fuel bundle requirements (for fabrication of Axial blanket pins and MOX fuel bundles),  $DDU-UO_2$  blanket assemblies for PFBR, Kalpakkam and for  $DDU-UO_2$  fuel bundle to be used in PHWRs for flux flattening. The entire campaign was carried out safely ensuring the air activity well below the permissible Derived Air Concentration (DAC) limit of  $1 \text{ Bq/m}^3$ .

25kL 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 1250Kg of Uranium was recovered from the above solution. This has resulted in great volume reduction and for converting 30KL tank stored with this lean solution into Crude Uranyl Nitrate Solution (CUNS) storage tank resulting in increased CUNS storage capacity. 3kL emulsified/degraded organic solution was chemically treated to recover about 100Kg of Uranium.

Vibration based Automatic pellet loading machine is developed indigenously for loading of  $UO_2$  pellets into Zr-4 tubes. It has greatly helped in reducing radiation dose to the plant personnel. It also is a step forward in the process of automation in fuel fabrication processes.

It has servo based horizontal and vertical movement with overload sensing spring system, pneumatic tube clamping system, Servo driven precision indexing conveyor, inbuilt load cell for material accounting. It simultaneously loads 19 pellet stacks into Zr-4 tubes. Production rate is 20 Trays / hrs.



*Manual Loading*



*Automatic Pellet Loading*

Manufactured 640 nos of 8.1 mm diameter cobalt pencils, 320 Nos of 10.5 mm cobalt elements and supplied to RMA for assembly of required reactivity mechanisms.



**19 Element Co-Nu Fuel bundles**

Manufactured 4 Nos. of special purpose 19 Element Co-Nu Fuel bundles similar to 19 Element PHWR fuel bundles for utilizing the cobalt for medical & industrial radiation applications after irradiation in PHWR reactors. The dimensional specifications, welding procedures for hermitical sealing of cobalt pencils and central cobalt element welds were finalized co-ordinating with BARC & NPCIL and dispatched the bundles to KGS reactor site within a short span of time.

Helium leak testing, dimensional inspection and Axial Load Testing of 1 No of Capsule Carrier Bundle of new design similar to PHWR fuel bundle for irradiation studies was carried out in co-ordination with BARC & NPCIL.

Relocation of Element Preparation Section of NUOFP(A) (Assembly Plant) from NUFAP building to the premises of NUOFP (Pelletizing) Building inside NFC main campus is completed. All end cap welding machines were shifted, re-commissioned, qualified, normalizing the production activities.

Three units of Integrated Spacer Pad & Bearing Pad Welding Units (ISBUs) are made during this period. These units are capable of welding Spacer Pads & Bearing Pads in fully automatic mode and meets the geometrical as well as weld quality specifications of NPCIL. These units are designed to handle 37-element fuel tubes at NFC-Kota.

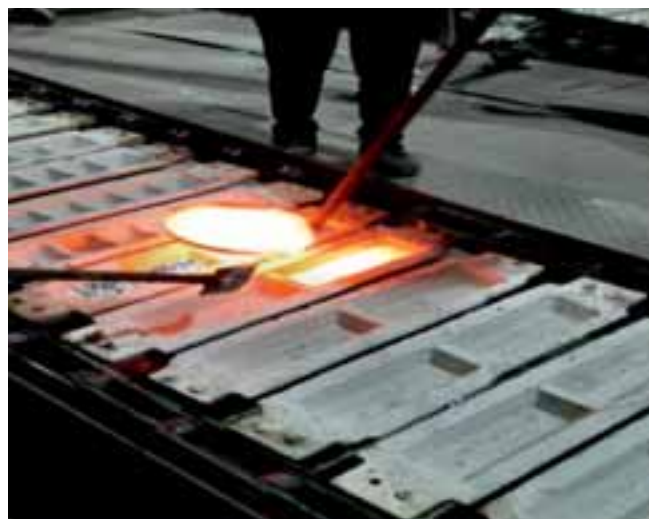
### **Metallic Fuels**

Nd Metal ingot of 5 kg scale has been successfully produced through Calcio-Themic Reduction. Calciothermic reduction of (Nd, Pr) fluoride at 250 gm scale using different crucibles/coating was also studied.

## **Structural Materials & Components**

### **Zirconium activities**

Higher capacity Zircaloy Scrap Chlorination Reactor of 25 MT/ month capacity in place of 15 MT/ month capacity has been successfully Installed and Commissioned. Successful Installation & Commissioning of Spray Column Scrubbers of 4 Nos. at Chlorination Facility and 2 Nos. in reduction operation. Installation & Commissioning of 4 Nos. of 26,500 m<sup>3</sup>/hr capacity Special Exhaust Blowers of ZSP against 3 Nos. of 18000 m<sup>3</sup>/hr capacity. Modified bleeding scheme (Bleed frequency of 20 min) has been implemented in one of the Reduction Unit on trial basis which has resulted to 10% reduction in reaction time and thereby increase in productivity. Optimization of Vacuum



**Casting of Master alloy**



**Ingots of Al-Zr Master Alloy**

Distillation cycle time & Temperature has resulted in 15% reduction in cycle time and increase in productivity & quality of Zr Sponge. 17 MT Zr Nb 2.5% Scrap was successfully chlorinated and 20 MT ZrNbCl<sub>4</sub> has been disposed. Joint development for developing Al-Zr based Master alloy using Zr-Nb turning has been done with outside firm. The development of the alloy was successful in all respects. The firm is willing to procure Zr-Nb turning from NFC. This development will be immensely helpful in removing problems associated with Zr-Nb turning.

Successful Installation & Commissioning of 8 Ton Capacity EOT Crane at Zirconium Sponge Handling and Sponge Storage Shed. Successful Disposal of 26.37 MT accumulated ring material using dissolution method.

#### **Renovation of the 500T Hydraulic Press, Zirconium Sponge Plant (ZSP)**

The 500T hydraulic press used for sizing of reactor grade Zirconium sponge is completely refurbished for enhancing its life and improving its availability. Some of the major works carried out includes complete replacement of the hydraulic power pack unit including hydraulic pumps, motor, DC valves, Pressure Relief Valves, Pressure Transmitter & Pressure Gauges, Introduction of manifold blocks in place of pipe connections for reducing joints which are points of potential oil leakage and also for easy problem identification; Thorough overhauling of the main



**Renovation of the 500T Hydraulic Press**

Cylinder Assembly which included honing of the cylinder bore, chrome plating on Ram, replacement of piston head and replacement of oil seals, Replacement of new table cylinder of modified design and replacement of old power panel with a new panel with PLC based control, installation of new operating station.

#### **Redundant server-based SCADA system in Vacuum Distillation**

In order to ensure a reliable control system, server – client-based SCADA system with redundant SCADA servers & RAID-1, dual redundant communication network is provided for vacuum distillation furnaces to ensure data redundancy and improve fault tolerance of the system. All the vacuum distillation furnaces are operating with server – client-based SCADA system for the past five months and the performance of the system is found to be satisfactory.

#### **Zircaloy fabrication**

Total 8924 nos. of extrusions have been carried out during the period.

#### **Development of low diameter (9m dia) Zr-2.5Nb-0.5Cu (ZNC) extrusion for wire product development for reduced process cycle**

Process development for extrusion of Zr-2.5Nb-0.5Cu has been carried out into 9mm rod instead of regular 21mm dia successfully for first time. 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 garter spring wire products for PHWRs.



**Development of low diameter (9m dia) Zr-2.5Nb-0.5Cu (ZNC) extrusion**



*Development of Titan-32 alloy*

## Development of Titan-32 alloy product for strategic requirement

Special Ti-Al-V based titanium alloys were required for strategic application in BARC. A process flow sheet was developed based on glass lubrication based hot extrusion followed by hot expansion to develop and supply shell of 175mm OD X 105mm ID in multiple lengths for first time and successfully supplied to BARC.

## Expansion & Extrusion of DMR 1700 grade steels pipes for defense applications

An alternative special grade ultra-high strength steel pipe has been developed indigenously for defense application with specific aim to reduce the cost of conventional Maraging steel grades in this area of application. NFC in collaboration with DRDL has developed two stage expansion followed by extrusion to manufacture Very high diameter pipes of 260mm OD X 165mm ID x 1.3 m L and supplied to DRDL, defense lab to meet strategic development.



*Expansion & Extrusion of DMR 1700 grade steels pipes*

## Extrusion of Special grade 9Cr-1Mo steel for extra-long length heat Exchanger pipes

A special 9Cr-1Mo steel grade has potential

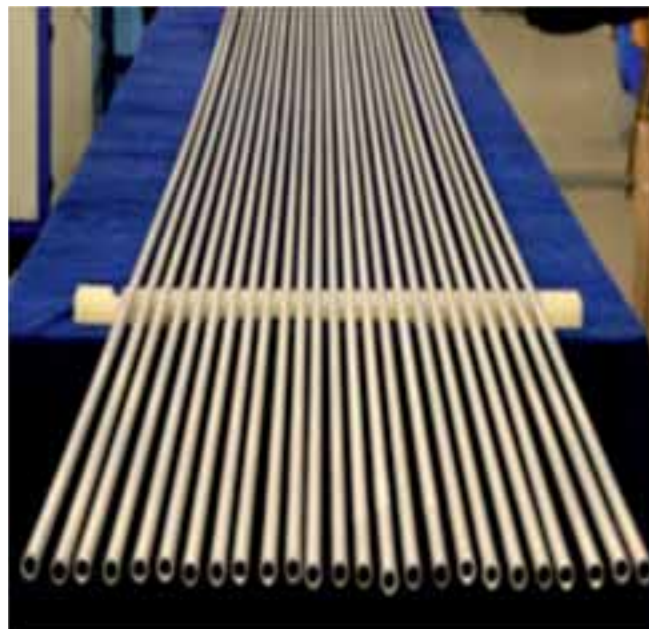
application as more than 27.0 m very long length heat exchanger tubes for fast reactor application. Special blank size of 76mm OD X 11 mm Wt were produced by hot extrusion with excellent quality and 23 nos were supplied to meet the finished long length in multiple pilgering pass from the single length of each blank.

## Fuel Tubes

During the current financial year 2021-22, 15.8 lakhs of PHWR Fuel Tubes has been produced. Apart from the Fuel tubes required for PHWRs and BWRs fuel assemblies, the Fuel Tubes section has developed & produced Titan 24 tubes, Titan 11 tubes, UNS NO-6690/6600 tubes, and Ni-Cr-Mo alloy tubes required for strategic purposes.

## Titan 24 tubes

NFC in collaboration with BARC, Mumbai had indigenously developed seamless titan 24 tubes as import substitute for strategic application. Titan 24 is having inferior workability due to high strain hardening rate and anisotropy nature of titanium. The manufacturing process steps from hot extruded blanks to finish size designed and analyzed at each stage w.r.t mechanical and metallurgical properties. The major manufacturing steps are hot extrusion followed by cold pilgering with intermediate vacuum annealing, acid jet cleaning and finishing operations. NFC has successfully

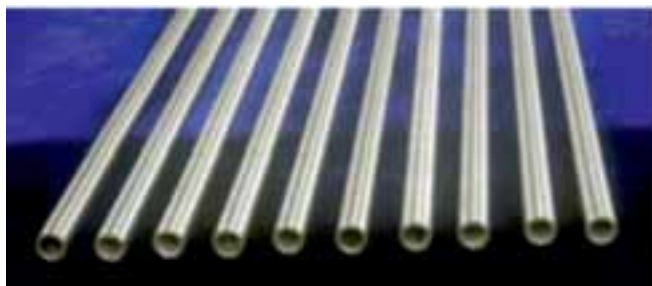


*Titan 24 tubes*

established the process flow sheet and supplied 1500 tubes of various sizes to BARC.

#### UNS NO- 6690/6600

The Ni-Cr-Fe Alloy seamless pipes of different grades & sizes are required for making Joule Melter / Vitrification process pot for projects of NRB/BARC at Tarapur, Maharashtra. These items will be used for high temperature application above 1000 deg C. Process flow sheet was developed and successfully manufactured 13 different sizes of pipes meeting all mechanical, metallurgical, creep rupture test and ultrasonic/ eddy current testing. It is a indigenously developed and will result in substantial saving of foreign exchange.



*Ni-Cr-Fe Alloy seamless pipes*

#### Titan 11 Tubes

NFC has indigenously developed seamless Titan 11 tubes as import substitute for defence application. NFC has developed manufacturing process flow sheet for four different sizes of diameter ranging from 14mm to 114mm. The major manufacturing steps are hot extrusion followed by cold pilgering with intermediate vacuum annealing, acid jet cleaning and finishing operations. NFC has successfully manufactured tubes meeting all stringent specifications w.r.t. ultrasonic testing, mechanical testing & metallurgical properties.

#### SS 321 Tubes

NFC has developed process flowsheet for manufacturing SS 321 tubes of four different sizes ranging from diameter 17mm to 42mm. Tubes meeting all the stringent properties as per specification have been supplied to BARC.



*Zircaloy-4 plates of 525 x 525 x 6 mm size*

#### Zircaloy-4 plates required for BARC

Zircaloy-4 plates of 525 x 525 x 6 mm size are required for BARC. 6 Nos. of plates have been cold rolled to final thickness and annealed. All the plates are QC cleared and are dispatch.

#### Vertical Honing cum Reaming Machine

Two nos. of vertical honing cum honing machine has been installed at NZFP for ID conditioning of hot extruded blanks of size 32-50mm. The machine is having three independent stations controlled through a hydraulic powerpack. Coolant circulation and filtration and hydraulic oil chilling unit is provided for enhancing the machine performance. The facilities are being successfully used for meeting the stringent requirement of conditioning of blanks of various grades of materials such as Titan-24 blanks, Incaloy-800 blanks, D9 blanks, Zircaloy blanks etc.

#### Establishment of New Degreasing Section at NZFP

New Degreasing Section was established. New Equipments such as Hot Alkali Tanks, Hot Vapor



*Establishment of New Degreasing Section at NZFP*

Degreaser, Hot Air Blower and High-pressure water Jet rinsing systems along with 2 Nos. of EOT Cranes were commissioned. The section is equipped with SCADA control of process systems with advances safety features like Activated Charcoal Trap, primary exhaust systems, Secondary Ventilation facility and safety eye wash showers. The section is working satisfactorily and catering the requirement of Fuel Tubes as well as special tubes.

## Automation of Vertical Vacuum Annealing Furnaces I & II at ZFP

Vertical Vacuum annealing furnaces (VVA-1 & 2) are operating under high vacuum for heat treatment of zircaloy components like fuel tubes, fuel blanks, sheets and garter spring wires. VVA-1 is a three zone and VVA-2 is a six zone vacuum furnace. Both the furnaces are 360KW capacity with maximum operating temperature of 850 °C. The entire operations are carried out under high vacuum of 10-6mbar. Control systems of two furnaces (VVA-1 & 2) were successfully commissioned and were tested for both temperature and vacuum logic for its sequence of operation and interlocks. After Installation, both the furnaces were tested for axial and radial temperature profiles by surveying and it is found to be +/- 3 °c.



*Automation of Vertical Vacuum Annealing Furnaces I & II at ZFP*

## Revamping of 25 VMR Pilger mill control panels at ZFP

The 25 VMR Pilger Mill in NFC is used for intermediate tube manufacturing. The conventional system used is electronic card-based system which is a 30 year old system. Due to aging and limited life, and



*Revamping of 25 VMR Pilger mill control panels at ZFP*

obsolescence of the electrical switch gear has led to multiple breakdowns and due to lack of proper documentation, fault finding used to consume time. All these problems led to replacement of control panel with complete wiring and switch gear. The work involved complete dismantling of cables, panels, rewiring, termination and checking of PLC logic for interlocks and working of machine. AC Drives communication to the PLC and HMI via PROFIBUS were added features to the new control system. The total pilger mill control logic tested with all the operational and safety interlocks for proper operation of the pilger mill. All the alarms were configured to identify the fault in the system. Developed control system was properly documented for future reference/operation/maintenance.

## Hot zone revamping of HVAF at ZFP

Horizontal vacuum Annealing furnace is a 6 zone electrically heated vacuum furnace used for heat



*Hot zone revamping of HVAF at ZFP*

treatment of Zircaloy components. It is a 240KW capacity furnace with maximum operating temperature of 1000°C. The entire operations are carried out under high vacuum of 10-6mbar. The furnace is a 30 year old and most of the heating elements were damaged and required dimensional heating elements were obsolete. Ceramic bricks used as refractory bricks for support of the retort are collapsed due to stress during axial expansion and contraction of the retort during heating and cooling cycles. Due to this, requisite temperature uniformity of  $\pm 3^{\circ}\text{C}$  both radially as well as axially is difficult to achieve and furnace is used only for intermediate stage heat treatment of fuel tubes only. Completely dismantled the existing heater panel along-with the structure, junction boxes, thermocouples and disconnected the cable terminals at the field side. Placed the new hot zone structure in line with the two cooling chambers and aligned. After successful placement and alignment of hot zone structure, fibrothal heating pads were placed at appropriate locations i.e. two each on either side and two on top for each respective zones while ensuring 10mm gap between each of them. New junction boxes were also placed, electrical connections to heaters were reconnected. After complete commissioning, surveying of the furnace was carried out for temperature uniformity inside the furnace for different furnace temperatures and it was found to be  $\pm 3^{\circ}\text{C}$  both radially as well as axially. Now the furnace is using for final stage heat treatment of Zircaloy fuel tubes.

#### **Modernization of Control System of 25VMR Pilger Mill at NZFP**

Thirty years old obsolete control system of 25VMR was revamped with latest PLC and HMI based control specifically used for industrial automation. Also, remote I/O concept along with digital communication between PLC and drives were carried out.

#### **New Vacuum Baking Furnace**

Installation & Commissioning of New Vacuum Baking Furnace, from M/s Therelek is completed. This furnace is used for baking of graphite coated tubes, working at high vacuum in the range of  $5 \times 10^{-6}$  mbar with leak rate less than 1 lusec and temperature control



*Installation & Commissioning of New Vacuum Baking Furnace*

accuracy of  $\pm 1$  Deg C, suitable to bake 4,000 tubes at a time.

#### **Process Development for production of Titan-24 Bars**

As first-of-its-kind effort, developmental strategic work was taken up and the manufacturing process was established for production of Titan-24 rods for strategic applications. As per requirement of BARC, 60 meter of Dia 14 mm Titan-24 rods were manufactured and supplied.

#### **Augmentation of Capacity of Automated Machining Center (AMC) to machining of Pressure Tube Billets for 700 MWe PHWRs**

AMC is highly specialized cluster of machines designed for automated handling and machining of Fuel Blank Billets (Dia 142 mm). The Pressure Tube (PT) billets demands extreme accuracy in machining and hence productivity is inadequate with manual machining in lieu of dedicated facility. The capacity of the existing AMC was augmented from Dia 142 mm to Dia 230 mm with multiple modifications to enable critical machining of PT billets. Depicts process flow for machining of PT billets. The development involved modification of complete Automation set up along with machine set up including hardware and software modifications. New end effectors & Work hold fixtures were designed and fabricated and system parameters were modified during augmentation. With the modification, productivity of PT billets was increased

by 400% as compared to manual, resulting in saving of approx. 800 man-days per year and reduction of processing time by approx. 50%. The modification has facilitated in-time supply of PT billets to meet the NFC targets.

## Optimisation of process route for manufacturing of PHWR Zr Bars

Process route for manufacturing of Zr bars of Dia 14 mm involves four passes of swaging and finishing operations. To improve the recovery and to reduce the processing stages, optimisation of the bar process route was taken up without modification of cold work schedule. After detailed Study and Analysis, the length of each bar per lot at pre-final stage was increased to improve productivity at each process. The subsequent modifications due to increased length, were executed on all the process stations. The activity enabled in reduction of one stage of final finishing process and hence reduction in end discards. The modification resulted in improvement of recovery from average of 82% to average of 90% and hence overall productivity enhancement by approx. 35%. The productivity improvement also resulted in reduction in demand of exclusive raw material and scrap generation by approx. 25%.

## Structurals

One reactor charge consisting of 9 Nos. of Horizontal Flux Unit Assemblies for upcoming 700 MWe PHWR were manufactured and dispatched to RAPP-8 reactor site.

Total 12 nos. of Cobalt Absorber Assemblies were manufactured and dispatched to running 220 MWe reactor sites.

Modified Start-Up Counter Assembly was manufactured first time at NFC and supplied to KAPS-1 & 2 site of 220 MWe PHWR. This assembly is proposed to be used during start-up of reactor and has better design features. This assembly is 11.6 meter long and is supplied in two parts. Special size tube was manufactured for this assembly and it met all stringent specifications. Final assembly was thoroughly checked by various gauge passing methods, Helium Leak test

and Liquid Penetrant Examination to ensure functionality at site.

Inner Guide Tube Assembly (IGTA) was manufactured first time at NFC on urgent basis and supplied to KAPS-3 site of 700 MWe PHWR. This assembly is proposed to be used during start-up of reactor and it is placed inside existing adjuster rod guide tube of reactor. This assembly is 12 meter long and met all stringent specifications as per drawing. A full scale mock-up of assembly insertion was carried out at NFC in presence of NCPIIL to ensure proper functionality at site. Pneumatic Pressure Test, Helium Leak Test and Liquid Penetrant Examination were carried out to check assembly integrity.

## Special Materials

The Plant has produced 2921MT of Niobium metal granules. Major achievements during the year includes carrying out of refining trials by multiple electron beam melting to improve Residual Resistance Ratio (RRR) of Reactor grade Nb and Produced large dia (200mm) Nb ingot. RRR of 120 was achieved from the starting material with  $RRR < 40$ . Development of indigenous and inherently safe process for refining commercial grade Magnesium. Successfully carried out bench scale trials & optimized the parameters for refining. Supplied 285 x 200 x 2.8mm Niobium sheets to VECC, Kolkata for accelerator applications. Process trials for development of alternate route for preparation of Nb sheets by cold forging instead of hot extrusion to avoid pick up of O,N during processing have been taken up. Preparation of 70mm $\Phi$  x 800mm & 45mm $\Phi$  x 300mm Niobium rods is for accelerator applications is completed. Development of process for preparation Nb45Ti alloy by Electron beam melting route for superconducting applications at RRCAT, Indore has been taken up. Trials are in progress and process parameters have been standardized for first melting & 60 kg 1st melted alloy produced. Second melting trials are in progress. Supplied 7kg Nb-5Mo-1Zr-0.1C & 2 kg Nb-1Zr-0.1C alloy produced by Electron beam melting to MSD, BARC for thermo-mechanical processing studies of the alloys. Prepared & supplied 715 Nos. of  $Sb_2O_3$  cast SS capsules required for Source SAs of PFBR. Highest ever recovery of 90% was achieved.

Successfully produced high purity Zr ingot (>99.9%) by Electron beam refining to meet requirement of NML. Prepared 50kg high purity, special grade Niobium oxide for BARC for strategic applications.

### Commercial Activities

The Stainless Steel Tube Plant (SSTP) has successfully manufactured & delivered 2nd Set of Steam-Generator tubes & 3rd set is nearing completion which is required for upcoming 700MWe PHWR of GHVAP



*Manufacturing & delivery of 2nd set of Steam Generator tubes*

### Modification of tube feeding system in CRTM 32 pilger mill

CRTM-32 Pilger mill at SSTP is used for pilgering of various critical products such as PFBR Fuel



*Modification of tube feeding system in CRTM 32 pilger mill*

clad tubes (SS D9) & PHWR Steam Generator (SG) tubes (Alloy800). The existing tube feeding system of the mill was modified to meet the stringent quality requirements of SG tubes. Innovative intermittent guides with non-metallic lining & metallic supports were fabricated in-house & successfully integrated with existing feeding system. This development has led to significant reduction in OD defect & also avoided need for frequent inspection of mandrel bar, thereby improving the availability of the critical mill for final stage pilgering of SG tubes.

### Projects

#### Green field Projects of NFC

##### NFC-Kota

NFC-Kota Project, Rawatbhata, Rajasthan, a green field project, is planned to produce 500 Tons Per Year (TPY) nuclear fuel for PHWR type nuclear reactors.

##### Major Events/Milestones

Subsequent to receipt of sanction for revised cost (Rs 4256.20 crores with a completion period upto July 2022) for NFC Kota Project in October 2020, the Project activities picked up momentum and the cumulative physical and financial progress achieved upto December 2021 is 48% and 30.21% respectively. Major machinery such as 65mm CRT Pilger Mill, CNC Mandrel Grinder, Deep Hole Drilling Machine, Sintering Furnaces, Centreless Grinder, Lathe Machines, several process tanks, agitators, pumps for powder plant, breathing air bullets etc are received at Project Site. Construction of major Plant Buildings like Module II of PFFF, Melt Shop, Extrusion Shop, Work Shop, Extrusion Shop, Fuel Tube Shop etc was completed to an extent that the erection of equipment in these buildings can commence. Balance construction activity like Module I of PFFF, and other auxiliary civil works for Utilities are in progress. Two nos of 2000 T Hydraulic Presses were installed & commissioned in Melt Shop. Equipment erection at work shop also completed. Erection of 3 Nos Horizontal Vacuum Annealing Furnaces is completed. 33KV Main Receiving Substation for NFC Kota Project was energized in December 2021 after obtaining the requisite statutory clearance from Central Electricity

Authority. Pipe rack for extending various utilities like cooling water, compressed air, power, control and communication cables etc is also completed to cover major facilities. Balance pipe rack for PFFF etc is under fabrication and erection. Laying of piping (fire water, raw water etc) commenced. Erection of compressed air plant is completed. Erection of Vacuum Arc Re-melting Furnaces at Melt Shop, Extrusion Press at Extrusion Shop and 65 mm Pilger Mill at Fuel Tube Shop commenced and mechanical erection is nearing completion. Erection of 50 Nos of process tanks is completed in Module II of PFFF. Associated piping, erection of agitators is in progress. Construction of Raw Water Treatment Plant, Building and Storm Water Reservoir has started. In Township site grading, road laying etc works are completed and construction of 2 Nos of blocks (each block of S + 13 floors) for Type II quarters and Guest House commenced. Total value of the purchase order, work orders placed and value of the purchase & works proposals in progress amounts to approximately ₹ 3000.00 crores.

### Zirconium Complex

About 390 MT of nuclear pure zirconium oxide and 190 MT of zirconium sponge were produced during the year till December, 2021.

### Magnesium Recycling Technology Development and Demonstration Facility (MRTDDF)

MRTDDF is being set up at Zirconium Complex to convert magnesium chloride generated during the production of zirconium sponge into magnesium and chlorine. The civil work 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. Construction of shed for housing DG sets is in progress and expected to be completed soon. Procurement activities of various equipments such as Multi-polar Electrolytic Cell, Melting furnaces and Vacuum Ladle are in progress. Major Electrical items like DG set, Transformer, MCC, rectifier, etc. supplied at site and installation is in progress. Major supplies for PLC based SCADA system have been received and installed.

### Augmentation of ZC township infrastructure

In order to cope with the requirement of expansion of sponge production, augmentation of infrastructural facilities like construction of additional residential quarters, expansion of Guest House and laying of peripheral roads are planned with a capital outlay of Rs. 65 Crore. Bhoomi pooja has been done on 25th November 2021 and work commenced.

## BACK END FUEL CYCLE

### Fuel Reprocessing

A Special Nuclear Material (SNM) was recovered from the spent fuel of Research Reactor Dhruva through PUREX based reprocessing route implemented at the Trombay reprocessing facility.

$^{90}\text{Sr}$  is the prominent fission product present in High Level Liquid Waste (HLLW) and its daughter product Yttrium- $^{90}$  ( $^{90}\text{Y}$ ) is of particular interest for its radio-pharmaceutical applications. Using a Supported Liquid Membrane (SLM) Generator, around 34 batches of 150 mCi of carrier-free radiopharmaceutical grade  $^{90}\text{Y}$  were produced from  $^{90}\text{Sr}$ - $^{90}\text{Y}$  solution. These batches were supplied to RMC for radiopharmaceutical applications.

$^{225}\text{Ac}$  was found to be a very promising -emitting radionuclide for targeted alpha therapy. Presently, this radioactive nuclide is not being produced indigenously. The main source of  $^{225}\text{Ac}$  is  $^{229}\text{Th}$ , which is formed through alpha emission of  $^{233}\text{U}$ . A feasible process has been identified and deployed for separation of 240  $\mu\text{Ci}$  of  $^{229}\text{Th}$  from aged  $^{233}\text{U}_3\text{O}_8$  for targeted alpha therapy of cancer.

About 50,000 Ci of Cesium-137 was separated from Uranium-lean HLLW by using indigenously developed solvents, including Calyx crown. Several other valuable actinides such as Sr-90, Ru-106 were also recovered through solvent extraction based partitioning system. The recovered Cs-137 of 6423 Ci was converted into glass form and melted in SS pencils for Blood Irradiation purposes. 21 Nos. of Cs glass pencils, having specific activity of 2 Ci/gm, were successfully made and dispatched to BRIT.



*Facility for welding and overpacking of Cesium Pencil*

Resistance brazing methodology for brazing of Ru-106 plaques of desired quality was successfully developed and established by using indigenously developed brazing machine. 11 numbers of fully-brazed Ruthenium plaques were produced in coordination with PSDD, BARC and dispatched to hospitals through BRIT.



*Resistance Brazing machine for Ruthenium Plaques*

Nuclear Recycle Group has developed Ruthenium Brachytherapy (RuBy) Plaque for affordable treatment of eye cancers. In addition to round and notched configurations of the plaque, two new configurations are being developed for pediatric applications. The calibration and rate of distribution of dose from RuBy plaque source onto the tumor is monitored through a Windows, Linux-compatible simulation software developed in BARC. Over 70 patients have been treated successfully with the help of these plaques, which are in use at seven hospitals in the country.

## Waste Management

Design and fabrication of process equipment for Decontamination Facility for recycling of contaminated water and effluent has been completed.

120m<sup>3</sup> of active solid waste and 25 tons of inactive solid waste was processed and disposed off under BARC Swachhata Abhiyan.

Through a suitable chemical treatment flowsheet comprising of chemical co-precipitation, centrifugation and cementation processes, 72,622 m<sup>3</sup> of low-level radioactive waste collected from Trombay operations was treated to remove low level effluents before its final disposal.

Radioactive solid wastes of combustible type are plasma incinerated to reduce their volume significantly and are later stored in engineered disposal modules to isolate from human environment. A Plasma incineration demonstration facility was operated in Trombay for minimising the volume of such wastes by a factor of around 40. The compacted waste was disposed in Near Surface Disposal Facility (NSDF) at Trombay.

During the year, a total of 430 m<sup>3</sup> of radioactive solid waste had been disposed in Near Surface Disposal Facility (NSDF) in Trombay after its volume reduction. Disused sealed radioactive sources numbering 165 collected from various parts of country were being processed for safe management here.

About 500,000 liters of water of low-level liquid waste origin was decontaminated and processed by employing membrane based Reverse Osmosis technique and Ion Exchange process to obtain recyclable water from the pilot-scale hybrid system installed at the Effluent Treatment Plant.

A Wet off-gas system, which is capable of reducing the temperature of exhaust gases to below 200°C from a high of 800°C, and for minimising the toxicity of these gases to permissible levels, was planned for installation in BARC. The system consists of quencher, venturi scrubber, packed column, condenser, demister and a heater arranged in series. Works related



*Wet off-gas system at RSMS, Trombay*

to system instrumentation and readiness aspects are currently under progress.

An engineering scale prototype of Cold Crucible Induction Melter (CCIM) for vitrification of HLW was taken up in BARC, to overcome the limitations of the present vitrification melters. Around 2100 liters of simulated waste was successfully vitrified using 95kg of glass frit at a feed rate of 30 liters per hour to produce approximately 170kg of glass in a five-day operation. The CCIM was integrated with cooling system and power supply system and operated to evaluate the efficacy of all features. It offers considerable advantages, including high temperature availability, high waste loading and long melter life. The equipment is now being transferred for its implementation in WIP Tarapur.

## HEALTH, SAFETY AND ENVIRONMENT

Glass fiber media with a minimum retention efficiency of 99.97% for 0.3-micron size particles were developed by BARC. Three types of masks have been

developed using this HEPA filter based technology. These include High-Quality Respiratory Face Mask (HQRFM) for industrial as well as general use; dual use Engineered Valveless Transparent Face Mask (EVTFM) (P-100 type) equipped with a replaceable cartridge with potential applications in medical & industrial areas, nuclear sector was also made using the glass fiber media developed in-house.

More than one lakh units of High Quality Respiratory Face Masks, 1000 nos. of EVTFM have been produced and deployed in public domain through transfer of technology to private parties. Masks developed using in-house developed HEPA filter based technology are reusable.



*High Quality Respiratory Face Mask*



*Engineered Valve-less Transparent Face Mask*

A Bayesian Network model was implemented to understand the probability of human error in an operating plant as well as to aid risk analysis studies related to Operational Health Safety Management.

Aerosol generator was used to carry out studies on the particle size distribution and average concentration of Cs and Sr nitrate aerosols in various particle sizes and its comparison with the standard aerosols such as Sodium Chloride (NaCl) & Di-Octyl Phthalate (DOP) to understand their size distribution characteristics for proper selection of respirators as well as its implication in the internal dose estimation during incidents involving internal exposure.



*Portable Aerosol Spectrometer*

BARC provided services related to Radiological Safety, Surveillance and Occupational Radiation Protection for back-end fuel cycle facilities such as Reprocessing plants, Waste management facilities, MOX fuel fabrication plant, PRP, AUGF and RMP located at Tarapur, Kalpakkam and Mysuru. It pertains to area monitoring, hot-spot monitoring, air monitoring, personal monitoring and monitoring on environmental discharges. All environmental discharges through atmospheric and aquatic routes from the facilities were found to be well within the limits set by regulatory authority and technical specifications of the facility. The average individual dose for back-end fuel cycle facilities for the year 2020 for PREFRE-2, KARP & KARP-II was 0.73 and 0.55 mSv, respectively and collective dose was 607.7 and 571.4 mSv, respectively.

A hydrodynamic and contaminant transport model of the Kudankulam coast was set up for the study of recirculation and dispersion of radioactive effluents released from the main outfall of Kudankulam Nuclear Power Plant, Tamil Nadu. Based on the studies, it was concluded that: there will be negligible recirculation of the radioactivity released from the outfalls to the intakes of the Kudankulam nuclear power plant and the breakwater structure plays a very vital role as a barrier to effluents from entering the intakes. Without the breakwater structure, large ingressions of the discharged effluents to the intakes are predicted.

Environmental Survey Laboratories (ESLs) are established at each nuclear energy facility for periodic monitoring of radioactivity content in environmental matrices. Samples of various environmental matrices such as soil, sediment, air particulate matter, water, milk, food items, sea food, grass up to 30 km radial distance from the facility are collected, processed and analysed for activity content using various radiometric techniques. The results of the environmental surveillance carried out this year clearly indicate that the



*ERM-SAT established at L.L.R.R.L, Kollam*

dose to the member of public at fence post of the facility is only a small fraction of regulatory limit of 1000 micro Sievert per year. Onsite radiological monitoring and environmental surveillance support has been provided at BARC facilities.

About 40 units of Environmental Radiation Monitor with Satellite Communication (ERM-SAT) have been installed at different locations throughout the country. These systems monitor atmospheric environmental radioactivity and relay data regularly to the Earth Station, established at CTCRS, Anushaktinagar, Mumbai. Various software applications for data reception, storage, processing, etc. have been developed and implemented into the Central Station.

During the year, 8280 occupational workers were monitored for external and internal radiation exposure in the front-end of nuclear fuel cycle operations. In-plant radiological survey and radiation dose evaluations were carried out for Uranium Corporation of India Ltd (Jharkhand & Andhra Pradesh), Indian Rare Earths Ltd. (Kerala, Tamil Nadu, Odisha) and Nuclear Fuel Complex (Hyderabad) to ensure compliance with regulatory norms. The occupational radiation doses to workers in underground uranium mines and Thorium handling facilities were well within the regulatory limit of 20 mSv/y. Regulatory clearance from Atomic Energy Regulatory Board has been obtained for renewing mining operations at the UCIL facilities at Bagjata, Mosabani in Singhbhum district of Jharkhand and Tummalapalle in Kadapa district of Andhra Pradesh.

To investigate the predictability of earthquake using radon monitoring technique, a country-wide radon network using in-house developed standalone type radon geo station has been established with central station at BARC, Mumbai under the Project INDRA-SA. Till date, 60 stations have been installed across the country with a target to set up 100 stations by December 2022. Radon signal originating from tectonic stress build up process are detected using intelligent algorithms at central station. A correlation analysis made between 3924 Radon precursory signal and 3966 earthquake events (magnitude > 4) during the monitoring period shows a promising correlation ( $R = 0.8$ ). Early radon

signal was observed in 81 % of total earthquake events in an advance time gap of few hours to a week time. It is hoped that current practice of online radon monitoring in a large network and application of machine learning technique will be helpful to make a predictive statement on earthquake occurrence.

A reliable method based on Solid-Phase Extraction Chromatography (SPEC) has been developed and used for the separation and assay of  $^{90}\text{Sr}$ ,  $^{99}\text{Tc}$  and  $^{239}\text{Pu}$  from environmental sediment samples, which gives reliable and reproducible results within 24 hours. In case of an inadvertent event, rapid analysis of radioactivity will help the authorities in decision-making to implement the counter measures. Studies were undertaken to develop low-cost natural adsorbents for decontaminating the water. Fly ash, an abundant by-product of thermal power plant, has been found to have high adsorption capacity and removal efficiency for U, and is found to be suitable for decontaminating the water containing high U concentrations.

Numerical model for simulating flow and contaminant transport for groundwater was developed by employing Alternating Direction Implicit (ADI) scheme to solve groundwater flow, and the dispersion equation for migration. The Model is capable of including different types of boundary conditions. This approach was found to be rational because measuring the contaminant concentration in the groundwater downstream the facility may not be physically viable as the effect, if any, will take hundreds to thousands of years and in most of the cases will not be in the range of detectable quantity.

## 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 aimed towards achieving continual enhancement of nuclear & radiation safety, reliable operation, Vendor base broadening, product development and cost reduction of Nuclear

Power Plants. For Financial Year 2021-22, 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.

PCPTF Structural Building erection completed. Civil construction for Control Room etc. are in adv. stage of completion. Delivery of Pipe fittings, Orifice plates, CS pipes, Pumps, C&I portion (partly) are completed.



*PCP Test Facility Building Structure*

### Reliable Electrical Power Supply System (REPS)

REPS is being set up as an extension to TAPS-1&2 Switchyard for supplying enhanced capacity electrical power to the present installations of NPCIL and BARC at Tarapur as well as for upcoming facilities. This is being established under MoU between NPCIL and NRB, BARC.



*One of the Two 50 MVA Transformers Received at REPS Site, Tarapur*



*700 MWe PHWR Fuelling Machine at FMTF*

### Fuelling Machine Test Facility (FMTF)

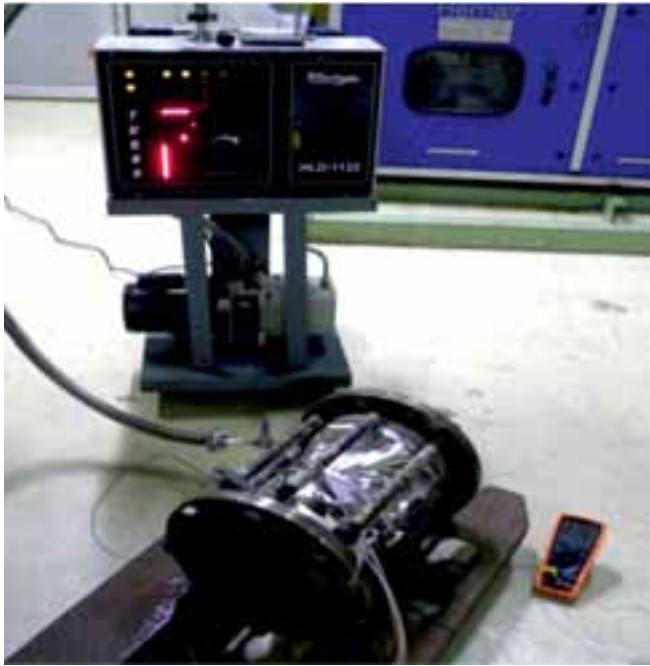
Performance evaluation of 700 MWe Fuelling Machine (FM) Head received from new Vendor for RAPP-7&8 has been completed in the dedicated FMTF at R&D Centre, including Weir Level Control experiments. Coolant channel emergency service tools like Channel isolating Plug (CHIP) & Flow Blocking Plug (FBP) have been tested and qualified at design process parameters.



*Test Set-up for Coolant Channel Pressure Drop Measurement*

### Pressure Drop Measurement across 700 MWe Coolant Channel Internals

For qualification of new design of Liner Tube of 700 MWe PHWRs and to improve streamlining of coolant radial flow from End Fitting to axial flow in Liner Tube, a dedicated set up erected to measure the pressure drop across Fuel Locators and Fuel Bundles for the existing design and proposed design. Phase-1 experiments carried out in the test set up.



*Helium Leak Testing of CT Spool at 150°C*

## Calandria Tube Rolled Joint Qualification at 150°C

Test set up has been designed and fabricated in-house to qualify the Calandria Tube rolled joint up to a temperature of 150°C.

## Environmental Qualification (EQ) Activities

During 2021-22, major components tested are Ion Chamber Amplifier, MAPS Moderator Control Valve along with accessories, Junction Boxes, Coating Samples, etc. Irradiation tests were completed for one scaled down Shutdown Cooling Pump Motor.



*EQ Testing of MAPS Moderator Control Valve along with Accessories*



*Experimental setup for Breather Drain Device Evaluation*

## Breather Drain Device for Junction Boxes in 700 MWe Reactor Building

Extensive experiments carried out to qualify Breather Drain Device for pressure equalization in Junction Boxes in 700 MWe PHWR Reactor Building for various scenarios. The experiments were carried out using three different makes of Breather Drain Devices for different sizes of Junction Boxes.

## Remote Tooling

### Coolant Channel Life Management Related Activities

As part of planned shutdown activities, In-Service Inspection (ISI) campaign of PHWR coolant Channel Pressure Tubes using BARCIS system was carried out successfully at 220 MWe Operating Units viz. KAPS-2, MAPS-2, KGS-1, RAPS-3&6. Enhancement of inspection techniques for the same continued.

### Hatch Beam Opening Sealing System (HBOSS) for KAPS

This sealing scheme for KAPS-1 Calandria Vault



*HBOSS System Manipulator*

(CV) Top Hatch Beams (THBs) was developed to close the openings made earlier for inspection inside the CV. After development of HBOSS assembly with detailed testing & qualification, same is ready for deployment.

### **Cobalt Adjuster Rod Dismantling System (CARDS)**

A Cobalt Adjuster Rod Dismantling System (CARDS) was developed for 700 MWe. Rigorous testing & qualification of the system was completed successfully.



*CARDS under Operation*

### **PRESAM Tool Head**

PRESAM Tool is used for measurement of sag profile of Pressure Tube (PT). Bulk manufacturing of the



*PRESAM Tool Heads (3D Model and Final Assemblies)*

Tool Heads was successfully completed for use in various 220 MWe PHWR Units.

### **Indigenization**

Indigenous development and Vendor base broadening for various critical components and equipment continued by NPCIL, in line with Atma Nirbhar Bharat. Adoption of the indigenous technologies developed in the recent past, is being done with commercialization for current and future 700 MWe reactors. Covid-19 pandemic has impacted the progress of many indigenization activities.

### **Electrical Penetration Assemblies for High Voltage Power Cables**

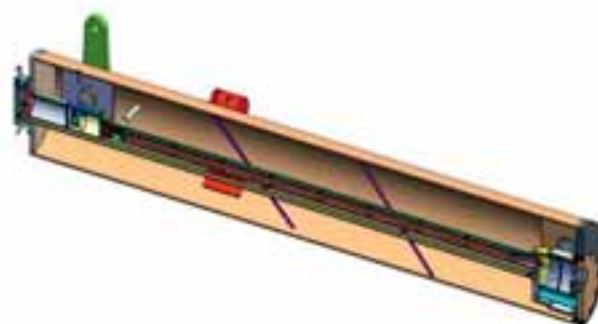
Indigenous development of Factory-built Electrical Penetration Assemblies (EPAs) for High Voltage (HV) Cables is in progress. First prototype HVEPA demonstration is completed.



*H.V. EPA Prototype*

### **700 MWe CoAR Shielding Flask**

The CoAR Shielding Flask design is completed. The first CoAR Shielding Flask is under manufacture for reactor use.



*Cobalt Adjuster Rod Shielding Flask Assembly (Section view, excluding lead)*



*Borated Wood Test Specimen*

## High density Borated Plywood

To resolve the challenges in manufacture of high density Borated Plywood for neutron shielding application in 700 MWe PHWR Ion Chamber assemblies, development is in progress. After production and testing of multiple batches of samples, process route is optimized. Prototype samples with optimized process route are manufactured with required Boron content & density. Enhancement of testing facility for the specific requirements has generated all required results, which are satisfactory.

## Drive Motor of 700 MWe Reactor Drive Mechanisms

For Control Rod and the Adjuster Rod application, the Motor has to operate at variable speed as per reactor regulation requirements. Design and manufacturing of the Motor, insulation system designed for voltage harmonics, etc from alternate Vendor has been completed and type tests are in progress.



*Reactivity Drive Mechanism Motor*

## High Flux Electric Heaters for Pressurizer Heater

After successful prototype manufacture and testing of the heater with specific size and configuration suiting to the Pressurizer application, all manufacturing documents have been completed. First two Heaters were fabricated to demonstrate and optimize manufacturing process. Further, fabrication of High Flux Electric (HFE) Heaters is in progress.



*High Flux Electric Heater Prototype*

## Boiler Feed Pumps for 700 MW reactors

Indigenous development of Boiler Feed Pumps (BFP) for 700 MWe reactors by second Vendor is in progress. Performance testing of Main Pump, NPSH & hot run tests carried out.



*Feeder Cutting Laser*

### Feeder Cutting Laser Machine

This is a remote operated cutting machine for Fuel Channel Feeder Pipes. It has been designed and a prototype is developed.

### Automatic Orbital TIG Welding Machine (AOTWM)

This special custom built machine is being developed for automatic orbital TIG welding for plant requirements. Complete machine with control console is ready. Welding trials are in progress.

## R&D in Electronics, Control & Instrumentation

### Electronic Systems

For identified Computer Based System Input / Output modules and Alarm Modules, Schematics, PCB design and component layout were completed for the improved design. Engineering Work Station new software version which allows modification in software at site and which is to be used in future projects is released for testing by user group.

Software of in-house developed systems of KAPP-3 were updated after operation / audit feedback, and laboratory validation was completed. Operator Work Station software was upgraded for 700 MWe PHWRs. Computer based channel Temperature Monitoring System software of all 220 MWe and 540 MWe reactor was upgraded.

## Engineering

Design, Development, Analysis and Detailed Engineering for various projects and Design Support for all Operating Power Stations were continued.

### KAPP-3&4, RAPP-7&8 and general for 700 MWe PHWRs

Turbine Instrumentation commissioning of KAPP-3 was completed successfully. Specification for NDCT package for RAPP-7&8, additional chillers for KAPP-3&4 and RAPP-7&8 were finalized. Balance major

machines/ equipment like Fuelling Machine Head, Mobile Transfer Machines, New Fuel Magazines, Tray Loading Machine, TLB Shielding cum Sealing Gate and Sealing Gate assembly was manufactured and delivered to KAPP-4 and RAPP-7&8 projects.

Indigenous development of ESR Quality Stainless steel 403 Forgings for high pressure



*Pressure Housing*



*End Cover of FM Head*

application such as Pressure Housing and End Cover of FM Head was completed.

Completed indigenous development of high precision & radiation resistant AC Linear Variable Differential Transformers (LVDTs) for Fuel Handling System completed.

Indigenous development of precision measurement & radiation resistant, 2-part Level transmitter for Fuel Handling System (prototype) is successfully completed.

## GHAVP-1&2

Piling of Nuclear Buildings of GHAVP-1&2 is completed. 3D based integrated design and detailed engineering of safety related buildings/ structures are completed. Analysis, qualification and design of systems, structures & components and detailing with regard to standardization of 700 MWe PHWR for GHAVP-1&2 are also implemented along with integrated engineering of each building. Major portion of civil construction drawings and other construction deliverables are also prepared & completed. Balance documents/ construction drawings are also nearing completion. Technical Specification for power transformer and 400 kV reactor package for GHAVP-1&2 are completed.

Except a few, all requisitions for procurement of all supply as well as EPC packages were issued. Layout Engineering of Electrical equipment in main plant and switch yard is completed. C&I Specifications for Field Instrumentation Package and Nuclear & Radiation Instrumentation Package are prepared and completed.

## Fleet Mode Project

Excavation consent of Kaiga-5&6 is in the advance stage of review by Regulatory Body. Design Basis Ground Motion (DBGM) and Design Basis flood level for Kaiga-5&6 are approved by Regulatory Body. Siting application of Mahi Banswara Rajasthan Atomic Power Project (MBRAPP) is submitted to AERB. Activities related to placement of work order for Plant Engineering and 3D modelling design consultancy work for Kaiga-5&6 is in the advance stage.

## Light Water Reactors

In respect of KKNPP-1&2, Periodic Safety Review (PSR) was completed and got re-license for operation up to 2025. Significant events were reviewed for better understanding and possible improvements in SSCs and logics& interlocks for steady operation of the Units. Various other engineering activities are in progress.

In respect of KKNPP Unit-3&4, the in-house analysis for PSAR (some chapters) was carried out and reports were finalized. Various engineering deliverables prepared by the Indian manufacturers/ vendors, under various package contracts, for various indigenized equipment are reviewed. Working documentation including Final Safety Analysis Reports for various SSCs was reviewed. Towards Indian scope of supply, various tendering/ procurement activities are in progress. Purchase Order (PO) is placed for EPC package of "Physical Protection System" and supply of "Instrument support stand".

## Operating Stations

In-Service Inspection (ISI) campaign of PHWR coolant Channel Pressure Tubes using BARCIS was carried out with integrated Inspection Heads at 220 MW and 540 MW Operating Stations. Upgradation of DG fire engines and electronic controllers was done for various operating stations. Upgradation of control system at various stations is under progress.

## Design, Development of CoNU fuel bundles having Cobalt element for 220 MWe PHWR

For getting low specific activity Cobalt-60 which



CoNU Fuel Bundle

is of more use in societal applications, a new 19 pin Cobalt Natural Uranium CoNU fuel bundle has been designed and fabricated along with BARC and NFC.

### General

Task Information Management (TIME) is customised & developed, which will act as Management Information System (MIS) tool and will help in generation of group wise monthly progress report on activities associated, against monthly baseline physical and financial targets.

### Information Technology

NPCIL HQ has implemented and established Secured Internet Access Facility. Using Application Virtualization technology, this solution achieves separation of Internet from NPCIL internal IT network. Internet based interface is developed and made live on NPCIL website for extending support to retirees for handling their service related grievances online. In addition, various need based applications are developed/ being developed.

### Simulator

Pilot versions of new operator information & guidance systems, namely, the Online Instrumented Channel CHFR (Critical Heat Flux Ratio) Computation System (OICCS) developed by NPCIL & the artificial intelligence based Online Event Identification System (OLEIS) developed by BARC, were validated in operating simulators in NPCIL.

Fuelling machine hydraulic systems were simulated as part of Phase-2 Fuel Handling System (FHS) simulations in the first 700 MWe Full Scope Replica Operator Training Simulator (FSTS) developed with KAPP-3 as the reference plant. The second 700 MWe FSTS with RAPP-7 as the reference plant has been fully commissioned at the Nuclear Training Centre (NTC) at RAPS along with replica hard panels & the latest soft operator interfaces like Electrical Supervisory Control and Data Acquisition (ESCALADA) & Operator Work Stations (OWSs). The validation of simulator lesson plans used for operator training is in progress. Preparation of Wiring Diagrams for the simulator control

room panel Input-Output (IO) systems of the third 700 MWe FSTS with GHAVP-1 as the reference plant, is nearing completion. Kaiga-1 & RAPS-3 Simulators have been upgraded with new improved plant system model software.

### R&D relating to PHWR

Eight column sections of 1.05 meter diameter each of heavy water upgrading tower were fabricated in BARC and delivered to NPCIL for its 700MWe capacity KAPS-3&4 units.



*Column Sections of Heavy Water upgrading tower loaded onto a trailer for dispatch*

A laser spectroscopy-based system has been developed for interference-free real time monitoring of heavy water leaks in PHWRs. Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) has been used for high sensitivity of detection and analysis. The HDO and H<sub>2</sub>O absorption lines in 1390 nm wavelength range are used to estimate the concentration of water and semi-heavy water in the air using this system. Field level testing of the instrument has been carried out in Dhruva research reactor and the test results showed very good correlation with the traditionally used tritium activity measurements.

In-service performance of the Zr-2.5%Nb Pressure Tube (PT) used in the Indian PHWR reactors are largely governed by the texture of the material. It is extremely important to determine the texture of the PTs reliably. Kearns parameter (f), the fraction of basal poles



*The 19-inch rack-mounted system for detection of heavy water in air installed in Dhruva facility*

oriented along a given reference direction, is one of the most widely used texture quantification parameter for Zr-alloys. Bulk texture of different generation of PTs used in Indian PHWRs have been determined using X-ray diffraction technique to arrive at  $\phi$ . It was observed that the newer generations of PTs (produced from forging + extrusion + single pilgering route) have higher degree of basal poles along the tube's transverse (circumferential) direction in comparison to the old route of fabrication (involving extrusion + double pilgering) of PT.

In the aftermath of Fukushima accident, greater emphasis has been laid towards developing alternate Accident Tolerant Fuel (ATF) cladding materials having significantly higher oxidation resistance. Materials Processing & Corrosion Engineering Division, BARC established a test facility for conducting oxidation tests on various fuel cladding materials in high temperature steam. Using this facility, the baseline data of high temperature steam oxidation kinetics of the existing fuel cladding materials produced in India (Zircaloy-4, Zircaloy-2, Zr-1Nb) in the temperature range of 700-1200 °C for durations ranging from 1 to 48 h has been generated. Hydrogen absorbed by the fuel cladding

during high temperature oxidation in steam at various temperatures is also currently being analysed.

Reactor Engineering Division, BARC has successfully demonstrated Pressure Tube Rolled Joint Detachment (PTRJD) technology for detaching 220 MWe PHWR pressure tube without cutting it from the end fitting. The technique works on the principle of induction heating of pressure tube from inside followed by fast cooling using liquid nitrogen through applying axial force on the end fitting.



*PTRJD tool of 220 MWe PHWRs*

A new Channels Health Assessment System (CHAS) which can accommodate 3-4 times additional probes for en-masse inspection of coolant channels of 700 MWe PHWRs and for minimising human intervention at the reactor face, was tested in BARC. The system provides many other advantages which are not available with the existing Fuelling Machine set up used for inspection operations. A comprehensive qualification programme to qualify the system along with inspection probes was planned in the next phase.

Large amplitude flaw indications that were identified during the inspection of coolant channels of 540 MWe PHWRs were characterised using Ultrasonic Time of Flight Diffraction technique. A methodology was developed using this technique for characterization of flaws having depth  $\geq 10\%$  in pressure tube wall and across closely spaced notches. It was successfully implemented for characterization of large amplitude flaw indications in coolant channels of TAPS 4.

A system for measuring defects in the inner surface of pressure tubes of 540 MWe Indian PHWR has been designed and developed in BARC. The 3D laser based Profiler system with its two-line lasers provides maximum amplification of identified flaws across the dimension of object in minimum time. The captured flaw profile of vertical sections along length of the replica is stitched to generate 3D profile of the flaw



**Renovation of Type E Quarters**

on object under test. The system is functional with a repeatability of 50 microns across variety of samples.

Eddy current based technique has been developed in BARC to measure calandria tube and poison injection unit gap in 540 MWe PHWRs. Due to the sagging of coolant channel, design gap of 49.5 mm reduces over a period of time. The system used for measuring this gap comprises of an inspection tool having a differentially connected eddy current probe, calibration fixture, software and eddy current instrument. The technique was implemented in TAPS-4.

A multichannel system for measuring strain and temperature in components of Primary Heat Transport of 700 MWe PHWR was developed jointly by BARC and NPCIL. It consists of a real time data acquisition & processing system, a remote monitoring system for



**User configurable multichannel strain and temperature measurement system for 700 MWe PHWRs**

configuration, data analysis and transducers (strain gauge & thermocouple). Testing of the system has been completed and is now ready for field trials.

BARC has developed a new 'ZIPTAS' (Zirconium-2.5% Pressure Tube Assessment) code for assessing the service fitness of pressure tubes of Indian PHWRs. The size of flaw for a given loading for the pressure tubes used in 220 MWe and 540 MWe Indian PHWRs has been evaluated using the newly-developed code.

Pressure tubes are periodically subjected to Post Irradiation Examination (PIE) inside hot cell to assess their in-reactor performance. The current generation PHWRs use indigenously manufactured pressure tubes made from quadruple melted Zr-2.5% Nb alloy. A pressure tube from TAPS-4 which was made out of this alloy was subjected to PIE to examine fracture toughness, delayed hydride cracking velocity, hydrogen pick-up rate, extent of oxidation. The results confirmed that these tubes are expected to work satisfactorily for their designed life.

PIE of two fuel bundles discharged from the core of TAPS 3&4 540 MWe PHWRs was done inside the hotcell. Visual inspection, laser profilometry, gamma spectrometry and scanning, fission gas analysis, metallography and ring tension test of the fuel bundles confirmed that there was no misalignment in bearing pads, no undesired swelling of fuel pins, burn-up contribution for fuel pins and several other parameters were found to be on expected lines.

PIE of calandria tube from KAPS-1 PHWR was carried out for the first time. Results from visual examination of both inner and outer diameter of the tube surface as well as the metallography studies indicate satisfactory performance.

Indigenous database on PHWR clad material under LOCA conditions will cater to the regulatory requirements of re-visiting the fuel failure criteria. During LOCA, temperature and fission gas pressure inside the fuel pin may lead to ballooning and burst, and oxidation embrittlement which may severely affect the microstructure and mechanical properties of the clad. High temperature oxidation kinetics of Zircaloy-4 and its

response to thermal shock, ballooning-burst behaviour of burnup simulated Zircaloy-4 cladding were carried out to understand the safety of fuel pins under LOCA condition.

## R&D relating to LWR

A compact unit for measuring the rate of change in temperature of coolant has been developed in BARC. The unit consists of high resolution ADC, an FPGA for data acquisition, averaging and concurrent processing.

The in-core neutron flux mapping system in a Pressurized Water Reactor provides information on the neutron flux distribution in the reactor core at select locations by means of movable detectors. These detector cables run through guide tubes known as Thimbles, which are long tubular components of approximately 4 meters long. A stringent process control system was worked out for manufacturing 11 numbers of Thimbles.



*Source & Detector (S&D) Thimble  
for P4 Cold Facility*

Group diffusion equations and coarse mesh finite difference scheme was used to develop 3D space-time kinetics model for real-time transient response simulations of LWR with hexagonal lattice. The model was configured using physics and thermal hydraulics data of IPWR.

Over the years, extensive experimental investigations have been carried out to characterize the mechanical properties of Zr-2.5Nb pressure tube materials. Data obtained from different studies have been compiled to generate a comprehensive database

on tensile strength, fracture toughness and creep data of different generations of Zr-2.5Nb pressure tube material used in Indian Pressurized Heavy Water Reactors.

Fission Counter (FC) indigenously made from 1S-Aluminum, coated with SNM and having a sensitivity of 0.6CPS/nv has been developed in BARC. FC measures neutron flux under high gamma field during special start-up conditions of the reactor. The performance of the FC is comparable to that of imported detectors.

Various out-of-core reactor components from different nuclear reactors were investigated for failure analysis. Root cause of failure was established through metallography studies, chemical analysis and micro-hardness measurement in a detailed manner. These results confirmed that the nature of cracking in weld joint of TAPS-1 BWR was on account of intergranular stress corrosion cracking. In RAPS-2 PHWR, investigations confirmed the leak in delayed neutron monitoring tube was due to transgranular stress corrosion cracking propagated by Chlorine present on the OD surface. Eddy current based non-destructive testing technique proved that the multiple axial cracks observed on select Control Protection Safety Absorber Rods of KKNPP-1 was due to intergranular stress corrosion cracking.





*Computer Consoles of DDCS*

# **CHAPTER 2**

## **NUCLEAR POWER PROGRAMME STAGE-II**



***CAAS panels undergoing burn-in test  
at ECIL facility in Hyderabad***

## FAST REACTORS

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

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

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

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

### Prototype Fast Breeder 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 Prototype Fast Breeder Reactor (PFBR) at Kalpakkam**

Bharatiya Nabhiya 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:

Based on the experience gained from the Large Rotatable Plug (LRP) refurbishment activities carried out earlier and towards design standardisation, similar modification was carried out in the Small Rotatable Plug (SRP) bearings. The bearing ball design configuration has been modified from the existing exclusive load balls arrangement to load and spacer balls arrangement to improve its high temperature performance. The bearing performance after refurbishment works was found to be satisfactory. The inflatable and backup seals which are used as primary and secondary leak-resistant barriers in the annular spaces of both SRP & LRP were replaced as part of maintenance practice.

The rotor vibration analysis of the pump shaft was carried out and it was found that the existing clearance was well within the limits. However, as an abundant caution and following the international practice, the radial clearances of labyrinth assembly of one of the Secondary Sodium Pump was increased by carrying out partial dismantling of the pump assembly. Based on the operational experience of Secondary Sodium Pump, the labyrinth of one of the Primary Sodium Pumps were removed from the pump assembly and installed back in position after machining. During this process, the Eddy Current Flow Meter (ECFM) sensor used to measure the sodium flow in the pump was removed for design modification towards improved sealing arrangement and the same was installed back in position.

The trailing cable system arrangement which supports power / control cables during plug rotation had undergone few modifications. The trailing cable post was moved from its position for replacement of inflatable seals of rotatable plugs and the dis-connectable junction boxes were introduced in the trailing cable

system to facilitate for easy removal of the post during seal replacement.

The entire Fuel Handling system including its major components is being commissioned and integrated testing is in progress. Reactor Core Viewing System (RCVS) a remote visual examination device was deployed into the core to inspect the reactor internals. Based on the inspection trials, manual entry was made into the hot pool to carry out visual inspection during Transfer Arm operation to ensure that all design intents are met and also to inspect other core handling components.

In-Service Inspection vehicle (DISHA) which is used for monitoring the dissimilar weld joints in reactor vessel through, the Anti-Convection Barrier plug was tested at test facility at room temperature.

The activities that are planned to be completed for the remaining period of this financial year i.e. from January 2022 to March 2022 include smoothening of sharp edges of the foot guide for all the 731 Sub-assemblies; Testing of In-Service Inspection vehicle (DISHA) at elevated temperature at test facility and deployment trials at pile; Preparatory works for preheating of Main Vessel prior to Sodium filling and Preparatory works for Integrated Leak Rate Test of Reactor Containment Building.

Primarily hot pool works are in progress towards modification of sub-assemblies prior to boxing up of Main vessel. After completion of modifications in sub-assemblies, 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.

## RESEARCH & DEVELOPMENT FOR FAST REACTORS

### Fast Breeder Test Reactor (FBTR)

At IGCAR, it is planned to raise FBTR power to its rated power of 40 Mwt., in the next irradiation campaign (30th), Regulatory review of the safety report of the proposed 40 Mwt core has been carried out.

Based on the same, clearance has been obtained for commencing the irradiation campaign. Four poison subassemblies (B4C enriched to 50% for B10) have been received. Also 28 fresh Mark-I fuel subassemblies were fabricated. The core changes are planned to be carried out in six steps considering addition of large number of fresh fuel subassemblies and poison subassemblies to the core. As a preparatory work for raising the reactor power, normalization of three tubes in each of four SG modules have been completed and all the mandatory qualification tests were carried out. SG was filled on sodium side and normalized. Refurbishing of main cooling tower has been completed. All the fills, drift eliminators and reflectors were replaced and strengthening of civil structure has been carried out. As a part of event analysis, for one of the events viz., loss of feed water flow through one loop SG, even though there is no safety concern, automatic trip is not available to shut down the reactor. Hence an additional trip parameter based on reactor inlet sodium temperature high was incorporated after completing necessary regulatory review and approval. In addition, some of the sodium leak detectors in primary sodium purification cabin which were giving spurious alarms were rectified. Also, all the maintenance works related to raising reactor power such as cleaning of tubes of main & dump condenser, condensate cooler and turbine oil cooler have been completed.

Major surveillance tests such as biennial RCB leak rate test in “as-is-where-is condition”, reactor vessel internal inspection, replacement of RCB filter banks and efficiency testing have been completed.

After completing the necessary core changes, reactor power will be raised to its rated power towards the end of February 2022.

The burn-up limit for FBTR Mk-I Fuel Sub-Assembly (FSA), which is irradiated at a high linear heat rating of 400 W/cm and high sodium inlet temperature was estimated through thermo-mechanical modelling to be approximately 100 GWd/t. PIE on one such subassembly is being carried out to explore feasibility of extending burn-up beyond this value. X-ray radiography of irradiated fuel pins has enabled characterization of stack length and pellet to pellet/clad gaps.

## R&D relating to PFBR

### Technical Support Related to PFBR Commissioning

#### Performance Evaluation of Modified Annular Linear Induction Pump of PFBR Secondary Sodium Loops

The secondary sodium fill and drain circuit (SSFDC) of PFBR has an Annular Linear Induction Pump (ALIP) of capacity 170 m<sup>3</sup>/h for circulating sodium. Design modifications in the pump internal support arrangement were carried out to make the pump more robust, to withstand vibration loads and differential thermal expansion during transient conditions. The performance of the ALIP was evaluated experimentally and various characteristics like the head vs flow, input power vs flow and efficiency vs flow were obtained. The vibration was measured using high-temperature piezoelectric transducers and was found to be within acceptable limits. The experimental performance evaluation in sodium loop at various voltages and flow rates has established that the modified design of the pump has the capability to meet the requirements of SSFDC of PFBR.

#### Manufacture of Reactor Grade Back-up Seal in Silicone and Demonstration of in-situ joining

Back-up seal is an elastomeric seal of customized shape used in the support arrangement of PFBR rotatable plugs. The seal is fixed to the seal holder



**Test Seal with In-Situ Joint**

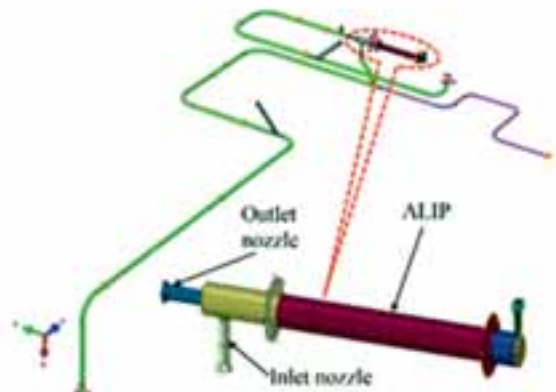
and the sealing is achieved by pressing the seal holder to the required amount, which in turn presses the seal. These are extruded seals and the seal ends are joined to form a ring, prior to fixing to the seal holder. 20 m length of seal was successfully extruded at shop and was successfully joined in-situ. The required seal material properties, seal dimensions as well as the joint splice strength were verified to be meeting the requirements. The establishment of in-situ joining technology simplifies replacement of the seal in the reactor.

#### Vibration analysis of Primary Sodium Purification Circuit Annular Linear Induction Pump

Annular Linear Induction Pump (ALIP) of 50 m<sup>3</sup>/h capacity is used in Primary Sodium Purification Circuit (PSPC). The high cycle fatigue due to flow induced vibration and electromagnetic induced forces



**20 m Length Extruded Seal**



**PSPC Piping Layout with ALIP**

at the stress concentration zones in ALIP was analysed. Acceleration time histories at different locations of ALIP were taken from measured vibration data at 450°C during pump tests in sodium loop. The stresses were verified to be well within endurance limit ensuring structural integrity.

### Design of Future FBR

#### Sizing of Reactor Assembly for 500 MWe FBRs meeting the Revised Safety Criteria

Beyond PFBR, it is planned to construct six more MOX fuelled sodium-cooled fast breeder reactors with improved safety and economy meeting the revised AERB safety criteria. The first twin unit (FBR 1&2) will be located at Kalpakkam. The design of FBR 1&2 is improved by incorporating the experiences from design, R&D, safety review, construction and commissioning of PFBR. Review of conceptual design of future FBRs was done with the objective of making essential design changes w.r.t. PFBR to meet the revised safety criteria. Physics design of 500 MWe core was carried out incorporating the additional safety provision of Hydraulically Suspended Absorber Rods (HSAR). Due to the provisions of HSAR and Stroke Limiting Device (SLD) in CSRDM, both Untripped Transient Overpower (UTOP) & Untripped Loss of Flow (ULOF) are avoided thereby practically eliminating the core disruptive accident. The sizing of reactor assembly was carried out and the main vessel diameter is arrived as 13.8 m. The height of the reactor assembly was also worked out as 15.2 m against 15 m in PFBR.

### Structural Mechanics & Dynamic Studies

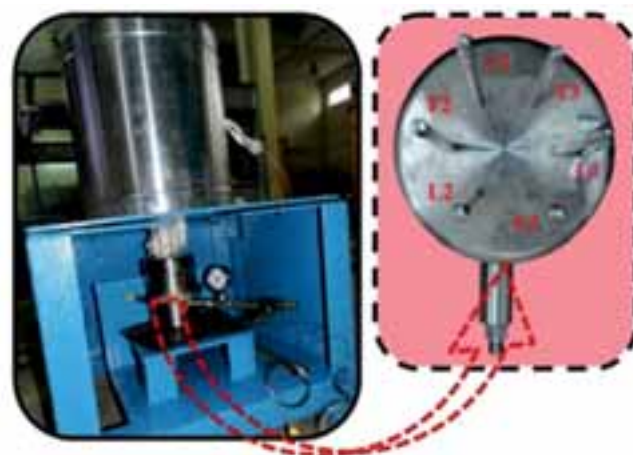
#### Seismic Integrity Assessment of Free-Standing Lead Wall Assembly by Shake Table Testing

In DFRP Lead Wall assembly, lead bricks are stacked with interlock arrangement. Shake table tests were performed to understand the dynamics of lead wall in a generalized manner to arrive an optimum design of the lead wall assembly, and the stacking arrangement to prevent the toppling of the lead bricks under different seismic excitation conditions. The integrity of the wall was checked for three different wall heights by

measuring the displacement, acceleration and strain on the structure. In order to find the generalized response, four different input excitations corresponding to USNRC Design Response Spectra (DRS); EI Centro record from the 1940 Imperial Valley earthquake; Site specific Review Based Ground Motion (RBGM) of Kalpakkam and Floor response spectra at an elevation +4.75m of DFRP respectively were used in this study. The test results have shown that presence of intermediate groove plates have helped in achieving a significant reduction in the rocking behaviour of the bricks even under strong excitation levels (PGA > 0.4g of tri-axial wave motion corresponding to USNRC spectra). Finally, the integrity is also checked under site specific floor response spectra at the prescribed elevation of the wall demonstrating seismic capacity of the lead wall for design and beyond design basis earthquake loads.

#### Qualification of Laser-Welded Fuel Pin End Plug Joint through High-Temperature Testing

The Fuel Sub-Assemblies (FSA) in PFBR houses 217 fuel pins. The fuel clad is a cylindrical tube surrounding the fuel column and is closed on both ends by end plugs. The material of construction of clad tube is 20% CW D9 alloy (15Cr-15Ni-Mo-Ti-Si), and that of the end plug is SS 316 LN. The clad tube and end plugs are presently joined by TIG welding process. Advanced Fuel Fabrication Facility (AFFF) is developing laser welding technique as an alternate process. As part of qualification tests, laser-welded clad-end plug samples were subjected to out-pile qualification tests and were found to be meeting the requirements.



**Out-pile qualification tests**

## Vibration measurements in Demonstration Fuel Reprocessing Plant Contactor cells

In Demonstration Fuel Reprocessing Plant (DFRP), eight banks of Centrifugal Extractors (CE) are employed in the contactor cell for the solvent extraction and stripping. Vibration measurements were carried out to troubleshoot the source of high noise in the contactor cell during commissioning. Measurements showed large vibration (23 mm/s) in the glass windows of the cell during operation of CE. Analysis of the results indicated the inadequacy of supports in the cells. The supporting structure was reinforced and the system operated after the modifications. Vibration measurements of the modified system showed significant reduction in vibration (2.2 mm/s)



**CE stage assembly**



**Experimental Setup**

## Sodium ejection through top shield platform of PFBR under hypothetical core disruptive accident

Simulation studies on ejection of sodium through top shield platform of PFBR under Hypothetical Core Disruptive Accident (HCDA) were carried out in an experimental facility simulating roof slab configuration. Sodium leak experiments were carried out at HCDA conditions (550°C and 2.4 bar). Experimental results revealed that the amount of sodium ejected out was found to be very less (290 g) as compared to estimated amount of 1.56 kg. The temperature of ejected sodium at the leak path was found to be about 140°C and no combustion of ejected sodium was observed.



**Experimental Setup for response time evaluation of core temperature probe**

## Response Time Evaluation of Core Temperature Monitoring Probe of PFBR

Response time of core temperature probe containing duplex thermocouples with thermowell was evaluated in a sodium loop simulating the actual sodium flow and temperature transients envisaged in PFBR core with respect to TC position in thermowell. Experimental results revealed that at 550°C and sodium flow velocity of 7 m/s, the response of the probe for a temperature gradient of 10°C is within acceptable limits ( $6 \pm 2$ s).

## Studies on sodium boiling

Experimental Investigation of boiling phenomena in a fuel subassembly of Sodium cooled Fast Reactor was carried out in static sodium. Quartz insulated cartridge type Kanthal heating element was



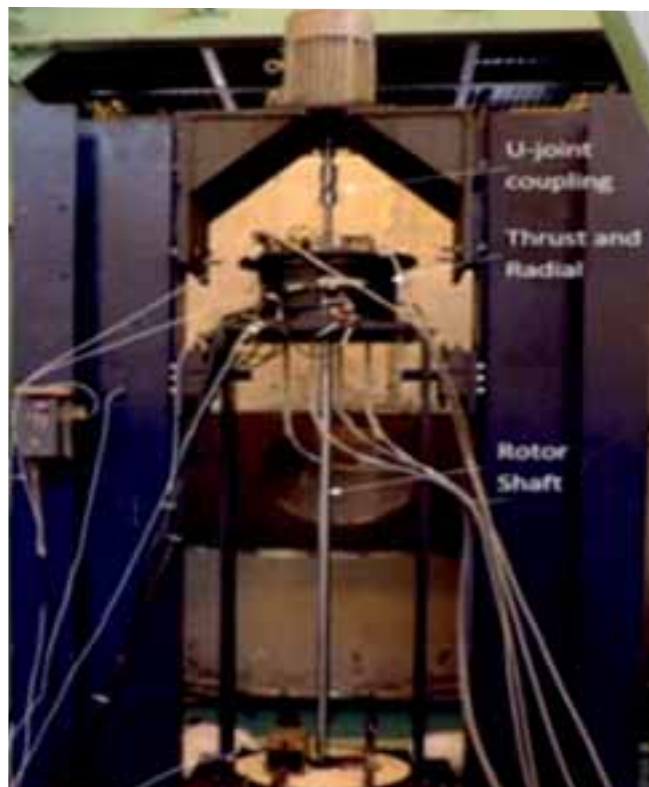
**Sodium Boiling setup with X-ray imaging system**

used for heating sodium to its boiling point ( $892^{\circ}\text{C}$ ). Sodium boiling phenomenon was successfully captured at 30 fps with  $400\ \mu\text{m}$  resolution through A 450 kV X-ray imaging system and a digital flat panel detector. Boiling parameters such as bubble nucleation site densities, departure diameters and frequencies were obtained by image processing.

## R&D on FBRs

### Studies on Performance of Active Magnetic Bearing

Centrifugal sodium pumps are used to circulate liquid sodium coolant in the primary and secondary circuits of fast reactors. The pump rotor is supported by conventional oil lubricated bearings at the top and by hydrostatic sodium pressurised bearing at the bottom. Active Magnetic Bearings (AMB) are oil free substitute for the top oil lubricated bearings as they eliminate the risk of oil leak into the primary sodium. As part of the ongoing work on developing oil free bearings and seals for main coolant pumps of future FBR's, collaborative work was done with M/s CSIR-NAL, Bangalore to study the effect of pump inclination on AMB performance. A scaled down model of the primary pump rotor was designed and fabricated and operated at the expected inclination to study the effect of pump rotor inclination on the performance of AMB. The dynamically similar rotor is supported by thrust and radial AMB at the top



**Active Magnetic Bearing Test Rig**



**Frozen seal sodium service gate valves of DN 100 and DN 200 size**

and by a radial roller bearing at the bottom. The thrust AMB consists of four independent actuator pairs, one per quadrant of the thrust disk. The radial AMB consists of an 8 pole heteropolar stator arrangement. The

performance of AMB was checked in static condition and for rated speed (590 rpm) in vertical condition as well as at inclination of 0.4 deg and found to be satisfactory as per ISO 14839.

## Indigenization of Sodium service Frozen seal Gate Valves

Frozen seal gate valves are being used in the large size sodium lines in fast breeder reactors. Primary sealing between the stationary parts and the moving actuator parts of the valve is achieved by a freeze seal in these types of valves. Low melting point of the service fluid, here liquid sodium is utilised for this purpose. A secondary seal in the form of gland packing is provided. Earlier such valves were imported. Two frozen seal gate valves with 100mm and 200mm nominal sizes for sodium service were designed and manufactured in India. These made in India valves are with almost half the height of imported valves and with considerably reduced cost.

## Upgradation of Distributed Digital Control System (DDCS) in Steam Generator Test Facility (SGTF)

Steam Generator Test Facility (SGTF) was constructed in 2004 and many experiments related to steam generator have been successfully completed. Due to obsolescence, the instrumentation system was upgraded with state-of-the-art indigenously developed Programmable Logic Controller (PLC) based DDCS developed by ECIL. The main advantages of the system are customised leak detector modules and analog



**Computer Consoles of DDCS**



**PLC panels of DDCS**

modules (mV) for flow signals which are not available in commercial systems. The three sub systems, namely- Interlock system, Data Acquisition cum heater Control System (DACS) and Leak Detection system (LD) form part of DDCS with Computer consoles and PLC panels. The salient features of PLCs are increased input/output (I/O) capability with Remote I/O (RIO) configuration and integrated signal conditioning functionality in I/O modules. The features provided in DACS are configurable capability, failsafe operation and display feature in user interface. The innovative method of leak detection system was implemented to detect leak with contact resistance up to 2Kohms. The installation and commissioning of DDCS has been completed successfully.

## STUDIES ON MATERIALS FOR FBRs

### Corrosion studies on FBR materials

High temperature corrosion studies on uncoated, zinc and manganese phosphate coated carbon steel were carried out for baffle plate of heater vessel in the hot argon supply system of inclined fuel transfer machine of PFBR.

### Molten sodium corrosion of laser surface remelted Ytria-stabilized zirconia thermal barrier coatings for FBR core catcher applications

Liquid-metal corrosion in molten sodium is a significant issue to Thermal Barrier Coatings (TBCs)

proposed for in-core fast breeder reactor applications. The viability of plasma-sprayed Yttria-stabilized zirconia TBCs is investigated by microstructure re-engineering using Laser Surface Remelting (LSR).

### Effect of $^{10}\text{B}$ enrichment on the thermal properties of Boron carbide

As a part of the in-house material qualification programme, a systematic experimental investigation was carried out on high temperature thermodynamic and transport properties of  $\text{E-B}_4\text{C}$ . The experimentally measured values were critically analyzed and compared with the properties of imported 90%  $\text{E-B}_4\text{C}$  and natural  $\text{B}_4\text{C}$  to understand the effect of  $^{10}\text{B}$  enrichment on thermal properties.

## FBR - FRONT END FUEL CYCLE

A Computed Radiography (CR) scanner system has been developed at BARC for performing X-ray Gamma autoradiography (XGAR) of FBTR fuel pins during their fabrication. On account of high dose sensitivity of image plates used in CR technique, it takes shorter exposure time to scan the fuel pins. Previously, radiographic techniques-based approach was practised for carrying out XGAR of FBTR fuel pins, which was considered quite cumbersome.



**Computed Radiography Scanner System installed at BARC Radiometallurgy Division**

A Computerized version of Alarm Annunciation System (CAAS), which is easy to maintain and operate, has been developed for the Fast Breeder Test Reactor. The TPLC-32 platform based CAAS is a distributed multi-nodal system with seven nodes, each node consisting of two subsystems, which are hot-standby to each other. The system was manufactured at ECIL as



**CAAS panels undergoing burn-in test at ECIL facility in Hyderabad**

per design inputs from BARC, and is ready for final integration.

During the year, 02 new machines were commissioned for axial gamma scanning of fast reactor fuel assemblies. The in-built system software is equipped with new control features that facilitate multi-axial and multi-directional scanning; enhanced data acquisition and quick data processing.

Scrap and rejected pellets generated during the fabrication of FBTR (Uranium-Plutonium mixed carbide) fuel pins are commonly recycled and reused. During recycling, the rejected carbide fuel is converted into oxide form using a mixture of oxygen and argon. Oxygen supply for this purpose is primarily met through gas cylinders, whose supply, however, dwindled during the second wave of COVID-19. To mitigate the potential shortfall in oxygen supply, commercially available oxygen concentrator of 10 LPM capacity at 8-10 psi pressure was used to produce up to 95% pure oxygen for recycling of fuel pellets. The quality of oxidation achieved through oxygen concentrator is same as that obtained using oxygen from industrial cylinders.

## FBR- BACK END FUEL CYCLE

### R&D on Fast Reactor Fuel Reprocessing

Compact Reprocessing facility for Advanced fuels of Lead cells (CORAL) continued to operate with an

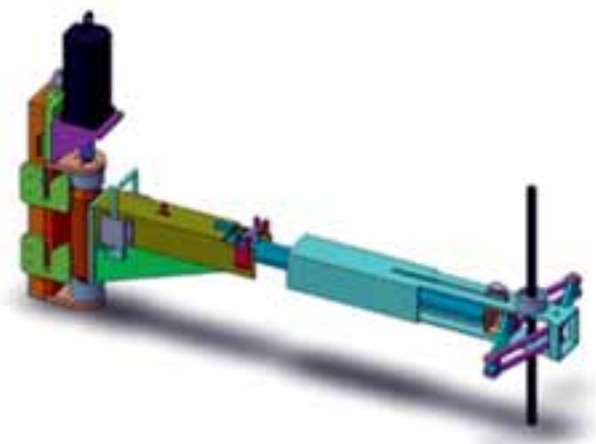
excellent recovery factor and radiation safety record. The 60th campaign was successfully completed. Constant surveillance was ensured in RTC shifts even during the lockdown period and the plant continued to operate safely.

At the Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP), commissioning trials with Acid-TBP, which is a major milestone towards hot commissioning of DFRP have been completed. The performance testing of all the processes and auxiliary systems have been completed and validated. Necessary documents pertaining to the acid-TBP runs, have been submitted to AERB and regulatory consent is being sought for starting the cold runs with Uranium. A first of its kind, remote sampling system, which was

developed in house at RpG, has been installed in DFRP and successfully commissioned. Leak testing of five hot-cells has been completed, and all of them were found to meet the prescribed leak tightness. Towards the preparation of process cells for the hot commissioning, the major task of pickling and passivation of all the liners as well as in-cell equipment and piping has been completed. A first of its kind, WiFi based overhead tank level monitoring system has also been installed to ensure the availability of the fire hydrant and to announce the same in the Control Room, remotely.

A passive three stage air sparged solvent wash system was designed, fabricated and commissioned in DFRP contactor cells after exhaustive hydraulic and mass transfer studies. This equipment would be used in the clean-up of the spent solvent.

Development of new equipment and processes for the future reprocessing plants and also R&D towards aqueous reprocessing of metallic fuel are being pursued ardently. The process parameters for the catalytic generation of U(IV) using both hydrazine and hydrogen as reducing agents with commercial Pt/SiO<sub>2</sub> catalyst has been optimized. Advanced platinum-based catalysts were also developed for U(VI) reduction and they are being evaluated for their performance under typical PUREX process conditions. A new software for simulating the PUREX solvent extraction profiles in the extractor banks was developed in house and its performance has been evaluated. It was found to perform better than the currently available commercial software. Many state-of-the-art radiation and chemical resistant polymeric composite materials with the requisite mechanical strength were developed in the form of finished products. They were designed, fabricated, performance evaluated before mounting / commissioning at site. These include EPDM (Ethylene Propylene Diene Monomer) based seals for lubrication lines, reagent lines, cables of CE, lighting cables and sampling station; Polyimide based sleeves for CE speed sensing cables; PEEK (Poly Ether Ether Ketone) based dampers for reducing the wear and tear in sampling stations and PEEK based filter material for filtration of the suspensions from spent fuel dissolver solution.



**New remote sampling system developed for DFRP**



**View of new solvent wash equipment**

Many equipment including the in-cell cranes have been performance tested and were qualified to serve their intended purpose.

A comprehensive investigation has been made to study the thermal stability and oxidation kinetics of PyG in simulated air and steam. It is found that higher pyrolysis temperature in CVD process resulted in highly oxidation resistant PyG.

## Fast Reactor Fuel Cycle Facility

The Blanket pin magazine is developed for storage and transfer of highly radioactive PFBR Blanket subassemblies at Core Subassembly Plant of Fast reactor Fuel Cycle Facility. The Blanket Pin Magazines can be directly stored in Storage Vault, and will be transferred in Modular shields. Blanket Pin Magazines are made leak tight to avoid ingress of Water and Dust Particles. Shock absorbing springs are provided at both ends, to prevent movement and damage during transfer or storage. High precision and accuracies are maintained while manufacturing pin magazines. The straightness of the Pin Magazines has been maintained within 1 mm. The Blanket pin magazines are successfully tested at Vault storage site.



**Blanket Pin Magazine**

Fast Reactor Facility (FRF) has received from BHAVINI the annualised requirements of 1st Re-load/2nd Core and subsequent replacement core Sub-Assemblies (SAs) for PFBR, for which the activities are going on.

Design approvals necessary for the construction of FRP have been provided regularly, to FRFCF, the construction of Waste Tank Farm (WTF) of Fuel Reprocessing Plant at Fast Reactor Fuel Cycle Facility (FRFCF) has been taken to completion.

Construction of the head end cells, process cells and reconversion laboratory are in progress.

## REPAIR & INSPECTION TECHNOLOGIES

### Development / applications of NDE techniques for FBR and associated fuel cycle programme

Sweep Frequency Eddy Current (SFEC), X-ray imaging under magnification and Infrared thermal imaging techniques have been developed for enhanced characterization of voids in sodium bonded metallic fuel pins. Room temperature demonstration of NDE inspection of roof slab dissimilar weld has been successfully completed. Industrial videoscope and in-situ metallography technique have been implemented for characterization of surface features in various critical components.

Ultrasonic mapping of wall thickness of the dissolver vessel of Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP) has been completed as part of Pre-Service Inspection (PSI) campaign.

An advanced Phased Array Ultrasonic Technique (PAUT) has been implemented for improved visualization of the morphologies of pits formed in the radioactive liquid effluent tanks at BHAVINI.

### Examination fuel subassembly irradiated at high linear power in Radio-Metallurgy Laboratory (RML) hot cells

A Mark-I mixed carbide fuel subassembly (FSA) irradiated at high linear heat rating of 400 W/cm, which has seen a burn-up of 105 GWd/t and higher coolant (sodium) inlet temperature was transferred to RML hot cells from FBTR for comprehensive Post Irradiation Examination (PIE). Remote dimensional measurement of hexagonal sheath, laser cutting and extraction of fuel pins, length increase measurement of fuel pins and gamma spectrometry of a few selected pins have been completed. Preliminary analysis of metrology of wrapper and fuel pins indicate dilation and strains to be well within available margins. Improvements in X-ray radiography technique used for the fuel pins has

resulted in significant quality improvement due to reduction of gamma fogging. Other non-destructive examinations are in progress.

### **Micro-analytical characterization facility in RML**

A micro-analytical characterization facility for the PIE of irradiated fuel and structural material specimens is being established in RML for augmentation of its PIE capabilities. Instrument for microstructural and microchemical characterisation has been commissioned with facility for leak-tight transfer of irradiated specimens prepared in RML concrete hot cells.

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

Effective field deployable Quality Assurance, NDE & inspection practices has been developed and implemented during fabrication of various Systems, Structures and Components in line with specification and stipulated codal requirements for PFBR, DFRP, FRFCF etc., Development of Ultrasonic testing procedure for inspection of LRP Bearing balls, Visual inspection using Videomagescope of Fuel Subassemblies, Optical inspection of fuel sub-assemblies were performed for PFBR. Radiographic inspection of Steam Generator (SG) modules pipe butt welds, Orifice sub-assemblies for SG sub-header, flow breaker to Orifice weld joints and for detecting choking in Primary sodium tank nozzle pertaining to FBTR and Electro Chemical Hydrogen Meter (ECHM) probes, ALIP pump modification works for PFBR. Radiographic inspection of various sodium loops and components in Sodium Technology Complex (STC) in IGCAR. Ultrasonic examination of Foot to Hexcan welds for fuel sub-assemblies for PFBR as per approved procedure. Immersion ultrasonic testing of Ni-B coating on stainless steel substrate and Alloy 625 over lay on Ferritic steel substrate was completed. Immersion ultrasonic testing of 30 m length SG tubes made up of Modified 9Cr-1 Mo for Future FBRs at NFC. Helium Mass Spectrometer Leak testing of CRDM translation bellows for FBTR, ECHM and sodium sampler for MC & MFCG, creep test chamber bellows for MMG have been successfully completed. QA, NDE & stage inspection activities

during fabrication of CSRDM, DSRDM at MTAR, fabrication of Cylindrical Tanks, Annular tanks for FRFCF and In-cell modification works of DFRP have completed as per approved Quality Assurance Plan.

## **HEALTH, SAFETY & ENVIRONMENT**

### **Radiological and Industrial Safety**

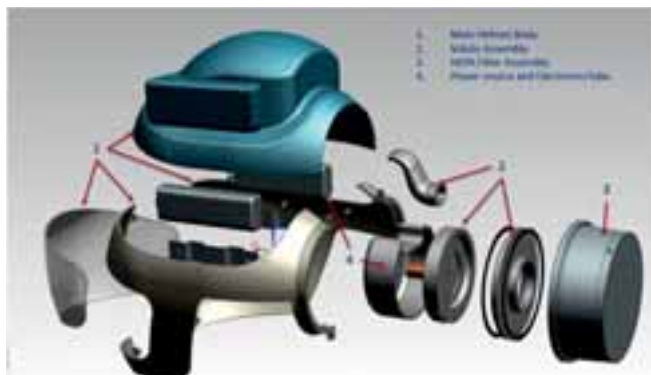
Health Physics units in all radioactive facilities of IGCAR provide uninterrupted radiological surveillance in round the clock. Health physicists are carrying out radiation surveys, radioactivity monitoring and measurement of radiation exposure on day-to-day operation as per AERB requirements. About 1200 radiation works are being monitored for radiation exposures (in-vivo and in-vitro). Cumulative dose expenditure for all nuclear facilities in 2021 was 178 PmSv. Special HP surveillances were provided during maintenance of sodium leak detectors in primary purification circuits, decontamination of guide tubes and assembling of PFBR fuel subassemblies at FBTR. In KAMINI, HP surveillances were provided during irradiation of samples at PFTS, thimble, DT1 and south beam tube at various reactor power levels between 8.2 Wt and 20 kWt.

Four reprocessing campaigns were carried out in CORAL with a collective dose of 140 PmSv. No occupational radiation worker exceeded the monthly, quarterly or annual dose limit. The effluent release through stack was less than 1% of authorised limit. Training to plant personnel on radiation protection was provided. 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 facilities at IGCAR. Industrial safety training was provided to young officers/ engineers and supervisors of IGCAR. Safety induction training (605 nos.), Height pass test & training (256 nos.) 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, periodic sanitation of buildings, CISF main gates, buses and all department & hired light vehicles were executed.

At BARC, a prototypes of Powered Air Purifying Respirator (PAPR) meant for occupational workers handling nuclear materials were developed by BARC based on 3-D printing technology. The design aspects of an optimized PAPR having four major modules, namely Main Helmet Body, Volute Assembly, HEPA Filter Assembly and Power Source and Electronics Prototype was completed and has been readied for batch scale production. PAPRs can also be deployed in the operations of pharmaceuticals, chemicals and healthcare sectors.



**Powered Air Purifying Respirator**

## **R&D in radiological safety, dosimetry, environmental monitoring and radiological services**

Experimental study on sodium combustion aerosol distribution in a large volume Mini Sodium (MINA) fire facility ( $140 \text{ m}^3$ ) was conducted with the aim to ascertain evolution of spatio-temporal and physico-chemical characteristics of aerosol concentration and size distribution and to develop/ validate the codes for the evolution of spatio-temporal distribution of aerosols inside the confined volume followed by settling. The study is conducted by keeping sodium aerosol concentration nearly  $4 \text{ g/m}^3$  simulating bottled-up condition of Reactor Containment Building (RCB) under Core Disruptive Accident. The maximum average suspended aerosols concentration at the bottom,

middle and top elevation is  $4.01 \pm 1.08$ ,  $2.42 \pm 0.52$  and  $2.87 \pm 0.92 \text{ g/m}^3$ , respectively. Based on the aerosol's concentration measurement, the aerosols distribution is not well mixed entire periods.

Continuous coastal environmental and ecological monitoring was carried out for water quality (physicochemical properties, nutrients, and photosynthetic pigments), sediment quality (composition, heavy metal content), plankton diversity (phyto- and zoo-plankton) and background radiation measurements for water and sediment. A bloom of *Proboscia alata* (diatom) was observed and the bloom species densities were in the range of  $1.5\text{-}2.1 \times 10^4$  individuals per litre. Apart from the bloom observations, annual range of all the parameters in the water sample are found to in the range of values observed in previous study. NORM values for water samples were found to be BDL for all the seasons.



*Alkaline Water Electrolyzer plant  
with gas purification system*

# **CHAPTER 3**

## **NUCLEAR POWER PROGRAMME STAGE-III**



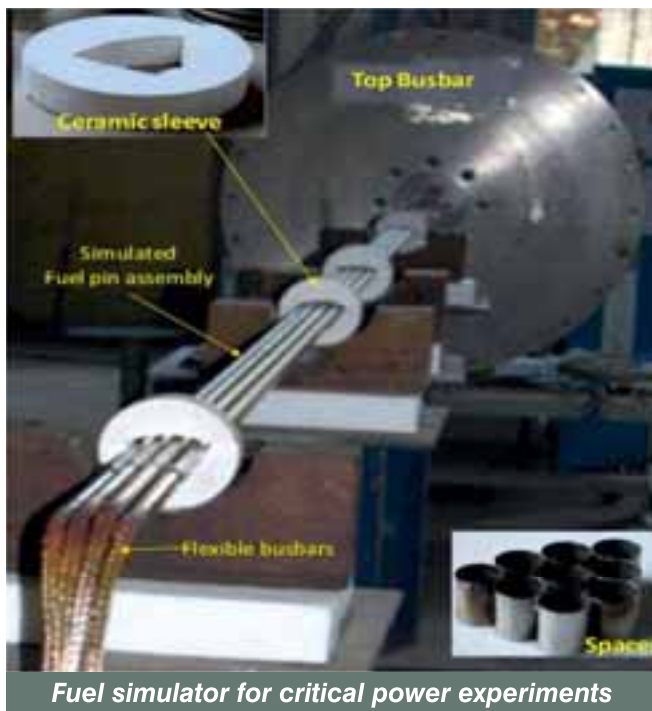
*Pb-Li Extractor Loop showing high temperature electromagnetic pump*

## 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

The critical power of AHWR fuel bundle has been demonstrated experimentally using a full-scale simulated fuel rod bundle under reactor operating conditions. The data obtained from the experiments was used to estimate critical power correlation of AHWR bundle design as well as its thermal margin.



An improved prediction method has been proposed for evaluating load bearing capacity of cracked dissimilar metal pipe weld between steam drum and down comer piping of AHWR as part of the studies done routinely for safety assessment of weld joints with defect.

A numerical simulation approach was used for evaluating load carrying capacity of concrete frames under seismic simulated loading conditions in shake table testing. A significant reduction in load carrying capacity was observed in case of corroded frames vis-a-vis the uncorroded frame.



**Crack pattern in Un-corroded (left) and Corroded (right) frames at failure**

A unique experiment for measuring the reactivity under different voiding fractions of High-Density Polyethylene (HDP) coolant was carried out in the AHWR Critical Facility at BARC. The experimental cluster consisted of seven pins of (Th, 1%Pu) MOX fuel whose dimensions were maintained same as that of AHWR type fuel pins. Experiments were performed with four different voiding conditions of 33%, 50%, 66 % and 100%. The maximum deviation in the predicted and measured critical heights for the various configurations

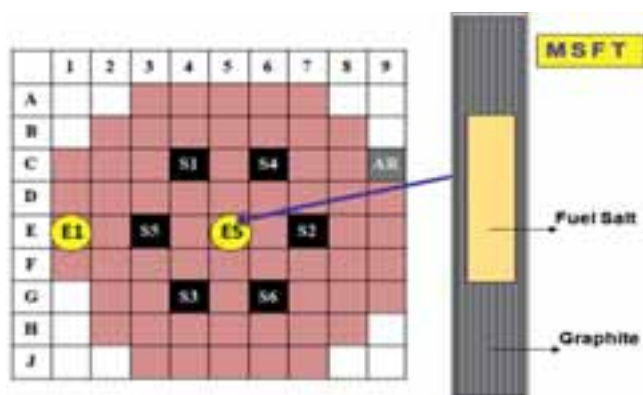


**High Density Polyethylene (HDP) coolant placed in different arrangements inside the cluster for different void fractions**

came about 0.23 mk in reactivity change. A very good agreement of this measurement with the modelling is another step-in code validation exercise and validation of AHWR physics design.

## THORIUM FUEL CYCLE

Pre-experimental analysis with 5.8Kg of fuel salt ( $\text{LiF-UF}_4$ ) to assess reactivity effects of introducing a Molten Salt Fuel Tube (MSFT) was carried out in the central and peripheral locations of the lattice arrangement at the AHWR Critical Facility. The levels of moderator were varied to achieve a definitive critical core with the fuel salt assembly. Efforts are in progress to estimate the quantum of tritium produced during the experiment.



*Schematic of the Molten Salt Fuel Tube (MSFT) in AHWR Critical Facility*

## KALPAKKAM MINI (KAMINI) REACTOR

The U-233 based Kalpakkam Mini Reactor (KAMINI) was available till October 2021 for neutron activation analysis, neutron radiography and testing of indigenously developed neutron detectors and a proposal for continuing KAMINI reactor operation with de-bonded fuel plates has been submitted for regulatory review and approval.

## OTHER THORIUM REACTOR SYSTEMS

### 5 MWth IMSBR Coolant Salt Circulating Pump (CSCP)

A vertical single stage pump of Ni-Mo-Cr-Ti alloy

make has been chosen as the Coolant Salt Circulating Pump (CSCP) for the experimental 5 MWth Indian Molten Salt Breeder Reactor. The set-up has been custom designed wherein the rotary assembly could be removed easily and can be subjected to inspection in a hot cell.

### Graphite Fuel Salt Interaction Facility (GFS-IF)

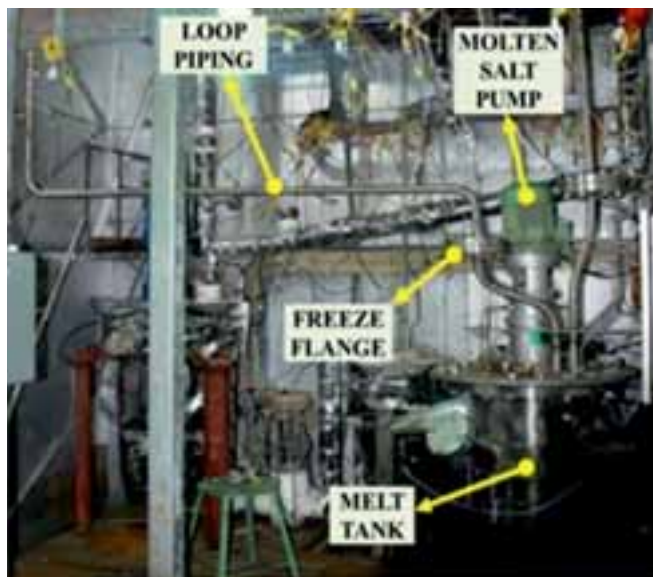
A Graphite Fuel Salt Interaction Facility (GFS-IF) for extensive study of interaction between graphite and molten fuel salt at the temperatures and pressure prescribed for the 5 MWth IMSBR has been established at the Molten Salt Breeder Reactor Long Term Test Facility (MSBRDF-LTTF) based at Vizag. Due to extreme sensitivity of molten salts to moisture and oxides, the facility was installed inside a negative pressure glove box.

### Design of Oscillating Cup Viscometer Mark 2 Version

An oscillating cup viscometer of Mark 2 Version is being developed for measuring the viscosity of molten salt of interest for IMSBR. The viscosity of the salt is determined by measuring the change in damping of free oscillations of the cup suspended from a wire both in presence of the sample and also without it. An electromagnet brake-based oscillation damping system has been included to allow faster reset of the system during its operation, which also functions as an alternate oscillation initiator. For measuring the oscillation parameters, a system based on reflection of laser onto a microprocessor-based photo-diode array has been developed. The Mark-1 version of the viscometer was successfully demonstrated earlier with surrogate samples.

### Forced Circulation Molten Salt Loop (FCMSL)

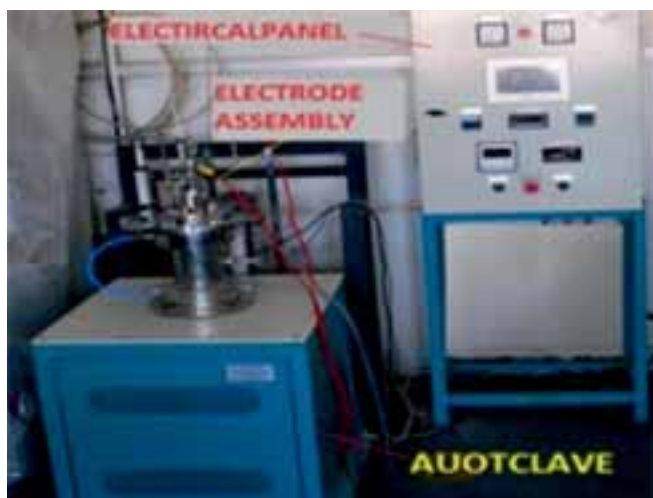
A Forced Circulation Molten Salt Loop (FCMSL) has been commissioned for the study of thermal-hydraulics of molten salts for MSBR. The instruments and components such as molten salt pump, freeze flange were designed for it. The design pressure and temperature of the loop are 5 bar and 565°C, respectively. The loop has been charged with 200 kg of Nitrate salt and operated successfully.



*Molten Salt Forced Circulation Molten Salt Loop (FCMSL)*

### Set-up for molten salt REDOX control and corrosion study

Two static high temperature systems - Auto dipping and Autoclave - have been commissioned in BARC for material testing and corrosion studies on high temperature systems, including Molten Salt Reactor. Electro chemical corrosion studies for developing of REDOX control techniques relevant to molten salt at high temperature were done at the autoclave system. The auto-dipping facility is designed to carry out corrosion studies in high temperature coolants by weight loss method. The maximum operating temperature and pressure will be 750°C and 0.5 bar, respectively.



*Autoclave for Molten Salt REDOX control studies*



*Auto dipping set up for corrosion studies*

## HYDROGEN ENERGY

### Cu-Cl thermochemical cycle for hydrogen production

Work on development of a 4-step Cu-Cl thermochemical cycle for hydrogen production was continued. The feasibility of all the four steps of the process - hydrolysis, thermolysis, electrolysis, and crystallization - was demonstrated at bench-scale. The membrane electrode assembly developed for electrolysis was found to perform satisfactorily for optimized process conditions.

### Compact Alkaline Water Electrolyzer Plant for producing Green Hydrogen

An additional Gas Purification Unit (GPU) was integrated with the Electrolyzer plant for production of ultra high purity grade Hydrogen. Process intensification was carried out on De-oxo bed system for mitigation of impurity in the product stream and back



*Alkaline Water Electrolyzer plant with gas purification system*

pressure regulators have been installed for improving pressure equalizing of the gas streams. The technology was transferred to public sector oil marketing companies HPCL & BPCL.

## MATERIALS AND TECHNOLOGIES RELATED TO FUSION REACTOR

### Lead-Lithium (Pb-Li) Extractor Loop

A test loop has been developed and installed for Hydrogen Isotope extraction studies from Lead Lithium (Pb-Li) eutectic at 450°C. The study will help in understanding hydrogen isotope behaviour in molten metal, which will be useful for future coolant and breeder for Test Blanket Module (TBM) in fusion reactor. The system consists of a recirculation loop with melting tank, electromagnetic pump, electromagnetic flow meter, structured packed column and gas extraction system.



*Pb-Li Extractor Loop showing high temperature electromagnetic pump*

### Aluminide coated P91 steel for fusion reactor applications

Pack aluminizing technique was employed for iron aluminide coating on P91 steel for TBM of fusion reactors. Iron aluminides have superior oxidation and corrosion resistance properties. Heat treatment of single phase  $\text{Fe}_2\text{Al}_5$  coated samples were performed in the temperature range of 600-750°C at varying times and the EDS scan results of the samples confirmed the formation of protective alumina layer.

### Metallic tungsten coating

Electrolysis using Direct current and Pulse current method with the eutectic composition of tungsten trioxide and sodium tungstate at 925°C was carried out for deposition of metallic bright, non-porous, adherent and uniform thickness tungsten coating on the initial barrier wall of storage vessel of fusion reactor. The deposited coating was characterized for its crystal structure, thickness uniformity, composition and top surface morphology. Further experiments to investigate coating bond-strength with the substrate, capability to deposit millimeter thick W coating are in progress.



*Newly installed production facility for  $^{177}\text{Lu}$ -PSMA  
under Advanced Facilities for Radiopharmaceuticals  
Production (AFRP) Project*

## CHAPTER 4

# APPLICATIONS OF ADVANCED TECHNOLOGIES AND RADIATION TECHNOLOGIES



*New rice variety -- Vikram TCR*

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 in Mumbai viz., Tata Memorial Hospital (TMH), the Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) and Centre for Cancer Epidemiology (CCE) in addition to new and upcoming cancer centres at Sangrur, Visakhapatnam, Mohali, Varanasi and Guwahati which provides Cancer Diagnostic and Treatment Services to the masses. It also engages in the programmes aimed towards Cancer awareness and its Prevention.

## RESEARCH REACTORS

### APSARA – Upgraded

Apsara-U reactor achieved its full rated power operation of 2 MW on October 8, 2021. The reactor was operated with high level of safety standards with an availability factor of 90% during the year. 44 irradiated cans comprising of various isotopes were delivered during the year. Feasibility of producing Neutron Transmutation Doped Silicon (NTD-Si) was understood through irradiation of silicon wafers and small size silicon ingots. Fabrication work on a turn table assembly for irradiation of larger size silicon ingots (150 mm



*Cherenkov radiation emanating from the core of Apsara-U*

diameter) is in advanced stage. Also, work has commenced on setting up of a neutron imaging and neutron depth profile experiment beamline.

### DHRUVA

Dhruva reactor operated at 70% availability factor during the year and produced radioisotopes for various applications, including 500 irradiated cans delivered to various users. A new adjustor rod tray section for producing Co-60 of high specific activity was completed. Irradiation of Antimony assembly for providing neutron source for light water reactor was commenced.

### CIRUS

Cirus reactor remained in 'Safe Storage' mode, for deferred decommissioning. A 100 Ci/batch I-131 processing facility in the reactor hall is in advanced stages of commissioning. The construction work on tritium-filled light source laboratory is currently under progress.



*The 100 Ci/batch I-131 processing facility in CIRUS reactor hall*

## ACCELERATORS

A preliminary baseline magnetic lattice of a 6 GeV electron storage ring with beam emittance 150 pm.rad and stored beam current 200 mA, has been designed to produce high brightness photon beam in the energy range upto 200 keV. Total 32 number of magnetic field free section of length 6 m each are provided to produce unprecedented photon beam brightness in the tunable energy range. In the lattice, total 224 number of dipole magnets, 512 quadrupoles are utilized to bend and focus the beam. The dipole magnet fields are kept below 0.6 T and with transverse gradient upto 40 T/m. The gradient in the quadrupoles is upto 80 T/m. Lattice studies reveals that, total 192 sextupole and 64 octupole magnets and their strengths are optimized to correct the chromatic aberrations resulted from beam energy error. Further studies related to error analysis in view of generating the magnet specifications are underway.

A five cell 650 MHz beta 0.92 niobium superconducting RF cavity has been successfully processed and tested for its performance qualification at 2 K using in-house developed facilities. Performance qualification of cavity was carried out at 2 K in the vertical test facility. The cavity achieved final accelerating gradient of 29 MV/m with low field quality factor of  $5 \times 10^{10}$ .



*RRCAT fabricated  $b=0.92$  650MHz bare cavities*



*Ti grade 2 Helium vessels for dressing*

RRCAT has fabricated and supplied 3 high beta ( $\beta=0.92$ ) 5-cell 650 MHz niobium bare SCRF cavities and their dressing components to Fermilab, under IIFC collaboration. Two bare cavities were processed and tested at RRCAT and third bare cavity was sent to Fermilab, USA. After baseline qualification, the bare cavities were cleared for dressing and were tested at 2 K in VTS (vertical test stand). After processing and testing, RRCAT's  $\beta=0.92$  650 MHz cavities have been qualified for PIP-II prototype cryomodule with required accelerating gradient and quality factor. The qualifying Eacc and Q0 for these cavities are 18.7 MV/m (with 10% tolerance) and  $4 \times 10^{10}$  (with 10% tolerance) respectively and all these cavities qualified for PIP-II prototype cryomodule. This is one of the major milestones of R&D phase of the project and is an important step of qualification of RRCAT fabrication facility.

A large magnetron sputtering deposition system, for catering to the need of thin film coatings of



**Magnetron sputtering deposition system with vacuum chamber installed for coating**



**Ti-Zr-V Non-evaporable Getter (NEG) coated vacuum chamber installed in ultimate vacuum test setup**

accelerator vacuum chambers, has been indigenously developed and deployed in ultra-high vacuum (UHV) lab. Vacuum chambers upto length of 3500 mm and cross-section dimension up to 290 mm can be coated using this system. This is unique facility of its kind in country and deposition of range of metals in elemental, alloy and compound form can be carried out using this system. Thin film deposition of Ti and Ti-Zr-V alloys have been successfully carried out so far using this system. Recently, thin layer deposition of Titanium and Ti-Zr-V alloys respectively to the ceramic and aluminum chamber for Indus-2, have been successfully done using this system.

A 25 kV, 6.5 A high frequency switched Capacitor Charging Power Supply (CCPS) for the linear



**25 kV, 6.5A CCPS along with 6.0 MW microwave system**

charging of PFN capacitors of 130 kV, 100 A, 300 Hz pulsed modulator has been designed, developed and qualified. The modulator is also integrated and tested with 6.0 MW S-Band klystron amplifier. An average RF power 20 kW has been extracted from the klystron-based microwave system. This development will pave the way for indigenous development of the crucial microwave technology.

A 10 MeV, 5 kW RF Linac of horizontal orientation has been readied at EBC Kharghar for irradiation of various industrial products. The subsystems of the accelerator such as electron gun, accelerating cavity, klystron-based RF source, electromagnets, vacuum system, beam extraction system have all been fabricated and are ready for beam trials.



**The RF electron Linac under commissioning at EBC**

The 6/4 MeV dual energy linac based X ray source was developed for the first time for cargo scanning application. The Linac was tested and integrated with all sub systems.

A new project for development of 30 MeV Linac for Radioactive Ion Beam and neutron time of flight experiments was proposed at BARC Vizag.

Development of two number of  $\pm 5A$ ,  $\pm 20V$  current-regulated, true-bipolar, 100ppm stability class power supplies have been done at VECC. It has been further installed and commissioned for the steering magnets for the e-LINAC system of RIB Facility. A novel topology of high performance smooth-varying dc current- regulation based on “Pulse-Width-Modulation with Unipolar-Voltage-Switching” has been used for the development of these power supplies. Analog multi-loop regulation scheme with inner fast voltage-control loops and outer slow integral type DCCT based current feedback loops will ensure the output current to be within the error band of 100ppm in respect of its short- and long-term stability.



**$\pm 5A$ ,  $\pm 20V$  current-regulated true-bipolar dc power supply**



**0-20kV/5mA High-Voltage DC Power Supply**

High voltage DC power supplies find a wide range of applications in the field of electrostatic systems of any accelerators as well as in Laser based systems, medical diagnostic equipments and in industry for high-voltage testing of components and cables. A state-of-art soft-switching based continually variable 0-20kV / 5mA max, dc-regulated power supply to operate in constant-voltage constant-current (CV/CC) mode, has been done at VECC and it has been installed and commissioned for the extractor system of RIB ion source. DC-DC converter topology based on Half-bridge resonant inverter with a resonant tank circuit followed by high-frequency step-up transformer and 4-stage Cockcroft Walton multiplier is being adopted for the development of this power supply. The converter operates at a constant frequency near resonance of the tank circuit and is controlled by PWM duty-cycle control.

In a recent experiment, Radioactive Ion Beam (RIB) of Carbon-11 has been produced for the first time at VECC. Carbon-11 is a PET radio-isotope with the half-life of about 20 minutes and is a potential candidate for next generation hadron therapy using radioactive carbon beams. The experiment was conducted at VECC's RIB facility with the aim of optimizing the production technique and commissioning the indigenously developed 2.45 GHz gas-jet ECR ion source for production of RIB.

RF modulated thermionic electron gun floating at 100 kV and Low Energy Beam Transport (LEBT) line has been indigenously developed and is operational at VECC. Transverse emittance of 100 keV electron beam extracted from the electron gun has been measured using solenoid magnet scan technique. Here the solenoid has been used as diagnostic tool for determining energy of the beam and to ensure alignment of beam trajectory with respect to solenoid magnetic axis by optimum setting of upstream steerers. Second moment distribution of beam has been measured for evaluating 4D transverse emittance. Tomography using Algebraic Reconstruction technique has been adapted to reconstruct the transverse phase space using measured beam profiles and the normalised RMS emittance in two transverse planes was deducted to be about 5 mm mrad. This measurement provides a valuable input in tuning beam in the LEBT

and accelerating the beam finally to 10 MeV using superconducting elliptical cavity.

The Facility for Research in Experimental Nuclear Astrophysics (FRENA) is a high current 3 MV tandemron facility. It has been installed at SINP in March 2018 and in the process of receiving the AERB permission for trial operation. The machine is ready to deliver light and heavy ion beams and has ready beam-lines for nuclear physics and astrophysics experiments. A small high vacuum chamber is being fabricated for gamma and charged particle measurements. This chamber has also arrangement for monitoring temperature profile of target by thermal imaging camera, essential in high current beam induced studies. Calibration experiments using (p,n) reactions will be carried out very soon.

## LASER TECHNOLOGY

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

A laser micro-welding workstation for welding of high dose rate (10 Curie) Ir-192 radioactive source in a capsule of 1 mm diameter and 200 m wall thickness in hot cell has been developed and will be installed in hot cell at BRIT for production of Ir-192 Brachytherapy assemblies. This workstation has been equipped with rotary stage, CCD camera based viewing system, interlocks for laser operation, gas purging and controller



**Laser micro-welding workstation for Ir-192 brachytherapy assemblies**

for laser operation. Lead shielding for safety of CCD camera has also been developed.

An engineered 500 W of an all-fiber single transverse mode Yb-doped CW fiber laser was developed and integrated with galvano-scanner, powder spreader and vertical actuators for the development of Powder Bed Fusion based Laser Additive Manufacturing (LAM) System. The developed system has been used to build structures with build accuracy within 50 microns.



**Laser powder bed fusion system**

An engineered version of 'Agni-Rakshak' – A Raman Scattering optical fiber based distributed fire detection system has been designed, developed and demonstrated. The system contains the pulsed laser (1064 nm), the lens assembly, beam splitter, notch filter and Raman anti-Stokes & Stokes filters. The temperature is estimated from the ratio of Anti-Stokes to Stokes Raman signal. The spatial location of fire is estimated from the time of return of scattering signals. The optical fiber sensor of length 100 m having core/clad size of 62.5/125  $\mu\text{m}$  which is covered inside an SS tube of diameter 2.0 mm was coupled to the system. A panel of ten LEDs indicating 10 fire zones, each corresponding to of the length 10 m in 100 m long sensing fiber was also interfaced to the system. The complete system (size 70 cm  $\times$  50 cm  $\times$  113 cm) was installed for demonstration in Fire Drill Tower at Fire & Safety Cell, RRCAT. The system was tested with two fire zones each of width 1.5 m, created artificially with the help of burning of chafing fuel gel at the spatial location

of 65 m and 84 m creating temperature of 81°C and 91°C respectively. The Alarm temperature was set at 500°C. The 'Agni-Rakshak' system could successfully detect the presence of fire at both the locations and started creating an alarming sound. The system was able to provide not only the information about the presence of the fire but also its location and the corresponding temperature. The snapshot of Graphical User Interface (GUI) of 'Agni-Rakshak' is depicted in the picture. The developed system is being put up for technology transfer.

A machine vision based metrology system based on non-contact shadowgraph technique has been designed and developed for automated dimension measurement of End Caps of PHWR fuel elements. This system has field of view of 45 mm x 35 mm and optical resolution of better than 10 micron. It measures eleven dimensions of each end caps with accuracy of  $\pm 10$  micron and repeatability of better than 10 micron. Overall throughput of system is 12 end caps / minute. A user friendly graphical user interface facilitates operation of system even by un-skilled operator. System has been qualified and will be deployed at NFC.



**Machine Vision System**

The CO<sub>2</sub> lasers, owing to high absorption of its wavelength in glass, are best processing tool for glass. An automated CO<sub>2</sub>-laser based system has been developed for cutting and sealing of glass tubes. The system is being developed for BRIT, Mumbai for the fabrication of tritium-filled self-illuminated glass tubes. An automated system for cutting and sealing of



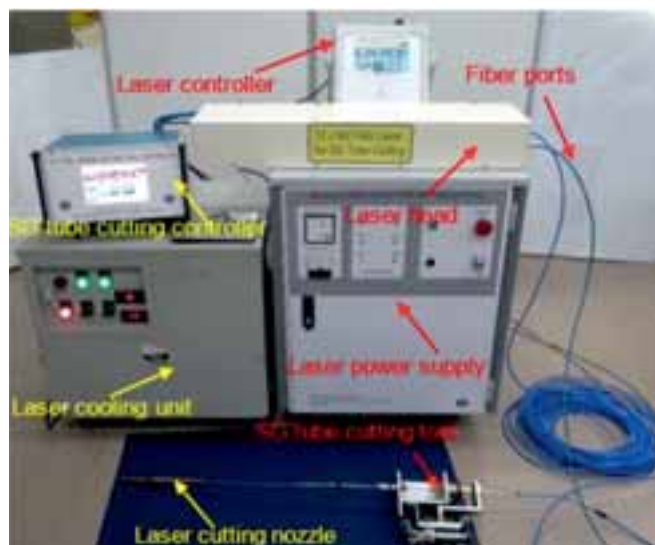
**Glass tube cutting and sealing system**



**Cut samples of glass tubes**

borosilicate glass tubes has been developed as per the requirement of BRIT, Mumbai. The system consists of a 50 W sealed-off CO<sub>2</sub> laser tube, rotary stage for rotation of glass tube, linear translation stage for tube movement and vacuum pump for realizing pulling of glass tube after melting of glass by CO<sub>2</sub> laser beam. The whole process of movement of glass tube, its rotation, irradiation by CO<sub>2</sub> laser beam for defined time and finally pulling with the help of vacuum pump is controlled by an Arduino based controller. The system was used to demonstrate cutting and sealing of 3 mm diameter glass tubes (length: 5 - 10 mm.).

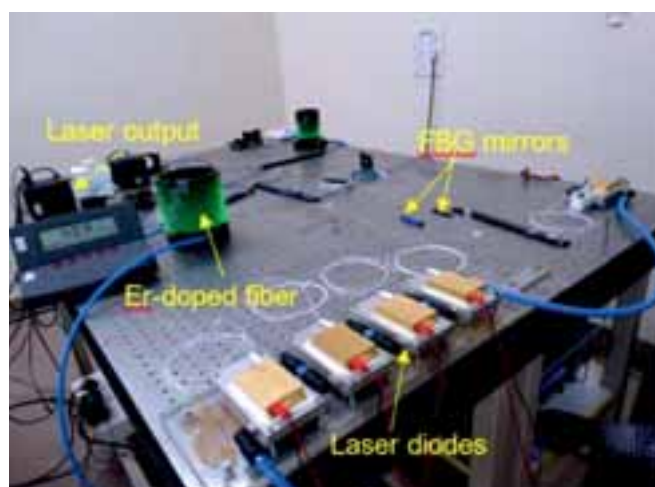
A compact 12 J pulse energy fiber coupled pulsed Nd:YAG laser has been developed for cutting of leaky steam generator tubes. Laser pulse duration and pulse rep rate can be varied in the range from 2-12 ms and 1-4 Hz respectively. The Inconel 800 SG tube of diameter 24 mm is cut from inside by inserting the laser



**12 J pulse energy Nd:YAG laser system  
for cutting of SG tubes**

cutting nozzle. The SG tubes can be cut circumferentially at a height of up to 3 m as well as a window to take out sample of SG tube for post irradiation examination studies.

A 50 W of eye-safe Er-doped CW fiber laser at 1600 nm using Master Oscillator Power Amplifier (MOPA) configuration has been developed. Major challenges faced are removal of high heat load from thin Er-doped fiber of 250 m diameter due to high quantum defect of 61% and lower efficiency due to high re-absorption losses at signal wavelength along Er-doped fiber. This laser has potential defense application in target illumination. The figure shows a table-top view of 50 W eye-safe Er-doped CW fiber laser at 1600 nm.



**Table-top view of 50 W eye-safe Er-doped  
CW fiber laser at 1600 nm**

Laser cutting tools for removal of single selected coolant channel of 220 MWe PHWR have been upgraded with Liner tube, end fitting, bellow lip cutting and underwater pressure tube stub cutting tools to make the laser cutting process more reliable and user friendly. Based on upgraded design, these tools have been fabricated, assembled and tested for mock-up trials. These tools can be used at NPCIL nuclear power plant sites for removal of single selected coolant channels.

Narrow linewidth seed source was scaled to 50 W level from 20 W in a multi-stage all-fiber configuration. The multi-stage amplifier consists of a pre-amplifier and two amplifier stages. Output power of 50.4 W was measured when pumped with 76.6 W power giving rise to 65% optical to optical conversion efficiency. Line-width was found to be 1.7 MHz and power stability was measured at 51.3 W average power for 30 min with a standard deviation of 0.57 W.

High transmission Anti Reflection (AR) coated windows of size 150 mm diameter have been developed with transmission of 99.4 % at wavelength 1053 nm and laser induced damage threshold of 4.5 J/cm<sup>2</sup> for 3 nsec. laser pulse. Optical substrates were polished and were coated with two alternate layers of SiO<sub>2</sub> and Ta<sub>2</sub>O<sub>5</sub> by dual ion beam sputtering technique

Laser induced surface texturing of biomaterials improves their bioefficiency in terms of superior biocompatibility and anti-bacterial properties. This improvement depends on the type of structuring. About 10 unique microstructures were created on biomaterial surface by varying the laser parameters, including the fluence, scan speed and overlap factors. These samples were immersed in simulated body fluid prepared in the laboratory for a known period of time. The growth of apatite, the bone cement, was studied by SEM and the same was also ascertained by taking the Raman spectrum. While the Raman peak indicated the formation of apatite, the SEM pictures revealed superior growth when compared to the untreated sample. Further experiments are in progress to arrive at the best surface patterning.

A Fiber Optics based Perimeter based Intrusion Detection System (FO-PIDS) has been developed to detect physical intrusion through the boundary fence created around an installation. The prototype was deployed in BARC for field trials. The system is based on Mach-Zender Interferometer (MZI) technique. It is equipped with a single cable sensor and does not require power supply along the fence. It gives very low false alarm rate in presence of background interferences like rain, wind and vehicular noise.

The coherent interaction of the electric fields with the atomic medium which leads to phenomena like Electromagnetically Induced Transparency (EIT) are highly sensitive to the external magnetic fields. Using this fact, magnetic field with good spatial resolution and high sensitivity can be measured. In addition to the magnetic field strength, knowing the direction of the magnetic field is also important. Combining the coherent optical effects like EIT with the longitudinal and transverse magnetic fields make an opportunity for developing an EIT based atomic vector magnetometer which is sensitive to the direction of the magnetic field. An apparatus to study the effects of static longitudinal and transverse magnetic fields in a hyperfine  $\Lambda$ -type EIT system has been developed at SINP laboratory. How the EIT resonance is highly sensitive to the magnetic field direction as well as the polarization direction of the applied electric fields was shown. The selection rules of the EIT resonances can be controlled by controlling the polarization component of the laser fields with respect to the quantization axis.

## Laser Applications

A 2 kW fiber laser-based hybrid laser-metal inert gas welding system was developed by designing a Hybrid Laser Arc Welding (HLAW) head. The HLAW system combines the benefits from a laser beam as well as from a traditional arc welding process and eliminates the drawbacks from the individual technologies. The developed HLAW welding system is used to demonstrate the welding of 10 mm thick SS304L plates. It was found that a 2 kW fibre laser power can join about 3 mm thick SS304L plates in autogenous welding mode. On the other hand, MIG welding results in wider weld pool with excessive heat input.



*A view of developed Hybrid Laser Arc Welding System (HLAW)*

## ADVANCED TECHNOLOGIES

A 1.5 K refrigeration system has been designed and developed in-house to create cryogenic conditions suited for quantum computers. The system works on the principle of reducing the vapor pressure of liquefied He-4 and He-3 gas, which are mixed to an optimum level in the system. Quantum computers are required to be operated under high vacuum and stable mechanical/thermal environment to prevent unwanted excitation of qubit state.

A new hybrid design of field shaper for Electro-Magnetic Pulse Welding (EMPW) process has been proposed.

A 13.56 MHz hollow-cathode device is being developed for radioactive decontamination. It has successfully etched 30 cm<sup>2</sup> of different substrates such as Al, stainless steel, Ta and Zr.

<sup>nat</sup>boron carbide/n-Si heterojunction based portable solid-state thermal neutron detectors are being developed. A prototype device has already been fabricated and is now being characterized.

BARC has developed a low-cost easy-to-use positive airway pressure (PAP) device called as DEAP for easing of obstructive sleep apnea (OSA). The technology was transferred to four private firms for commercialisation. OSA is a condition in which the patient's airway is blocked during sleep, resulting in



**Device to ease apnea problem (DEAP)**

snoring, gasping for air and frequent stoppage of breath.

The mechanical design and development of a seismometer having inertial type sensors and a flat response of up to 40 Hz has been completed. The seismometer is capable of sensing ground motions over a wide range of frequencies. It is a three-component, force-balance broadband seismometer suitable for portable and fixed applications. It operates over a wide temperature range without manual re-centering. The extended response at higher frequencies makes it ideal for local and regional networks as well as volcano hazard monitoring and aftershock studies.



**3D model of mechanical system of Seismometer**

Full scale demonstration of a gantry-type cargo scanner is in final stages at BARC, Trombay. The ANSI-N 42.46 and IEC 62523 based scanner moves over a container trailer within a radiation shielded area to produce an X-ray image of the object. The performance



**Full scale demonstration of a gantry-type cargo scanner underway**

of core technology was on par with the similar kind of commercial products available in the international market.

A hand-held portable instrument for identifying various radioactive isotopes (PRID) and for measuring radioactive dose rate in the range  $10 \mu\text{R}/\text{Hr}$  to  $1 \text{R}/\text{Hr}$  was developed in BARC. The instrument detects radioactive elements of industrial, medical, SNM and lab categories, with an option to tag the location of the radioactive element. The instrument is powered by a rechargeable Li-ion battery for 8 hours of continuous operation. It also has Wi-fi connectivity.



**The PRID instrument**

Production of electrolytic oxygen as a by-product stream of electrolytic Hydrogen production was successfully demonstrated. The system consists of compact alkaline water electrolyser plant along with multistage oxygen gas boosting and bottling system. A new gas compressor capable of boosting oxygen pressure from 0.5 bar (g) to 150 bar (g) has been installed, commissioned and integrated with the plant.

A four channel Flash X-ray (FXR) system has been designed and developed for dynamic radiography. The system has been installed at VSSC, Thiruvananthapuram and is used for thin resolution dynamic radiography of detonator firing event.

Field-deployable high-resolution seismic data recorder has been developed in BARC as an import substitute. The recorder is interfaced with broadband seismometer and records large dynamic range seismic signals with high accuracy. The data acquisition is synchronized with Global Positioning System (GPS) for time stamping. The recorders are installed at remote and unmanned sites. The mechanical chassis of the portable seismic recorder is light weight and designed to protect electronics from dust and rain. The functional testing and performance evaluation of two units has been completed at Seismic Data Centre, BARC. Field testing of the integrated system is in progress.



*High resolution seismic data recorder*

A novel Platinum-based Dixon ring shaped catalyst system was developed in-house for Hydrogen-Oxygen recombination reaction. The developed catalytic system has shown excellent characteristics for deployment.

Laser based isotope separation methods have been successfully implemented for enrichment of  $^{152}\text{Sm}$ , isotopes of Ytterbium ( $^{176}\text{Yb}$ ,  $^{174}\text{Yb}$  &  $^{168}\text{Yb}$ ). The high-power laser facility comprises of CVL and DPSSL pumped process Dye Lasers (DLs) was employed to generate required wavelengths, spectral widths (100

MHz to 3 GHz) and average laser powers as per requirement for efficient selective photo-ionization of the isotopes.

The enrichment of Lu-176 obtained using natural sample (2.6% abundance) was improved from 28 % to 96 % through a three – step selective photo-ionization.

The work on development of a new design of prototype linear source for high throughput of samarium and ytterbium vapour has been completed. The testing of complete separator system is under progress.

An automated neutron irradiator system has been designed and developed for facilitating fast and thermal neutron irradiation of specimen using Cf-252 neutron source. A motorized conveyor assembly with a lifting gate is provided to facilitate fast neutron irradiation of specimen at varying distances. Two collapsible channels with specimen slots at 100 mm & 200 mm distance from source are provided to facilitate thermal neutron irradiation. The system has been installed at Gamma Field in BARC Trombay.

In the wake of Covid-19 Pandemic situation, the demand of medical support systems motivated the necessity of development of an in-house oxygen concentrator at affordable price. Accordingly, a prototype oxygen concentrator system based on Pressure Swing Adsorption technology has been developed. The system consists of twin towers of Zeolite molecular sieve which preferentially adsorbs Nitrogen from the air, thereby, producing Oxygen rich outflow. The prototype is currently producing 85-92% Oxygen concentrated output up to 3 litres per minute flowrate as measured through medical grade Oxygen sensor. The output gas has been liquefied by circulating liquid nitrogen around the gas output duct. A pale blueish liquid similar in appearance to liquid oxygen has been obtained. Also, the gas has passed Flame Rekindle Test which is a standard test for Oxygen. Further detailed chemical analysis of the output gas is awaited. One of the main foci of the development has been to regulate the cost of the system to as low as reasonably achievable with respect to other commercially available Oxygen Concentrators.



*Prototype Oxygen Concentrator*



*Flame Rekindle Test for Oxygen*

## Electronics & Instrumentation

BARC has developed USB based hardware device called AnuNishta to ward off security threats on portable computing devices like Laptops. It blocks



*USB based AnuNishta*

unregistered kernel drivers, shared libraries, application executables, scripts and firmware modules.

An in-cell video microscopic imaging system has been developed in BARC for deployment inside a hot cell for automated analysis and measurement of reactor core components of 100 x 100 mm size and up to 100 times magnification.

Next Generation CPU Board VME1013 for NUCON PLC has been developed. It is built on 32-bit processor operating at 1200 MHz, with two 1GBPS Ethernet ports. In-house developed Real Time Operating System ESOS and open-source RT Linux OS has been deployed.

A compact, low noise standalone Integrated HPGe readout system comprising of Spectroscopy amplifier (Shaper), Multichannel Analyzer (MCA), +/-5 kV High Voltage (HV) Supply and low voltage (LV) in a single unit has been developed in BARC. The unit is



*Integrated high resolution multi-channel analyzer*

interfaced with in-house developed ANUSPECT spectrum analysis software package through Ethernet. The system gives 1.8 keV FWHM resolution at 1332.5 keV peak of Co-60 with FWTM/FWHM ratio 1.88.

The Iron Calorimeter (ICAL) experiment of India based Neutrino Observatory (INO) is proposed to use 28,800 numbers of Resistive Plate Chamber (RPC) detectors, each of 2 m x 2 m size, leading to around 3.6 million readout channels. A new BiCMOS ASIC chipset with high speed Quad Amplifier ASIC and Octal Comparator ASIC is developed to meet the complex front-end readout requirements of this INO-ICAL RPC detector. In order to accommodate the ASIC chipset-based FEE module in the compact space of the RPC tray, a low-profile octal shielded FEE module (size 190 mm x 23 mm) has been developed.



*BiCMOS ASIC chipset*

BARC has developed Antenna Control Unit and Supervisory Gateway Controller of the 18-meter Indigenous Deep Space Network (IDSN) antenna facility of ISRO for deep space programs. Installation, commissioning and system acceptance test have been completed at IDSN site. The system is required to steer the Antenna in Azimuth ( $\pm 270^\circ$ ) and Elevation ( $-2$  to  $92^\circ$ ) with pointing and tracking accuracies better than 20m deg (1 sigma) and 14m deg (1 sigma) respectively, at 60 kmph wind speeds. The terminal was dedicated to the nation by the Chairman, ISRO on 10th November 2021.



*BARC developed Antenna Control Unit (extreme left), and Supervisory Gateway Controller (centre) for the IDSN -18 antenna (last)*

## Robotics

A dual robotic arm TIG welding station has been installed to address shortcomings faced in manual welding and for producing high quality weld joints, which are essential in the case of critical nuclear components.



*At play are the twin two robotic arms of the welding station*

## Special Programmes

Jaduguda Underground Science Laboratory (JUSL) is situated underground at 555m depth in the mine of Uranium Corporation of India Limited (UCIL), Jaduguda. Data of cosmic muon flux, radon and gamma rays are being monitored and recorded by scientists. The laboratory was inaugurated on Sept 2017 and the measurements at the underground laboratory have been started since then. During the period, the wireless communication from the mine to the data monitoring Unit at the Health Physics Section of UCIL has been completed. From the underground tower of JUSL, there is a radio link to the Health Physics Laboratory. The experiment can be monitored from the Health Physics Lab through a desktop installed there. The job was executed with the help of SINP, JUSL Electrical Section Health Physics Unit, UCIL and was funded by SINP.

## 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, 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.

During 2021-22, RC, Kota, processed 4244 kCi of Cobalt-60 activity. This is mainly used for fabrication of indigenous Cobalt-60 Teletherapy Sources (CTS) and High intensity Multi-Purpose Gamma Irradiator Sources. Successful fabrication of Two hundred and Sixty-Five (265) Multi-Purpose Gamma Irradiator Sources, which included One hundred and Seventy Six (176) number of BC-188 type and Eighty Nine (89) number of W-91 type sealed sources was achieved and this amounted to 4433 kCi of activity.



**Handling of Cobalt-60 Adjuster rods in  
BRIT-RAPPCOF storage pool**



**Multi-Purpose Gamma Irradiator Sources and  
the national and international consignments**

Total 4792 kCi of Cobalt-60 sealed sources are supplied in 48 number of consignments which included Eleven Cobalt-60 Teletherapy Sources and Two hundred and Ninety Seven (297) Multi-Purpose Gamma Irradiator Sources, consisting of Two hundred (200) number of BC-188 type and Ninety Seven (97) number of W-91 type sealed sources. These were used for radiation processing applications such as Medical sterilisation, post-harvest food preservation, sludge hygienisation, etc., to various Multipurpose gamma irradiators in the country and abroad.

Exported total of Seventy-Two (72) numbers of BC-188 type Multi-Purpose Gamma Irradiator Sources with total activity 750 kCi to various countries which include 250 kCi to M/s. Ansell Lanka, Sri Lanka and 500 kCi to M/s Ansell Malaysia.

Source loading operation of Seventeen (17) Multi-Purpose Gamma Irradiators in various part of the country was carried out in 2021-2022.

## AGRICULTURE

### Crop Improvement

Radiation induced mutagenesis along with recombination breeding was used to develop new crop varieties. Six crop varieties three in mustard, one in groundnut and two in rice have been released and notified for commercial cultivation by the Ministry of Agriculture and Farmers Welfare, Govt. of India. Mustard varieties include Trombay Akola Mustard 108-1 (TAM-108-1) for Maharashtra; Birsra Bhabha Mustard-1 (BBM-1) for Jharkhand; Trombay Himachal Pradesh Mustard-



**New mustard variety - Trombay Him  
Palam Mustard 1**



**Seeds and pods of new groundnut variety - TAG 73**



**New rice variety - Vikram TCR**

1 (THPM-1). In Groundnut, Trombay Akola Groundnut-73 (TAG-73) was released for Maharashtra. Two rice varieties Vikram TCR (VTCR) and CG Jawaphool Trombay (CGTJ) have been Gazette notified for commercial cultivation in Chhattisgarh.

For popularization and supply of quality seeds to farmers, breeder seed multiplication was taken up in Trombay groundnut, pulses and rice varieties. 303 quintals of groundnut varieties, 65 quintals of pulses,



**Breeder seeds of Trombay groundnut variety-TG 51**

and 80 quintals of rice varieties were distributed to various National and State Seed Corporations of Gujarat, Karnataka, Maharashtra, Madhya Pradesh and West Bengal.

In biotechnological approach for crop improvement, a rapid, reproducible and sustainable micropropagation protocol was developed for ginger. This offers a disease-free good quality planting material throughout the year and can also be used in germplasm conservation of elite ginger varieties.

In tobacco, transgenic lines harbouring PMusaCHI-1-GUS which guard the cells of leaves against negative effects arising due to drought, salinity and cold, were developed.

## FOOD PROCESSING

In the area of basic research, molecular dynamic simulation approach was applied in identifying A-cadinol as a potent inhibitor of ACE enzyme (-50 kJ/mol) in beans extract and the results showed that it had greater efficacy compared to captopril (-25 kJ/mol).

In-silico analysis of DNA binding ability of antimutagenic compounds isolated from brinjal was performed. Antimutagenic potential of N-Caffeoylputrescine, a conjugated amide found naturally in brinjal could be attributed to its remarkable DNA minor groove binding affinity (total binding energy of -7.57 kcal/mol) in molecular docking studies.

Purification of major allergen, P34 from Soybean oil bodies was accomplished. Besides, studying structure-function relationship for the major allergen protein, P34 from Soybean, its purification from oil bodies of seeds was standardized. The purified fraction exhibited proteolytic activity towards P34 as well as beta casein and BSA.

Aeromonas specific phage characterization was done utilizing TEM. The TEM analysis of a bacteriophage (S1) against *Aeromonas salmonicida* showed that it belongs to family Siphoviridae of order Caudovirales whose Capsid size is about 40 nm and tail length is 300 nm.

The microbial diversity of fruit and vegetable surface upon radiation processing was elucidated through metagenomics. Changes were observed in the diversity of major phylums such as Firmicutes, Planctomycetes, Proteobacteria upon irradiation.

Radiation processing of foodgrains by using Cs-137 source was demonstrated with a small scale Agro Irradiation Facility, built in BARC Trombay. Cs-137 source pencils of high specific activity 4.5 Ci/g were developed for irradiation and the plant is equipped to deal with 21 kCi source strength.



**Radiation processed onion after 7 months**



**Non-irradiated potatoes (on the left) and irradiated potatoes after 7 months of storage in proper conditions (on right)**

Radiation processing alone or in combination with other treatments, including chemicals or heat was used for improving the shelf life of potato, onion, wheat and pulses. In case of potato, the irradiated samples were found to be in good condition till 7-8 months of storage. Onions when subjected to a minimum dose of 60 Gy were found to remain fresh with no sprouting till 8 months. Weight loss and microbial spoilage, including rotting was almost negligible in onion.

As a superior alternative to fumigation, irradiation technology was utilized in the long-term preservation of foodgrains, including wheat and various pulses. Even after 14 months of storage under ambient conditions, packaged and irradiated (with a radiation dose 650 Gy) wheat remained free of pests free with retention of quality attributes and grain integrity. However, non-irradiated wheat was spoiled due to pest



**Non irradiated split chickpea (chana dal) after 12 months (on left) and irradiated split chickpea during the same period (right)**



**Non irradiated wheat grains after 12 months (on left) and irradiated wheat grains during the same period (right)**

(*Sitophilus oryzae*) infestations. Similar observations have been reported for wheat subjected to electron beam treatment as well. Besides, irradiated split chickpeas ('Chana dal') also remained pest-free even after 1 year of storage whereas the non-irradiated ones completely spoiled within this time period.

Premium plums wrapped with PVA-pectin films developed in BARC improves the shelf life of plums to 15 days as against the normal 7 days for other types of packaging. The functionality of PVA- pectin film in increasing the shelf life of strawberries was also ascertained. It is observed that there was 39% weight loss in unpacked strawberry while in active packed samples only 20% loss of weight was seen after 15 days of storage in chilled conditions. As a result, unpacked strawberry had a shelf life of less than 7 days while those packed using active film were acceptable up to 15 days.

Low doses of gamma radiation were applied to improve the shelf life of foodstuffs, including milk-based sweets made by Amul India, flesh balls made out of Tilapia fish variety, mashed potato. For radiation

processing, very low doses of Gamma radiation in the range of 2-5 kGy were used.

The spoiling effect of *Salmonella Typhimurium* cells on Beetle leaves was eliminated without affecting its sensory attributes. Gamma radiation (2 kGy) was found to be highly effective in eliminating 10<sup>5</sup> *Salmonella Typhimurium* cells/gm of beetle leaves.

A technology has been developed by BARC for producing shelf stable Strawberry Candy Roll product from seasonally occurring jamun fruits. Through radiation processing, shelf life of Strawberry Candy Roll has been extended to 5 months and can lead to reduction in post-harvest losses of the fruit.



**Shelf stable Strawberry Candy Roll product made from seasonally occurring jamun fruits**

A technology has been developed to derive a value-added and preservative free dietary Jamun fruit product.

## Radiation Processing Services

### Radiation Processing Plant (RPP), Vashi

Radiation Processing Plant, Vashi has provided gamma radiation processing services for Spices and allied products to various exporters from all over the country. Twenty new customers were registered during the current year. Main products processed were spices (whole & ground both), pet feed, ayurvedic raw materials & healthcare products. Industrial samples like induction motor, armoured cable, transmitter etc were received from NPCIL vendors & exposed with desired doses of gamma radiation as per qualification test criterion.

During the current financial year, 2021-22, 4400 MT of spices, Ayurvedic raw material, healthcare products and other products were processed.

Surveillance audits for ISO 9001:2015, 22000:2018 and ISO 13485:2016 were got carried out by certifying agency and found in full compliance with the Standard's requirement.

Dosimetry Laboratory carried out the following work during the period April 2021 to December 2021.

Plant commissioning dosimetry for radiation sterilization of medical products was carried out in gamma plant of M/s. Solas industries, Mathura, and commissioning dosimetry for medical products sterilization and Class VI food products, was carried out at M/s. A.V.Gamma Tech, Ambarnath.

Plant recommissioning dosimetry for medical and food products were carried out in 5 Nos of gamma plants namely M/s. Universal Isomed, Vadodara, M/s Hi media – Ambarnath, M/s Alligned Industries – Haryana, M/s. Agrosurg Irradiator- Vasai, and M/s EMI – Vadodara.

Production and supply of 2.0 lakhs Ceric-Cerous dosimeters was made to various gamma irradiators in the country, for absorbed dose measurement.

Export of 5000 Nos. of Ceric-Cerous dosimeters & 15 Nos of irradiated standard dosimeters were supplied to Atomic Energy Regulatory Board, Sri Lanka, during the reported year 2021-22.

ISO 9001:2015 Certification was obtained for Dosimeter Production Laboratory, Vashi.

Dose rate certification of 3 No's of Blood irradiator and One Gamma chamber - 5000 were completed.

### New MoU for Radiation Processing Plants in Private Sector

MoU was signed with M/s Accumax Lab Devices 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 Mehsana, Gujarat.



**Signing of New MoU's for Radiation Processing Plants in Private Sector**

MoU was signed with M/s Advanced Micro-devices Pvt. Ltd., for setting up a Gamma Radiation Processing Plant for disinfestations, shelf life extension of food products and sterilization applications of healthcare products, at Ambala, Haryana.

Gamma radiation processing plant of M/s Solas Industries, Noida & M/s AV Gamma Tech., Mumbai, were commissioned during the reported period of 2021-22.

## 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.  $^{18}\text{F}$ -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 need to be produced in strict GMP compliance.

Weekly production and supply of the most-user friendly acidic alumina column based Mo-99/Tc-99m radioisotope generator (COLTECH) to avail Tc-99m at nuclear medicine centres for SPECT based diagnostic imaging of patients, was continued. Significant increase in demand for the COLTECH generators supplied by BRIT was seen in 2021-22 as compared to the previous year. A total of 1073 consignments were sent during the reported period and eight new hospitals were added to the existing customer list. More than 2 lakh patients were benefitted from the COLTECH generator supplied by BRIT. Solvent extraction generators (TCM-2) were also supplied on demand from the hospitals. A total of 111 consignments of TCM-2 were supplied during the reported period.

About 75,000 cold kit vials (towards formulation of Technetium-99m, Rhenium-188 and Lutetium- 177

radiopharmaceuticals) were supplied to nuclear medicine centres throughout India. Majority of the cold kits were supplied for preparation of  $^{99m}\text{Tc}$  Radiopharmaceuticals towards early disease diagnosis. More than 2.25 Lakh diagnostic procedures were carried out using these kits. HYNIC-TATE and HYNIC-RGD kits were introduced for SPECT-based cancer detection.

1,400 Radioimmunoassay (RIA) and Immunoradiometric Assay (IRMA) kits were supplied to the various nuclear medicine centres, diagnostic laboratories and research institutes throughout India.

Iodine-131 as  $\text{Na}^{131}\text{I}$  is one of the most important radiopharmaceutical products supplied to hospitals for the management of thyroid disorders, including thyroid cancers. From April to Dec. 2021, 370 Ci of I-131 products was supplied to nuclear medicine centres all over India. This includes oral solution and capsules in different denominations, I-131 labelled mIBG, which is used for the diagnosis and treatment of Neuro Endocrine Tumors (NET) and  $^{131}\text{I}$ -Lipiodol (used for the treatment of Liver Cancer).

Total 733 consignments of injectable radiopharmaceuticals were produced and supplied to different Nuclear medicine centers all over India which includes  $^{177}\text{Lu}$  and  $^{153}\text{Sm}$  based radiopharmaceuticals. There was significantly increased demand for Lu-177 radiopharmaceuticals namely,  $^{177}\text{Lu}$ -DOTA-TATE for treatment of metastatic (somatostatin receptor positive) neuroendocrine tumors &  $^{177}\text{Lu}$ -PSMA for the treatment of Prostate Cancer, which was successfully catered to. Other therapeutic products supplied by BRIT included the newly launched  $^{90}\text{Y}$ -HA and  $^{177}\text{Lu}$ -HA for treatment of rheumatoid arthritis.



**Newly installed production facility for  $^{177}\text{Lu}$ -PSMA under AFRP Project**

Regular production of  $^{177}\text{Lu}$ -PSMA-617 was initiated in the new production plant installed under the 12th Plan project 'Advanced Facilities for Radiopharmaceuticals Production' (AFRP) which concluded in March 2021.

Tissue culture laboratory was maintained for carrying out the in-vitro uptake studies of new radiopharmaceuticals. AR-42 J and LNCaP cell lines were propagated and cell uptake studies were carried out for testing no carrier added (NCA)  $^{177}\text{Lu}$ -DOTA-TATE and NCA  $^{177}\text{Lu}$ -PSMA respectively. LNCaP cell line specific for prostate cancer was also propagated and used for in-vitro cell uptake studies of  $^{177}\text{Lu}$ -PSMA-617,  $^{68}\text{Ga}$ -PSMA-11 and  $^{99m}\text{Tc}$ -HYNIC-PSMA.

Two proposals on no carrier added (NCA)  $^{177}\text{Lu}$  are planned to be submitted to Radiopharmaceutical Committee (RPC), DAE to obtain approval for their regular production & supply. The proposals are i) nca-Lu-177 as an Active Pharmaceutical Ingredient (API) for radiopharmaceutical end-use and ii) nca- $^{177}\text{Lu}$ -DOTA-TATE and nca- $^{177}\text{Lu}$ -PSMA-617 for treatment of neuroendocrine tumors and prostate cancer respectively. The studies towards development /standardization were completed successfully and it is planned to submit the two proposals for approval in forthcoming RPC meeting in early 2022.

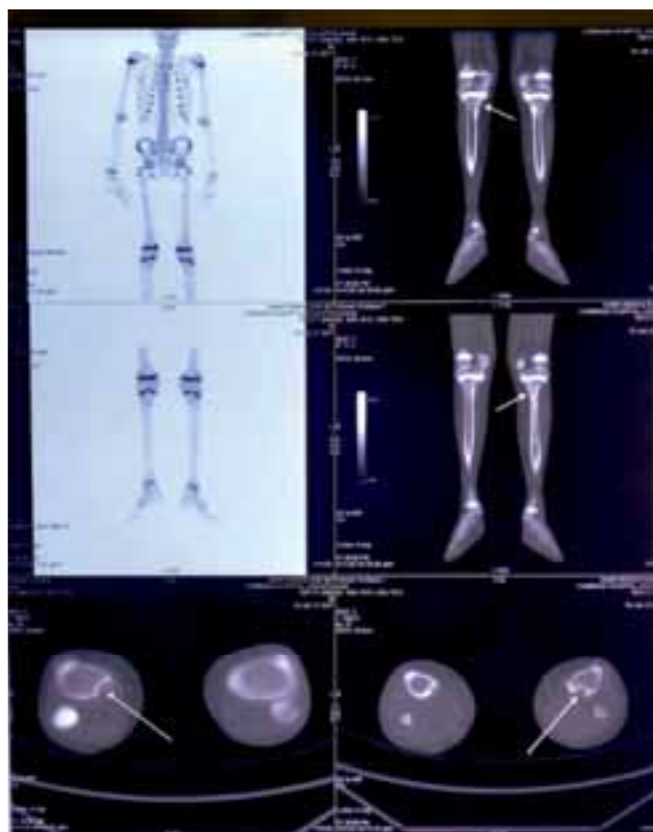
The Medical Cyclotron Facility (MCF), Parel, continued the production and supply of PET radiopharmaceuticals, mainly  $^{18}\text{F}$ -FDG and  $^{18}\text{F}$ -Sodium Fluoride and to a lesser extent the newly launched  $^{18}\text{F}$ -Fluro Ethyl-L-Tyrosine (FET).

Regular and uninterrupted supply of PET radiopharmaceuticals such as  $^{18}\text{F}$ -FDG,  $^{18}\text{F}$ -NaF, and  $^{18}\text{F}$ -FET to various hospitals, in and around Mumbai, accounting for nearly 125.36 Ci of radioactivity was supplied, during the year 2020-21. More than 15000 patients benefitted with PET investigations in the reported year.

$^{18}\text{F}$ -FDG is the most successful PET radiopharmaceutical so far. The advancement in synthesis and quality control of  $^{18}\text{F}$ -FDG, together with its approval by the US FDA and the availability of reimbursement, are probably the main reasons for the

flourish of clinical PET. During the reported period from April – December, 2021 total activity supplied to different hospitals was approx. 62 Ci

A fully automated large-scale production of sodium [ $^{18}\text{F}$ ]fluoride ( $^{18}\text{F}$ ]NaF) using SYNTHERA module with a modification in integrated fluidic processor (IFP) has been developed. This modified IFP module is used to prepare [ $^{18}\text{F}$ ]NaF with more than 98% non-decay corrected radiochemical yield within 5 min with specifications in accordance with United State Pharmacopeia (USP) monograph.. The final product has been supplied to Command Hospital, Kolkata for clinical studies.



**McCune Albright syndrome patient with fibrous dysplasia [ $^{18}\text{F}$ ]NaF PET/CT image at 60 min**

In the 75th year of Azadi ka Amrit Mahotsav (AKAM), Regional Centre, Board of Radiation & Isotope Technology (RC-BRIT), Kolkata, has launched the radiopharmaceutical Thallium-201 chloride (TI-201) for cardiac imaging studies towards early diagnosis of heart ailments. The RC-BRIT jointly with VECC, Kolkata, produced TI- 201, for the first time in India from the CYCLONE-30, by irradiating TI-203 enriched target

undergoing the nuclear reaction  $^{203}\text{Ti}(p,3n)^{201}\text{Pb} \rightarrow ^{201}\text{TI}$ . TI-201 chloride has been approved, for its use in cardiac imaging, by Radiopharmaceutical Committee, DAE. The TI-201 patient doses were supplied to NH Rabinathanath Tagore International Institute of Cardiac Sciences, Kolkata. Feedback has been received from the hospital on the SPECT imaging performed in two patients for ischemia evaluation and viability assessment respectively. The TI-201 Chloride produced by RC-BRIT, Kolkata, reportedly showed good biodistribution with good cardiac uptake, due to which excellent quality images could be obtained. Uptake of TI-201 in the liver and soft tissues was low as compared to that of  $^{99\text{m}}\text{Tc}$ -MIBI in the same patients. With this mammoth achievement, BRIT, Kolkata, has once again reiterated its commitment towards bringing out more and more useful radiopharmaceuticals at economical costs for the benefit of the suffering patients in the country.

Numerous PET based imaging agents used for diagnosis of prostate cancers and bone metastasis; anti-hypertensive-sartan drugs, which are not readily available in the country were synthesised in-house in BARC. These include PSMA-11 ligand for preparation of  $^{68}\text{Ga}$ -PSMA-11, which is a PET based imaging agent for diagnosis of prostate cancers. PSMA-617 ligand for preparation of  $^{77}\text{Lu}$ -PSMA-617 which is used in prostate cancer therapy has been synthesized and supplied to BRIT for kit formation and supply to hospitals pan India. Cu (MIBI)  $\text{BF}_4$ , which is a precursor for preparation of  $^{99\text{m}}\text{Tc}$ -sestamibi used for myocardial perfusion imaging, has been synthesized in BARC and supplied to BRIT for kit formation. A NOTA-alendronate conjugate has been synthesized for developing  $^{64}\text{Cu}$  based theranostic for bone metastasis.

At VECC, a 30 MeV, 350  $\mu\text{A}$  Medical cyclotron facility along 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, has been made operational. 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.



**30 MeV Medical Cyclotron at Chalkgaria campus of VECC, Kolkata**

The proton beam from cyclotron irradiate the target of enriched  $^{18}\text{O}$  water to produce positron emitting radioisotope, called Fluorine-18 ( $^{18}\text{F}$ ), from which FDG (Fluoro-deoxyglucose) radiopharmaceutical is finally produced after carrying out necessary chemistry. FDG is used in Positron Emission Tomography (PET) for diagnostics of tumor/cancer. Since June, 2020, commercial production and delivery of FDG to various hospitals and nuclear medicine centres in and around Kolkata, is continued on regular basis.

The cyclotron is also used for the production of gamma emitting radioisotopes such as Gallium-67, Gallium-68, Thallium-201, etc. and related radiopharmaceuticals, are used with a gamma camera for Single Photon Emission Computed Tomography (SPECT).

In a major development, Board of Radiation & Isotope Technology #BRIT, the industrial arm of DAE for production of radioisotopes, has successfully made Thallus Chloride #radiopharmaceutical using the 30MeV Medical Cyclotron Facility (MCF) operated by Variable Energy Cyclotron Centre #VECC at Kolkata. The radiopharmaceutical, called Thallus Chloride, has been supplied to the Rabindranath Tagore International Institute of Cardiac Sciences, Kolkata for conducting Cardiac studies (Rest Stress on Ischemia evaluation and also rest only for viability assessment) in patients referred for suspected coronary artery disease evaluation and has received encouraging results.

The Thallus Chloride-TI 201 radiopharmaceutical is used in certain procedures called planar scintigraphy or single-photon emission computed tomography (SPECT). This Thallium-201 radioisotope produced by BRIT at MCF, VECC, Kolkata,

shows good bio-distribution with excellent quality images, very good cardiac uptake, liver and other soft tissue uptake low compared to  $^{99\text{m}}\text{Tc}$ -MIBI performed on same patients (Images are shown in Figure 13 below). For the first time in India, the indigenously produced TI-201 radioisotope has been used for human applications and this will definitely minimize the import of the Thallium-201 radioisotope in near future, resulting in availability to the common man at an affordable cost.

This scintillating achievement is a significant step towards development of indigenous healthcare tools and techniques for an #AtmaNirbharBharat.

## Radiation Technology Equipment

### Blood Irradiator

Two Blood Irradiators-2000 units with Cs-137 source have been supplied to hospitals in India during April 2021 to December 2021 and supply of 02 units of BI-2000 is expected upto March 2022. One old BI-2000 unit was decommissioned while service was provided for 6 units.

### Radiography Camera

Total 28 numbers of Radiography Cameras, ROLI series, and 2 Nos. of recently launched COCAM-120 radiography device were supplied to various NDT users within India upto December 2021. Fifteen nos. radiography cameras are expected to be supplied soon. Inspection and services were provided for 615 numbers of BRIT and imported radiography cameras. Expected servicing for ~204 radiography cameras (both imported and domestic) would be provided.

### Gamma Chamber 5000

Supply of two units of GC-5000 with Co-60 source is expected upto March 2022, while one unit of GC-4000A & GC-900 were decommissioned during the reported year 2021-22. Inspection & servicing was provided for one unit of GC-5000. Replenishment of source for one of the units of GC-5000 and decommissioning of another unit of GC-5000 is expected to be taken up in another 2 months time.



**Halbach Magnet**

## A portable Halbach based permanent magnet dipole

As part of diagnosis, a compact, lightweight and portable Halbach based permanent magnet dipole has been designed and developed for imaging of body parts, including head, wrist and ankle. The 0.2 T magnetic dipole can be mounted on a vehicle and can cater to the needs of patients in remote areas. The field measured at the center of the dipole is 2.14 Kilo Gauss while the leakage field measured outside the magnet is less than 140 Gauss, owing to the Halbach arrangement of magnets.

## Thyroid Uptake Measurement System

A Thyroid Uptake Measurement System based on gamma radiation probe has been developed with a motorized Gantry. It is equipped with a PC-based data acquisition system, which provides features for uptake analysis with energy spectrum, patient data recording, report generation and automated Iodine Capsule



**Thyroid Uptake Measurement System  
commissioned at RMC Mumbai**

counting. The system was clinically verified and commissioned at RMC Mumbai.

## Fabrication of PET Scatter and PET Sensitivity Phantoms

In the area of nuclear medicine imaging, PET Scatter and PET Sensitivity Phantoms were fabricated as per National Electrical Manufacturers Association (NEMA) standards. Testing of these systems will be carried out at imaging facilities of RMC, BARC and TMC, Mumbai. Phantoms are equipped to evaluate various image quality parameters such as reconstructed uniformity, spatial resolution, low contrast resolution, pixel size, slice width etc. of the SPECT/PET system. They provide accurate information on physiological processes in the human body in the form of 3D images.



**Scatter and Sensitivity Nuclear Medicine Phantoms**

## Development of a prototype Deep Brain Stimulator

A prototype Deep Brain Stimulator was developed for treating neurological conditions in deep areas of brain in a precise manner. It is used to treat neurological conditions by delivering electrical stimulation to precisely targeted areas of the brain responsible for motor function. The DBS system consists of implantable components viz. Implantable Pulse Generator (IPG), brain lead & intermediate lead and external components viz. External Interface Unit (EIU), Patient Programmer (PP) & Clinician Programmer



**Implantable Pulse Generator, a key constituent of Deep Brain Simulator**

(CP). The system was developed under an MoU between BARC and SCTIMST, Thiruvananthapuram.

## Radio Diagnostic & Treatment Services

Regional centres at Delhi, Dibrugarh & Kolkata, Hyderabad (also known 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 3000 patients of the region avail the (RIA & IRMA tests as well as RPhs products supply) services from this centre.

During the year 2021-22, approximately 220 Nos. of Technetium cold kits for formulation of  $^{99m}\text{Tc}$ -radiopharmaceuticals were supplied to various Nuclear Medicine Hospitals in Kolkata

Approximately 54Ci of F-18 was produced and supplied from CYCLONE-30 at MCF, Kolkata.

Around 150 batches of  $^{18}\text{F}$ -FDG were routinely analysed and certified by Quality Control during this period. Regular Quality Assurance was performed before the batch release of all the RPhs which were supplied through the Centre during the reported period. Regular production and supply of  $^{18}\text{F}$ -FDG to different hospitals from DAE Medical Cyclotron, CYCLONE- 30, Kolkata. The Centre continued to supply  $^{18}\text{F}$ -FDG even through the lockdown period.

A few batches of [ $^{18}\text{F}$ ]NaF, PET agent for bone imaging, was routinely analyzed and certified by QC before the supply of the new product,  $^{18}\text{F}$ -Na $^{18}\text{F}$ , during this period. Regular Quality Assurance was performed before batch release of all the radiopharmaceuticals which were supplied.

Regional Centre, Bengaluru has a Radioanalytical laboratory for the measurement and certification of residual radioactivity in various commodities such as food items for human & animal consumption, medicine and other miscellaneous items. The laboratory got accredited with ISO 17025:2017 by NABL (National Accreditation Board for Testing and Calibration Laboratories). RC, Bengaluru has analysed around 150 samples from different customers during the reported period.



**RAL Laboratory at RC, Bengaluru**

Commissioning of Gamma Blood irradiator (Cs-137 source), which was received from BRIT Mumbai, was carried out successfully in the month of November 2021 at Kidwai Memorial Hospital Campus, Bengaluru. Daily around 100 numbers of blood and platelets bags are irradiated at this Centre. RC, Bengaluru have irradiated around 2000 bags till Dec 2021.

Regional Centre BRIT, Bengaluru has supplied approx. 97Ci of  $^{99m}\text{Tc}$  to various (7 regular customers) Hospitals and Diagnostic Centers.  $^{99m}\text{Tc}$  from RCB is utilized by more than 8000 patients/ year in Bengaluru City. Around 650 TCK cold kits (20 regular customers) were supplied for preparation of  $^{99m}\text{Tc}$  radiopharmaceuticals.

Regional Centre for Radiopharmaceuticals, Delhi, continued the supply of clinical grade, ready to use diagnostic  $^{99m}\text{Tc}$ -radiopharmaceuticals injections in compliance with GMP and RPC, COLTECH/GELTECH Generators and TCM-2 ( $^{99}\text{Mo}$  Generator kit for Solvent Extraction) ( $^{99m}\text{TcO}_4^-$ ), for the nuclear medicine centres in Delhi and NCR regions.

Quality Control of ready-to-use Tc-99m & its labelled RPhs from 185 batches were analyzed during the said period. ~704 Nos. of TCK Cold kits have been supplied from retail outlet of Regional Centre, BRIT, Delhi, to different private and Government Nuclear Medicine Centres in Delhi, NCR & Northern region of India.

During the period, Regional Centre of BRIT, Hyderabad (Jonaki) supplied ready-to-use Tc-99m as Sodium Pertechnate (16.70 Ci) to local Nuclear Medicine Centres. It has supplied 562 Nos. of TCK Cold kits (produced at BRIT, Vashi Complex) from retail outlet of Regional Centre, BRIT, Hyderabad.

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 the local Nuclear Medicine Centres and Radioanalytical facility for providing radioanalytical services to the users.

Also, during the Year 2021-22, RC, BRIT, Hyderabad, continued the synthesis and supply of  $^{32}\text{P}$ -

labelled nucleotides (122.25 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  $^{14}\text{C}$ ,  $^3\text{H}$  and  $^{35}\text{S}$ -labelled products and various types of Tritium-Filled Self-Luminous sources.

During April 2021 to January 2022, Labelled Compounds Programme has supplied 12648 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.

The tritium gas facility at CIRUS reactor building, BARC, Trombay, is in the advanced stage of completion. Once this facility is ready for operation, the production activities of these products will be shifted to CIRUS facility. Collaborative work for assembling a module for the Laser cutting and sealing of glass tubes as part of bulk production of certain TFS is progressing at RRCAT, Indore.

Custom synthesis and supply of radiolabelled compounds, mainly, C-14 based compounds, is provided to research institutes. These find extensive applications as tracers in the field of biology.

Labelled Compounds Laboratory also continued the production and supply of  $^{14}\text{C}$ -Urea Capsules which is used for diagnosis of Helicobacter Pylori infection which causes stomach ulcers.

## Radio Analysis

Radioanalytical Laboratory, BRIT Vashi Complex carried out the measurement and certification of radionuclide content in commodities such as food items meant for human & animal consumption, water samples, metal & metal products, environmental samples such as coal, flyash, soil, rock phosphate,



*Instruments at Radioanalytical Laboratory*

phosphogypsum etc. The laboratory is accredited by NABL also empaneled by BIS for the testing of gross alpha and gross beta content in water samples.

During April-December 2021, RAL had carried out more than 5000 tests on export/domestic commodities and water samples. In addition, one on-site survey was also carried out to monitor the surface radiation dose of one steel consignment.

### **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 2021-22. A project, viz. 'Safety System Upgradation and Refurbishment of ISOMED facility', has been undertaken by BRIT with effect from November 2020.

Rectification of the perennial issue of source interference (in compliance to regulatory recommendation) is required, 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 impeccable 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, is underway.

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, is also kept in mind while renovating the facility.

Currently, the structural repairs work of the facility building is under progress. Also, as a parallel activity, the task of removing and shifting 72 nos of Cobalt-60 sources, is under speedy progress. The removal of sources would pave the way for the installation of new set of systems related to Cobalt-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.

The group has also been involved in the tender related activities towards the proposed task of outsourcing of the PAN India logistics for the radiopharmaceuticals and radiography cameras, being commercially produced by BRIT.

### **New Projects**

#### **Setting up of Fission based <sup>99</sup>Mo Production Facility**

Work at the Fission Moly Project site resumed in June 2021 after the COVID-19 related lockdown. Entire Machineries & equipment was supplied by the vendor. All consignments of consumables & sealed sources received. Installation and commissioning of Hot cells,



*Mo-99 Production Facility (Outside view)*



**Mo-99 Production Facility (Inside view)**

HVAC system, fire alarm system & security system is completed. Cold commissioning is in progress and hot trials are expected to be initiated.

## Advanced Facilities for Radiopharmaceuticals Production

Setting up and commissioning of a GMP-compliant production facility for (a) production of  $^{131}\text{I}$ -meta iodo benzyl guanidine ( $^{131}\text{I}$ -mIBG) for clinical management of neuroendocrine tumors & (b) production facility for  $^{177}\text{Lu}$  radiopharmaceuticals, were completed and the facilities were inaugurated by Director, BARC, during the period 2021-22.



**Inauguration of GMP-compliant facility for Production of  $^{177}\text{Lu}$  Radiopharmaceuticals**

Setting up of new facility for production of tritium filled sources is in progress.

Commissioning of low level exempt liquid waste storage facility at (a) Radiopharmaceutical Laboratory & (b) Labelled Compounds Laboratory, at BRIT Vashi Complex were completed and inaugurated by Director, DCSEM.

## Biomedical Applications

At RRCAT, a compact diode end-pumped intra cavity frequency doubled green laser for medical applications has been developed. A maximum 2 W of continuous (CW) green power was achieved at the fiber tip with 86% coupling efficiency. Output power stability was measured to be less than 5% for half an hour operation. Shot to shot pulse energy variation was measured to be  $\pm 5$  mJ.



**Photographs of compact green laser under operation**

Acquiring photoacoustic signature of hematocrit variation from lexus layer of in-silico human skin phantom, the study done at SINP investigates whether the signature of hematocrit variation from plexus i.e., the first skin layer having very small blood volume percentage distributed in capillary vessels, is retained by the detected photoacoustic response. The in-silico skin phantom is irradiated by a small footprint and low power (below 5 W) continuous wave LASER diode (405 nm) to generate detectable pressure from capillary blood vessels of plexus. with the increase in hematocrit from 10% to 50%, photoacoustic amplitude monotonically increased to double. This numerical model is expected to be an important basis to realize the idea of low-cost small footprint in-vivo photoacoustic hematocrit measurement device.

## Alternative Applications of Heavy Water

Non-nuclear applications of deuterium are diversified at large in medicinal chemistry/biological fields and are being pursued at academics, research

institutes and industries. Indian industries as well as academics have unique opportunity to grow in this field. It is possible to accelerate research and industrially scale up the activities with collaborative efforts. Since it is difficult for a single organization to cover all the fields of applications, HWB is therefore, putting efforts to collaborate with expert organizations to get the best outcome.

The projects under Development of Deuterated APIs and therapeutic use of Deuterium Depleted Water includes collaboration with Faculty of Pharmacy, Maharaja Sayajirao University (MSU) of Baroda and collaboration with Advanced Centre for Treatment, Research and Education in Cancer (ACTREC), Navi Mumbai. Work Order has been issued to Faculty of Pharmacy, MSU, Baroda. Proposal for issuing work order to ACTREC is in final stages.

M/s. Merck Life Science, India has approached HWB for long term assured bulk supply of Heavy Water for development of deuterated compounds. M/s. Merck Life Science, India is planning to expand two of its sites in India i.e. in Peenya and Jigani, Bangalore. They have indicated that the proposed expansion will benefit India with respect to the growth of local chemicals market and increasing exports.

For the project “Augmentation of production of deuterated compounds at HWP, Baroda”, engineering documents have been prepared and tendering for the process units is being initiated.

Besides dispatching small quantities of Heavy Water for R&D purposes, approval has been taken for supply of small quantity Heavy Water to various users viz. M/s Sigma-Aldrich, M/s Simson Life Sciences etc. Heavy Water has been supplied to M/s Clearsynth and M/s SyNMR under the existing collaborative agreement with these parties.

Tendering process has been completed for sale of Deuterium Depleted Water to various users and several offers have been received from interested parties.

Based on the MoU signed between BRIT and Heavy Water Board, deuterated NMR solvents were



*Tritium Filled Light Sources*

dispensed and supplied to various customers. All the solvents that were supplied had >98% Deuterium abundance.

## 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.

Tata Memorial Centre sees cumulatively over 1 lakh patients at its hospitals across the country. With its motto of providing affordable cancer care to all irrespective of socio-economic strata. In order to accomplish this objective, the institute has undertaken various initiatives to facilitate a patient's journey in the hospital. In addition to this, numerous noble organizations support various aspects of patient care in the hospital.

The “ImPaCCT Foundation” (Improving Paediatric Cancer Care and Treatment Foundation), which is one of the organizations closely associated with the Paediatric Cancers Department which ensures that every child with cancer coming to TMC receives treatment along with complete holistic support,

regardless of the family background. The foundation has mobilised more than 35 crores worth of funds, extending educational, financial, nutritional and psycho-social support to scores of children and their families, effecting a significant reduction in treatment refusal and abandonment.

Brain Tumor Foundation (BTF) of India was established with a mission to help and support patients with tumors of the brain and central nervous system, their family members and care-givers. The BTF, this year, added another feather to its cap by featuring in the International Brain Tumor Alliance (IBTA) News Magazine and also got recognised as member of the Asia-Pacific Brain Tumor Alliance (APBTA). In addition to the expertise provided in preparing guidelines for COVID-19 vaccination for brain tumor patients, the web-based information portal and brain tumor helpline provided succour to numerous patients during the pandemic when physical access to the hospital was hampered.

The Department of Preventive Oncology which is an integral part of the Tata Memorial Centre, continued to provide its services despite the challenges of the pandemic as prevention and early diagnosis of cancer are key to reducing the cancer burden of the country. Owing to the COVID-19 restrictions at the beginning of the year, the department conducted several virtual cancer prevention awareness activities for communities across the country. The on-site community cancer prevention activities were restarted once the Covid restrictions had relaxed, reaching out to 2000 plus participants across 32 institutions (schools, colleges,

etc.). Screening camps were also conducted for high-risk populations such as slum dwellers, factory workers and employees of 'Solid Waste Management Department' of Brihanmumbai Municipal Corporation. Under the "Collaborative Action for Control of Cancer and Other Non-Communicable Diseases among Mumbai Police", a total of 1103 health education sessions and 415 screening camps have been organized and conducted for Mumbai police. The department has also been involved in COVID 19 vaccination duties at TMH Vaccination Centre for general population, staff & their family members, patients and attendants and various corporates.

Women's Cancer Initiative– Tata Memorial Hospital (WCI-TMH) is a non-profit NGO started in 2003 as a partnership between Mrs. Devieka Bhojwani (herself a breast cancer survivor and a prominent social activist of Mumbai) and Tata Memorial Hospital. The WCI-TMH has provided financial support of more than ₹ 7.75 lakhs to several underprivileged patients suffering from breast and gynecological cancer in the past year. Three research projects undertaken by the consultants at Tata Memorial Hospital, a phase III double blind randomized placebo-controlled study and two randomised control trials are being financially supported to the tune of up to ₹ 20 lakhs. The three international conferences and celebration of the International Women's Day provided a wonderful opportunity to share, learn and advocate best practices in Women's cancer care.

In order to provide more personalized attention and addressing patient's needs, the Tata Memorial Centre in collaboration with Tata Institute of Social Sciences and with support from Tata Trusts has conceptualized a new speciality in Healthcare by introducing a one-year (full time) Post Graduate Diploma in Patient Navigation (KEVAT), for the first time in India, in 2018. In a very short span of time the Patient Navigators (Kevats) have become an integral and indispensable part of the patient care team at TMC. They help patients manage their medical experience, co-ordinate their care and assist them with navigation of complicated and multi-step medical system. They were of special assistance during the pandemic when patient flow in the Hospital was altered and new protocols were



**Screening camps conducted by  
Tata Memorial Centre**

introduced. The Kevats participated in screening duties contributing towards screening 140977 patients on entry into the Hospital. Kevats facilitated the process of entering patient data in the CIS and maintained meticulous records of the tele-consult, reducing the clinician workload considerably. Other initiatives such as pharmacy queue management, training to administrative staff and management of documentation enabled 100% functionality of the hospital. Empowered to address multitude of patient needs including communication and counselling, the Kevats, fellows and Assistants reached out to more than 50,000 cancer patients in need.

#### <sup>60</sup>Co Teletherapy Sources for Cancer Hospitals

Total 4792 kCi of Cobalt-60 sealed sources are supplied in 48 number of consignments which include Eleven Cobalt-60 Teletherapy Sources (CTS) and Two hundred and Ninety Seven (297) Multi-Purpose Gamma Irradiator Sources consisting of Two hundred (200) number of BC-188 type and Ninety Seven (97) number of W-91 type sealed sources used for radiation processing applications such as Medical sterilisation, post-harvest food preservation, sludge hygienisation, etc. to various Multipurpose gamma irradiators in the country and abroad.

Exported total of Seventy-Two (72) numbers of BC-188 type Multi-Purpose Gamma Irradiator Sources with total activity 750 kCi to various countries which include 250 kCi to M/s. Ansell Lanka, Sri Lanka and 500 kCi to M/s Ansell Malaysia.

## WATER

### Water Purification, Desalination of Water & Isotope Hydrology

BARC has developed a precipitation-assisted membrane-based technique for treating radioactivity present in effluents discharged during the processing of rare earth minerals.

An adsorptive gel material has been developed for production of Uranium-free water (<30 ppb U), in community scale, from contaminated ground water.



**Effluent Water Treatment Plant (AEWTP) of 500 litres per hour capacity**

An Advanced Effluent Water Treatment Plant (AEWTP) of 500 LPH capacity was installed by BARC for treating water contaminated with oil and dyes.

Under the DAE Project “Deployment of water purification technologies in 50 villages in India”, 400 point-of-use arsenic decontamination devices of 24 litres per day capacity were deployed for providing arsenic-free safe drinking water at a remote village in Bihar.

A 2000 litres per hour capacity plant was installed for providing drinking water free from fluoride to 4 villages of a remote district in Odisha. The plant was established based on the technology developed in BARC.

The Nuclear Desalination Demonstration Plant at Kalpakkam was operated by BARC to produce 145,204 m<sup>3</sup> of water. Long term evaluation of the indigenous SWRO (sea water reverse osmosis) membrane elements is in progress.

A covellite based adsorbent, christened 'Arsenil', for the remediation of arsenic from contaminated groundwater was developed in BARC. 25 gm of Arsenil remediates 25L water contaminated with 200 ppb arsenic in less than two hours. The method is conveniently suitable for household and point-of-use applications. A kit for the visual detection of arsenic in groundwater was also developed. The kit can detect arsenic contamination in terms of WHO and Indian specifications. The method is simple and can be performed with ease by common people. It has immense utility in any strategy on providing arsenic free drinking water.



**Measurement of in situ parameters and tank water sampling for isotopes is underway in Srikakulam district of north Andhra Pradesh**

As a part of Jal Shakti Abhiyan initiative of Govt. of India, an isotope hydrological investigation was carried out in three drought prone mandals in north Andhra Pradesh, namely Laveru, G.Sigdam and Ranasthalam to evaluate the impact of Tank water (surface water) on groundwater replenishment. Based on the isotope data it can be inferred that the tank water contribution to groundwater recharge is mainly governed by the nature of rock-strata. The shallow water recharges the groundwater in sandstone formation and deep fracture-controlled flows recharge groundwater in Granitic gneiss and Quartzite formations while Khondalite formation receives both shallow and deep flows. The tank water contribution was estimated using Multi-component End Member Mixing model and was found to be typically < 20% during pre-monsoon while in post monsoon season, it reaches up to 70% in some wells. Nitrate and fluoride are the major contaminants in the groundwater of this region.

The hgSBR is a compact biological waste water treatment system for effective removal of contaminants from domestic and industrial waste waters. hgSBR technology utilizes the unique features of SBR technology and bio-beads for effective waste water treatment in a single tank without requiring secondary settler. It makes use of the native microbes of waste water in the form of bio-beads (biofilms and granules) for removing contaminants. The hgSBR STP technology based domestic waste-water treatment plant of capacity 0.15 MLD at Sneh Rashmi Botanical Garden, Ugat,

Bhesan Road, Jahangirabad, Surat, Gujarat, was proposed by HWB in collaboration with the Surat Municipal Corporation for technology demonstration purpose. The same was accepted by the Corporation. This tender is for building the facility and operating it for one year from the date of commissioning of the plant. The tender's scope includes all the civil construction work, mechanical equipment's installation, electrical power panels and cabling and plant automation. This tender's execution will be monitored as a turnkey project. Presently the tender documents are under preparation.

## INDUSTRIAL APPLICATIONS

### Cobalt-60 based Industrial Radiography Device (COCAM-120)

BRIT is providing its exemplary services and playing a pivotal role since last three decades for the NDT industry in the country. BRIT is developing different industrial radiography device competing international standards and also providing complete services connected with the radiography devices. The newly launched indigenously developed Co-60 based Industrial Radiography Device "COCAM-120" is now commercially available for the NDT industry. The first device is handed over to the NDT user by the Chief Executive, BRIT in the event held on 18th September, 2021. The COCAM-120 is designed as an exposure device cum transport container for 4.44 TBq (120 Ci) of Co-60 source. It uses a unique hybrid shielding arrangement comprising of depleted uranium, tungsten



**COCAM-120 being handed over to the NDT industry by Chief Executive, BRIT for its commercial utilization**

alloy and lead to make it compact and light in weight. Zircaloy-2 tube in form of S shaped has been used for smooth movement of pigtail and to avoid any radiation streaming. The device can be used for the non-destructive examination of material of thickness ranging from 40 mm to 200 mm in steel. The device is designed, manufactured, tested & approved as a Type B (U) package by AERB vide. IND/40/B (U)-96 and as Category-II IGRED vide. 18-COMSUPPTA-335710.

The COCAM-120 is proving itself as an import substitute and contributing towards the “Atmanirbhar Bharat”. The commercial introduction of the device is wholeheartedly welcomed by the NDT industry. A no. of orders was registered by BRIT soon after its introduction. The tremendous response & enthusiasm shown by the NDT industry towards the COCAM-120 is definitely noteworthy.

#### **Development of Cryo Irradiator**

The existing Install and Operate type Irradiator have been upgraded to Cryo Irradiator to make it suitable for irradiating marine products. Cryo Irradiator is specially designed to irradiate the marine products, as maintaining the cold chain is necessary in marine products supply chain. Cryo Irradiator is basically a category I batch type irradiator in which source is stored in a dry container and it always remains shielded and no human access is physically possible where source is kept. The plant is designed as a batch type irradiator which can cater to all other products including food and medical, which are permitted to be radiation processed. Cryo Irradiator can accommodate a maximum of 400 kCi of Cobalt-60 in form of 40 numbers of standard BC-188 pencil placed in circular fashion in a source cage. Cryo Irradiator has a through put of 6 Ton/day with a dose rate of 7kGy/hr. The Cryo Irradiator consists of a building with concrete pit in which the cask containing the source is placed. The cask is made up of stainless steel and lead. Stainless steel is used as incasing material and lead as a shielding material. The other component of Cryo irradiator is Duplex plug, Upper shield, Product Carrier, Support Structure, Product incoming and outgoing conveyor, Hoist System with counter weight to move the product box up and down, ventilation system and a chilled air supply system.

#### **Designing of Cobalt Export Flask**

Cobalt Export Flask (CEF) is a type B (U) transportation cask designed to transport 30 kCi of Cobalt-60 in sealed form. The main objective of designing this transportation package is to meet the burgeoning demand of Co-60 in International market. With this cask BRIT can export Cobalt 60 sealed sources to Industrial Irradiators established in other countries.

The Flask is made up of AISI SS304L as encasing material and Lead as a shielding material. Fins are provided on the outer surface for lifting as well as for dissipating thermal heat generated by decay of Cobalt 60. The overall size of the package is 1200 mm x 800 mm x 800 mm. The weight of the package is less than 3 Ton.

#### **Electron Beam Melting Machine**

An indigenous 10 kW Electron Beam Melting machine has been designed and developed for purification of metals and preparation of alloys in small quantities. The performance testing of the EB melting machine was carried out by BARC.

#### **Magnetic Welding Machine**

A 30 kJ magnetic welding machine has been commissioned in BARC. Solid state welding between D9 steel to SS316LN was done using this machine. For the first time, 9Cr1Mo ODS steel clad to modified Grade 91 end plug was also established.

### **Radioisotope Sources supplied by BRIT**

#### **Radiography Sources**

A total of 533 Nos. of Ir-192 & two Nos. of Co-60 radiography sources with total activity 2100 kCi and 93.3 kCi respectively were supplied from April 2021 to December 2022. Another 150 sources of <sup>192</sup>Ir with activity of 6000Ci is expected to be fabricated & supplied up to March 2022.

#### **Co-60 CMR sources**

A total of 32 nos. with total activity 2996.04 mCi were fabricated (34 nos. with total activity 3178.26 mCi were supplied) up to December 2021. As per demand activity/sources is/are planned up to March 2022.

## Isotope Application Services

### Gamma Scanning of Reactor-Regenerator System (RRS) of Catalytic Cracking Unit (CCU), BPCL, Mumbai Refinery

In the Catalytic Cracking Unit (CCU) of a leading petroleum refinery of India, high catalyst losses and reactor overhead oscillations were observed post start-up of the damaged bellow valve replacement. Some mechanical damage or plugging of the internals in the RRS was suspected by refinery engineers. BRIT received an enquiry for the above stated problem. A technical discussion was held with the refinery engineers. It was decided to perform gamma scanning of the regenerator cyclones, air grid area, reactor cyclones, riser pipe and stripper vessel by using 80 mCi of Cobalt-60 radioactive source. Prompt action was taken by BRIT as per the urgency of the job. Mechanical fitting was done for all the equipment to be scanned as per the scan line orientation. Scanning was performed with the help of automatic column scanner which consists of a source holder, BGO detector assembly, source/detector operator, control unit and laptop. The scan profiles were interpreted and mechanical damages were not observed in the cyclones. Some plugging was observed in the reactor cyclones and bottom regenerator air grid. Riser pipe bottom was also showing normal behaviour. The gamma scanning report was very useful to assess the health of the internals and operational anomalies in the RRS.



**Gamma Scanning of Reactor Regenerator System of BPCL, Mumbai Refinery**

### Radiotracer Study for Leakage Detection in Underground CRWS/OWS Pipeline Network

Oil leakage was observed at various locations inside a petrochemical plant. The traces were enormously increased during the monsoon. Mixing of this oil to the ground water and outside water body was not permitted due to strict environmental norms. Identification of the source of this leakage was very important to avoid the product losses as well as the environment pollution. It was suspected by plant engineers that drainage pipe segments of Contaminated Rain Water Sewer (CRWS)/Oily Water Sewer (OWS) network may be leaking. These are huge pipes (dia. 300 mm approx.) buried around 3-4 meters depth underground connected with manway chambers located at every 20 m length. A radiotracer study was performed by multiple injection of Mo-99 as sodium molybdate in different manway chambers. Radiation detectors were placed at the inlet and outlet of the pipe segments. Travel of the radiotracer through these pipe segments was recorded by multi-channel data acquisition system. Analysis of the radiation data indicated presence of leak in the two pipe segments. The plant was a zero liquid discharge facility. In that scenario, this study was very helpful to identify the source of the leakage. The plant engineers were able to plan for the problem rectification as well as to meet the strict environmental norms. The above said industrial diagnostic services were able to provide benefits to the industries in terms of taking decisions on shutdown, pinpoint the malfunctions in running condition, minimize the downtime of the plant and avoid the huge financial losses as well as earning a valuable revenue for BRIT.



**Radiotracer study for Oil Leakage Detection in a Petrochemical Plant**





*MACE Telescope at Hanle, Ladakh*

# CHAPTER 5

## BASIC AND APPLIED RESEARCH



*Fish eye view of the cooling water system  
under installation at ITER site*

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

At HRI, the main themes of research of the mathematics were in the areas of Finite Group theory, Algebraic Geometry, Differential Geometry, Harmonic Analysis, Lie Algebras, and Number theory. Cohomology theory for braces acting trivially on abelian groups (viewed as trivial braces) was recently introduced and investigated by Lebed and Vendramin. Bachiler suggested some ideas about non-trivial actions. The investigation of second cohomology group of a left skew brace acting on an abelian group viewed as a trivial left brace and established a bijective correspondence between the second cohomology group and class of extensions of the left skew brace were carried out. A fundamental exact sequence connecting the second cohomology group of a skew brace with the automorphism group of extensions of the skew brace were constructed. Finite  $p$ -groups of order  $p^7$ , and a fine characterization of those groups  $G$  of order  $p^7$  whose commutator subgroup contains elements that are not commutators in  $G$  were investigated. Integrable representations for extended affine Lie algebras, where the center acts trivially on the modules were classified. A class of irreducible modules for loop-Virasoro algebras were studied. In number theory, they proved that if the trace of a linear combination of the Galois conjugates of a given algebraic number is an integer for an explicit finite set of conditions, then it is an algebraic integer. Work on the factorization of a triple product  $p$ -adic Rankin L-series was continued. A chow-Heegner class which is generalization of a chow-Heegner point have been successfully constructed.

At SINP, a new class of open, translationally invariant spin chains with long-range interactions, which includes the well-known Haldane-Shastry chain as a particular degenerate case, has been introduced. This spin chain has a novel interaction dynamics. Several statistical properties of the new chain's spectrum have also been analyzed. In particular, it has been shown that it is highly degenerate, which strongly suggests the existence of an underlying symmetry for this spin chain. In another work, global quantum quenches in the Long Range Kitaev (LRK) chains have been studied. The quench has been performed on the power law exponent that governs the long range interaction. The entanglement dynamics in such systems has also been studied.

The correlations of Nuclear Matter Parameter (NMP) with several properties of finite nuclei and of neutron stars within mean-field frameworks have been reviewed. From the correlations of nuclear matter parameters with neutron star observables, it is shown how precision knowledge of the radii and tidal deformability of neutron stars in the mass range 1 - 2 Msun may help cast them in narrower bounds. The importance of the constraints imposed by finite nuclei properties in unveiling the correlations of the tidal deformability with the symmetry energy parameters is investigated within the Chi-squared based Covariance Approach (CCA).

The principal goal of the relativistic heavy-ion experiments is to explore the phase structure of the underlying theory of strong interaction – Quantum Chromodynamics (QCD) - by creating in the laboratory the new state of matter “Quark Gluon Plasma (QGP)”. Addressing of various important issues of this newly emerging field of QGP has been actively pursued that has important relevance for the phenomenology of ongoing heavy-ion physics.

At BARC, a 2D Computational Fluid Dynamics (CFD) model has been developed for separation of Hydrogen from Hydrogen – Helium mixture in a Proton Exchange Membrane (PEM) based electro-chemical reactor. The current density versus cell voltage was predicted with reasonable accuracy. A single phase, laminar flow CFD model has been developed to study

electrolyte distribution inside flow channels with different geometries. A two phase CFD model of electrolyte flow channel geometry was also developed to study the influence of feed flow rate and current density on gas hold-up distribution inside the flow channel. Design and size specifications of cryogenic distillation column for Liquid Oxygen (LOX) or Liquid Nitrogen (LN) production was carried out using commercial process simulation software and in-house thermodynamics model library. The operating conditions, hydraulic performance and other related parameters for the distillation column were optimized and heat duties for the condenser and re-boiler were determined.

Molecular dynamics simulation approach was employed to elucidate energetic heterogeneity arising from well-defined surface structure of atomistic  $^{60}\text{Co}$ .

At TIFR, work was carried out on several questions and problems in Geometric Group Theory, Probability Theory, Complex Analysis, Conformal Dynamics, and Reflection Groups, Geometry and Topology, Lie Groups, Arithmetic Groups and Algebraic Geometry. Univalent polynomials have played an important role in classical complex and functional analysis. Researchers related the theory of univalent polynomials to the field of conformal dynamics, and introduced quasiconformal deformation techniques to the study of univalent polynomials. Using this technique, researchers gave a complete description of 'extremal' univalent polynomials in terms of simple combinatorial objects; namely, trees. In Geometry and Topology, researchers proposed two definitions of configuration Lie groupoids and in both the cases proved a Fadell-Neuwirth type fibration theorem for a class of Lie groupoids. Researchers showed that this is the best possible extension, for the class of Lie groupoids corresponding to global quotient orbifolds with nonempty singular set, the fibration theorems do not hold.

Research work was pursued in the areas of computer science as well as systems science. Researchers focused on machine (deep) learning based estimation of key information measures to utilize them in conditional independence testing; inventing

new information measures based on submodular functions, which generalize the classical entropy and mutual information; improving the optimization of latent space in auto-encoder networks for close-to-real generation task. In Complexity Theory, researchers considered the problem of parametric shortest paths in graphs, where every edge has a function. These functions determine the cost of a path from the source node to the target node. In this study, researchers formulate the problem in a general setting, and show that in some situations the problem remains tractable, while in others it is NP-hard.

The Institute of Mathematical Sciences (IMSc) continued to work in the areas of Computational Biology, Mathematics, Theoretical Physics and Theoretical Computer Science. A paper titled "Remarks on CCR and CAR flows over closed convex cones" authored by Anbu Arjunan, got accepted for publication in the journal *Infinite Dimensional Analysis, Quantum Probability and Related Topics* on August 19, 2021. K Srinivas, M Subramani and Usha K Sangale in a recent work showed that all imaginary biquadratic fields and cyclic quartic fields of class number 1 are Euclidean. This has appeared in the *Journal Rendiconti del Circolo Matematico di Palermo Series 2* with the title *Euclidean algorithm in Galois Quartic Fields*. A progress towards resolving a long-standing puzzle about the fate of anomalous axial U (1) symmetry for QCD with two light quark flavors in the chiral limit has been recently published as a peer-reviewed paper, authored by Sayantan Sharma and his collaborators Lukas Mazur and Olaf Kaczmarek in *Physical Review D*, 104, 094518 (2021).

## PHYSICS

In Astronomy and Astrophysics, the researchers at TIFR presented the abundance analyses of seven Carbon Enhanced Metal-Poor (CEMP) stars to understand the origin of carbon in them. The study used high-resolution optical spectra to derive abundances of various elements. Low-resolution Near-Infrared (NIR) spectra was also used to derive the abundance of O and  $^{12}\text{C}/^{13}\text{C}$  from the CO molecular band and compared their values with those derived from high-resolution optical

spectra. Researchers identified a good agreement between the values. In another study, observations of four bright stars observed with the AstroSat Soft X-ray Telescope (SXT) were presented and the study demonstrated how to extract the X-ray events without contamination by the visible light.

Scientific ballooning program is a key element for any space science program as it provides frequent and low-cost balloon flight opportunities. The TIFR Balloon Facility, Hyderabad extended its support to national and international user scientists for conducting balloon flights for space research. Under a joint collaborative program, TIFR Balloon Facility collaborated with atmospheric scientists from National Atmospheric Research Laboratory (NARL-ISRO), National Institute of Aerospace (NASA, USA), The French National Center for Scientific Research (CNRS, France), Divecha Centre for Climate Change (DCCC-IISc) and Space Physics Laboratory (SPL, VSSC) for conducting balloon flights for collecting aerosols and measuring black carbon from surface to stratospheric altitudes along with other meteorological parameters.

The motion of living organisms like biological motors, birds, bacteria is fundamentally different from the dynamics of inert objects like pollen grains on a fluid surface. A typical active matter model shows ballistic motion at short scales and normal diffusion at large scales. Researchers of TIFR reported a new kind of active particle dynamics in lab-grown motor-driven spheres that show anomalous diffusion belonging to the fractional Brownian motion. The non-trivial power-law correlation is unusual in such a simple tabletop experiment. The results showed non-gaussian fluctuation with a non-trivial symmetry that has been earlier predicted in theoretical toy models for non-equilibrium transport. A number of studies have recently proposed a novel route to  $\eta$ -pairing superconductivity through optical creation of doublons in Mott insulating Hubbard models. An AC driven Mott insulator, a normal quantum dot array, was studied using an analytical Keldysh field theory approach. The nonequilibrium steady state at high frequencies was found to strikingly resemble the  $\eta$ -pairing phase of a superconducting Josephson array.

Dense suspensions of bacteria form an intriguing class of non-equilibrium systems displaying a novel spatio-temporally chaotic behaviour called active turbulence. By using a hydrodynamic description of the bacterial flow, researchers showed that in the collective, and when highly active, these microorganisms give up on their meandering ways, walk the straight and narrow, and super-diffuse. In Fluid Dynamics, researchers studied the wetting of a thin elastic filament floating on a fluid surface by a droplet of another, immiscible fluid. It was found that a purely geometric theory gives a good description of the mechanical equilibria in the system. The estimates of applied tension and tension in the filament obey an elastic version of the Young-Laplace-Dupré relation. It was also found that when a highly-bendable filament completely wraps the droplet, there is continuity of curvature at the droplet-filament interface, leading to seamless wrapping as observed in a 3D droplet.

The Pelletron LINAC facility operations at TIFR continued through the pandemic, complying with Covid safety regulations. The LINAC user cycle started in February, 2021, continued till mid-April, 2021 and 8 experiments were completed successfully. The Pelletron operated from mid-July to end-October, 2021 as per user requirements, wherein a total of 18 experiments were carried out. The scientific output of the facility continues to be significant and competitive.

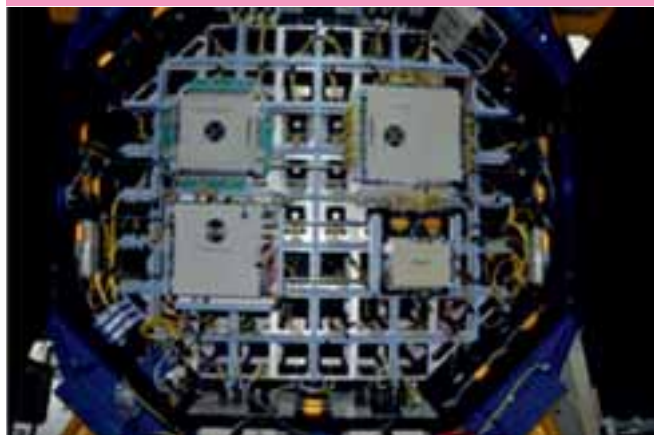
Atomic or nanoparticle clusters have properties very different from bulk materials. Cluster science is an active field of research due to applications in nanotech & colloidal science. Dusty plasmas can be used to study cluster science by creating 1-D, 2-D or 3-D finite classical Coulomb clusters. Dusty plasma is a multi-component system with neutrals, electrons, ions & highly charged massive dust particles. In this experimental work, the thermodynamics and self-organization of classical 2-D Coulomb clusters are studied as function of cluster size. Experiments were done in a DC glow discharge argon plasma, for clusters with different numbers of particles. Hexagonal symmetry around each individual particle is quantified using local orientation order parameter for all the configurations. The screened Coulomb coupling parameter, which plays a key role in determining the thermodynamic nature of a Coulomb cluster, is

estimated using Langevin dynamics and found to be sensitive to the number of particles present in a cluster. The process of self-organization and dynamics of individual particles, while going from the metastable to ground state, are studied. These findings may provide an intimate link between configurational ordering and thermodynamics of a strongly coupled Coulomb cluster system, and could be helpful in analysing and controlling micro-dynamics of micro and nano-particle clusters having applications in medicine, sensing, electronics, etc. This work has been recognized and put on the cover page of the journal *Physics of Plasmas* in July 2021.

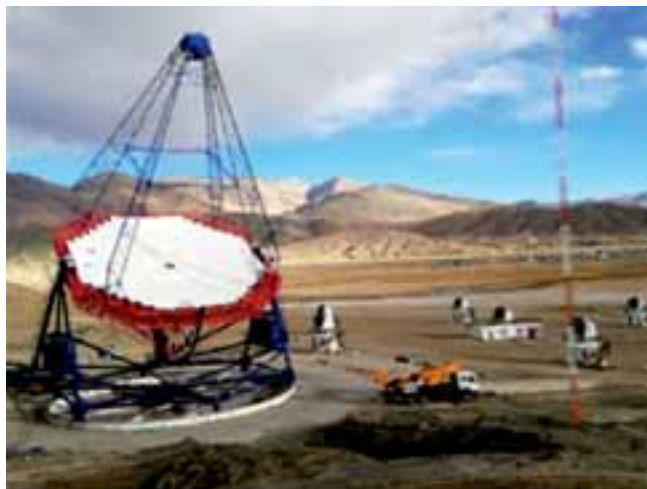
At BARC, a 1088 pixel PMT (Photo Multiplier Tube) based camera to capture Cherenkov events of 5-10 ns has been commissioned as part of the Imaging camera of Major Atmospheric Cherenkov Experiment (MACE) telescope established at Hanle in Ladakh.



*Front side view of the imaging camera*



*Rear side view of the imaging camera*



*MACE Telescope at Hanle, Ladakh*



*Large area Plastic Scintillator (PS) detector set-up ISMRAN*

The MACE telescope successfully detected high energy gamma-ray photons at the rate of 15 per minute from the standard candle Crab Nebula in April 2021. During October-November 2021 observation spell, the telescope was employed for gamma-ray observations from few nearby extragalactic sources. Few selected pulsars and active galactic nuclei will be performed during January-March 2022 spell.

A large area Plastic Scintillator (PS) detector set-up -- ISMRAN (Indian Scintillator Matrix for Reactor Anti-Neutrinos) -- has been installed at the Dhruva research reactor facility. The decay products of cosmic muons located inside the detector matrix as well as those passing through its full geometry have been

measured. ISMRAN consists of 90 plastic scintillator bars each 1m long arranged in 9 x 10 matrix and weighs 19.4 tons.

Operando structural studies were carried out on electrode materials of Li-ion batteries with synchrotron radiation to understand cyclic instability of the batteries during the charging/discharging processes, and for identifying short-lived intermittent species.



*Instrument for Operando structural studies on electrode materials of Li-ion batteries*

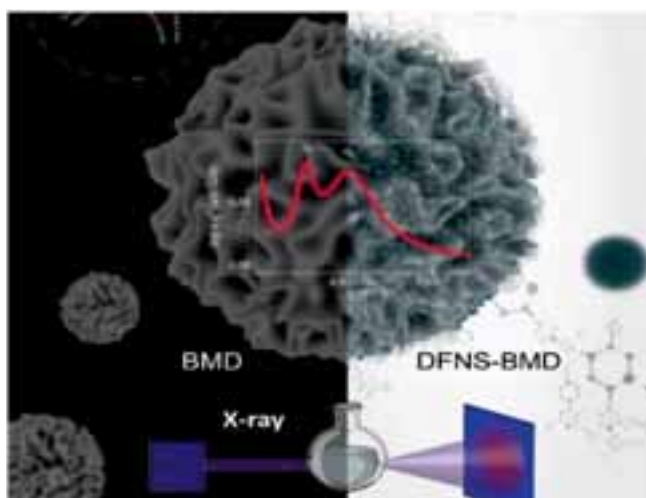


*Niobium RF superconducting cavity*

A cryogen-free low temperature set-up for testing of quantum components, including RF cavity and cold amplifier at 1K-2K temperature was made operational in BARC. The system uses dry helium gas at atmospheric pressure to facilitate low temperature physics and superconductivity experiments. It is presently being used for testing of in-house developed aluminum and Niobium superconducting cavities for RF performance.

Evolutionary crystal structure searches, ab-initio calculations have led to the prediction on existence of an unusual trigonal phase of superconducting LaH<sub>10</sub> seen stable at high pressures 250-425 GPa at 0 K. The new phase contains three units of LaH<sub>10</sub> in a primitive cell, and is expected to become superconducting at a critical temperature of about 175 K.

To unravel the formation mechanism and internal structure of Dendritic Fibrous Nano-Silica (DFNS), its structural model has been derived using small-angle neutron and X-ray scattering. Time-resolved SAXS measurements showed that DFNS originates during hydrolysis and condensation reaction through modulation of bicontinuous structure by the surfactant, co-surfactant, and the silicate species. The SAXS beamline at Indus-2 synchrotron and the Medium resolution Small Angle Neutron Scattering facility at Dhruva reactor were used for probing powder DFNS samples. Studies in DFNS may provide useful applications in the field of catalysis, CO<sub>2</sub> capture, and drug delivery.



*Internal structure of Dendritic Fibrous Nano-Silica (DFNS)*

A specialized supermirror neutron guide is being established as part of upgradation of neutron scattering facilities at Dhruva reactor. Two types of guide elements having lengths of 0.5 m and 1 m have been envisaged in order to get precise guide curvature and alignment. Experimental validation of 1 m neutron guide system (neutron guide and vacuum shroud) was accomplished with neutrons at Dhruva reactor. Overall neutron transmission of 94% was recorded with the guide unit in the beam.

An HPGe crystal detector was developed in-house from market-available HPGe single crystal. The n-type and p-type contacts were fabricated on the crystals by Li diffusion and Boron implantation, respectively. Ge film layer was deposited on the crystal diode to decrease the surface leakage current to less than 1 nA at a reverse bias of 1 kV. The diode was then mounted on the cold finger of a liquid nitrogen cooled dipstick and tested for gamma radiation. The resolution of the acquired spectra is found to be 0.3% at 662keV with line width of the  $^{137}\text{Cs}$  peak around 2 keV as compared to 1.5 keV with commercial detectors.



*HPGe detector*

Efforts were made for developing supercapacitors using hybrid electrode materials such as nanocomposites of poly (3, 4 - ethylenedioxythiophene) - poly (styrene sulfonate) (PEDOT:PSS) and  $\text{V}_2\text{O}_5$ . Coin cells of capacitance 1F were fabricated which offered gravimetric energy density of 7 Wh/kg and gravimetric power density of 1kW/kg.



*Supercapacitor made using nanocomposites of poly (3,4-ethylenedioxythiophene)-poly (styrene sulfonate)*

In Astrophysics at HRI, works on accretion physics around astrophysical black holes, analogue gravity phenomena, non commutative fluids, nonlinearity and chaotic behaviours of the light curves from compact objects, and on various other aspects of gravitation and field theory were carried out.

The Quantum Information and Computation (QIC) group of HRI conducted fundamental and application-oriented research from a wide range of topics that included physics, mathematics and computer science. The effect on the efficiency of the Shor factorization and the Grover search algorithms due to noisy environments was looked into a nonlinear measurement-device-independent entanglement witness was proposed a small quantum refrigerator in which the working substance is made of paradigmatic nearest neighbor spin-j quantum XYZ models and design a quantum battery made up of bosons or fermions in an ultracold atom setup, described by Fermi-Hubbard and Bose-Hubbard models respectively were explored a measurement- and quantum gate-based procedures to generate multipartite entanglement in networks was proposed.

Studies were carried out in string field theory to gain understanding of non-perturbative aspects of the theory. Aspects of the low energy effective action of string theory have been explored by making use of modular graphs. Conformal field theories have been studied, novel properties in their structure have been unravelled. Various studies to connect string theory to cosmology have been made. In this context, some implications of an early universe in the hagedorn phase have been explored.

Cryogenic Penning trap at VECC operated successfully at liquid helium temperature. A cloud of electrons was trapped in a closed-ended, 5-electrode, cylindrical Penning trap by applying a magnetic field 0.1T and quadrupolar electrostatic potential 10V. The image current induced by the trapped electrons on the Penning trap electrode was detected using resonant technique. The trap electrode assembly and detection circuits indigenously built at VECC operated successfully at 4K. The electron was generated by applying voltage (600 V) to Field Emission Point (FEP). The primary high energy electrons from FEP collided with the background gases and generated secondary electrons which were eventually confined in Penning trap. A ramp voltage was applied to the electrodes of the trap and it changed the axial oscillation frequency of trapped electron cloud. When the axial oscillation frequency matched with the resonance frequency of LCR circuit, a transfer of energy took place. This is observed as a dip signal when the power variation at the resonance frequency of the detection circuit was measured.

The Hoyle state of  $^{12}\text{C}$  is widely known for its  $\alpha$  cluster property as well as astrophysical importance related to nucleosynthesis. Similar kinds of states, known as the Hoyle analogue states, are predicted theoretically in different nuclei. The Hoyle analogue state in  $^{16}\text{O}$  was explored by inelastic scattering of 45 MeV  $\alpha$  beam from K-130 cyclotron at VECC on a Mylar target. The break up  $4\alpha$ s of  $^{16}\text{O}$  have been detected in coincidence with the inelastically scattered  $\alpha$  beam particle to probe the Hoyle analogue state of  $^{16}\text{O}$  in complete kinematics, for the first time. The data have been analysed for all possible configurations and the excitation energy of  $^{16}\text{O}$  has been reconstructed directly from  $4\alpha$  as well as for specific decay channels like  $^{12}\text{C} (0^{+2}) + \alpha$ ,  $^{12}\text{C} (3^{-1}) + \alpha$  and  $^8\text{Be} + ^8\text{Be}$ . The present data, being kinematically complete, provide a precision picture about the challenges one faces to identify and characterize the Hoyle analogue state in  $^{16}\text{O}$  and indicate the limitations of populating the state.

An extensive experiment was performed to measure the proton, neutron and GDR spectra from two deformed nuclei and one spherical nucleus, all

populated at 26 MeV excitation energy using the K-130 cyclotron at VECC. Intriguingly, the relative enhancement factors determined independently from all the spectra were very similar for both the deformed nuclei and only statistical decay for spherical nucleus. Moreover, the results indicated that the fade out of the collective enhancement does not depend strongly on the nuclear ground state deformation which is in stark contrast to the expectations of the phenomenological as well as microscopic calculations.

An experimental study on the Temperature (T) dependence of Giant Dipole Resonance (GDR) width was performed for  $^{74}\text{Kr}$  in the range of  $T \approx 2\text{--}2.5$  MeV using the  $^{16}\text{O}$  beam from the K-130 cyclotron. The measured data were compared with the model predictions of TSFM and phenomenological models pTSFM and CTFM, and it is observed that the data are only explained by the predication of CTFM.

A fast and efficient microscopic model has been proposed in order to predict experimental fission yields including the odd-even staggering in charge yields and neutron multiplicities for a wide range of nuclei. Fission fragment distributions of exotic neutron-rich and superheavy systems were also explored and compared with other state-of-the art global calculations.

The condensed matter theory group at Institute of Physics (IoP) remained involved in pursuing research with the main focus on understanding the organization of bacterial chromosome, various aspects of active matter, pattern formation, topological aspects of quantum condensed matter systems, driven higher-order topological systems, quantum transport in Dirac/Weyl materials, twisted bilayer systems, quantum magnetism, and strongly correlated electrons. IoP has investigated exact dynamical moments for trapped active Brownian particles to show a re-entrant non-equilibrium transition, emergence of dynamical pattern formation and running waves on spherical membranes due to active cytoskeletal proteins, time-reversal broken tight-binding model describing Kane-Mele model superimposed with Haldane model where eight different quantum hall effect including quantum anomalous Hall phases appear with one topological spin sector and multiple critical point with two topological phase co-

existence, Floquet generation of a second-order topological superconducting phase hosting Majorana corner modes, considering a quantum spin Hall insulator with a proximity induced superconducting s-wave and d-wave pairing in it, systematic generation of the cascade of anomalous dynamical first and higher-order modes in Floquet topological insulators, emergence of non-Hermitian physics at the heterojunction of a type-II Dirac semimetal and a dirty superconductor.

The Theoretical Nuclear Physics (TNP) Group at IoP remained actively involved in various areas of front-line research work. They studied the structure of neutron star along with their merger to estimate the Gravitational Wave Strain. The group studied the various modes of oscillation of neutron star, cooling of Neutron Star and Supernovae and the Dark Matter effects. The group also constructed various equations of state, which will be used by various astrophysics groups. In collaboration with other groups, the TNP group at IoP have also studied Nuclear Reaction Dynamics and various exotic structures of finite nuclei. The members are taking part in various developments of Nuclear and Astrophysics programs both Nationally and Internationally.

The experimental condensed matter group of IoP were involved in the cutting-edge research that focuses on Brain-inspired computing, Resistive switching, ion beam induced self-organized pattern formation and their nanoscale functionalization, photovoltaics, nano-bio glucose sensing and ion-beam modification of materials, organic and DNA overlayers for the understanding of interaction mechanism and sequestration of toxic materials like Mercury and Arsenic, novel electronic and magnetic phenomena in atomically engineered thin films/heterostructures, thermoelectric, electronic band structures of advanced materials and understanding of physical properties of atomically thin two dimensional layered materials such as graphene, transition metal dichalcogenides etc. In addition, the group is working on the development of a low-to-medium energy ion beam facility. The low energy 3 MV Pelletron accelerator of IoP is used by different external users to carry out their research. The work of

Prof. Satyaprakash Sahoo's group on Electric Field Modulated Charge Transfer in Geometrically Tailored  $\text{MoX}_2/\text{WX}_2$  ( $\text{X}=\text{S}, \text{Se}$ ) Heterostructures appeared as Cover page of The Journal of Physical Chemistry C (2021).

At SINP, in String Theory and Holography, one of the activities involved exploring how quantum aspects of black holes can teach us qualitative universal physics at strong coupling and vice-versa. In particular, within the context of Holography, we have been uncovering universal aspects of real-time strong-coupling dynamics by studying a large class of unexplored correlation functions and their subsequent ramifications to the physics of black holes. On one hand, such correlation functions are now-a-days experimentally accessible, thanks to the great strides made with cold atoms and the likes. On the other hand, remarkable progress in e.g. Event Horizon Telescope perhaps also makes them accessible in the context of black holes. In this process, a quantum information theoretic perspective furthermore emerges on both sides, that sometimes connects with cutting-edge research in quantum information. In addition, the ideas of quantum complexity, entanglement entropy, entanglement thermodynamics within the context of quantum field theory, gravity and black holes are also being explored.

At the National Institute of Science Education and Research (NISER), the School of Physical Sciences continued to offer the 5-year integrated Master of Science (M.Sc.) program in Physics which includes 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.

## CHEMISTRY

Certified Reference Material (CRM) of dolomite, BARC B1101, was produced jointly by BARC and AMD. The material is certified for six major and minor constituents and is about three times cheaper as

compared to similar international standards. The starting material was sourced from Tumallapalle area, Andhra Pradesh.

Ion beam analysis method based on carbon induced gamma ray emission technique has been developed for the isotopic analysis of lithium in inorganic compounds and geological materials. It has been utilized for analyzing spodumene samples from AMDER. A new ion beam method for the non-destructive determination of carbon is established. The method is validated by analyzing steel CRMs.

A visual method for the estimation of ethanol in ethanol blended petrol is developed. The estimation is based on colours developed on the addition of two reagents in succession to a sample of petrol. The method is very useful for quality control and quality assurance of the blended product. Similarly, a visual colorimetric method for on spot estimation of available phosphate in soil was developed. Phosphorus is an important nutrient and must be present in soil in optimum quantities for better productivity.

Five conductivity solutions with conductivities 10, 100, 150, 1000, and 1500  $\mu\text{S}/\text{cm}$  have been prepared using the protocols from the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC) and National Institute of Standards and Technology (NIST). The internal value assignments have been completed and the stability of the solutions is verified for the period of 8 months, and the solutions are under continuous monitoring. The analytical values are further evaluated through inter-laboratory comparison.

During the year, more than 4000 samples of wide varieties of matrices were analyzed under quality assurance. The important samples analyzed during this period include strategic samples from various DAE programs; He gas samples from AMDER for exploration studies; Uranium based samples for carbon content; Yb samples for purity check; HDP shielding materials for AHWR-CF; Alloy samples for AHWR; Ceramic magnets for reactor; Groundwater samples from Tumalapalle area; Li ion battery electrode materials; various cloth/gloves materials and metal organic frameworks.

High impact analytical works were carried out for different institutes and industries across the country. These include analysis of high purity chemicals such as tetraethyl borate and ethylene glycol for electronics industry, Ni-based superalloys for aero-engine applications by DMRL and Co-W alloys and sulphuric acid for defense.

To develop indigenous sacrificial core catcher for Indian thermal power reactors, physico-chemical studies have been carried out on red-mud after suitable thermal conditioning. In this direction, Red-mud bricks were prepared and characterized by powder XRD and XRF for ascertaining their suitability as a sacrificial core catcher for Indian thermal power reactors. The formation of  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$  based solid solutions, nepheline, minor amounts of Na hexa-aluminate and rutile was observed in the sintered brick samples. The water absorption-desorption studies suggest that the prepared bricks do not have tendency to retain water under ambient atmospheric condition. The thermophysical properties of red-mud bricks were found to be conducive for using them as sacrificial core-catcher materials.

Development of stable matrices for immobilization of radioactive Cs has technological relevance for effective utilization of the radioactive nuclei. A stable complex phosphate,  $\text{Cs}_3\text{Fe}_4(\text{PO}_4)_5$ , that can accommodate 36 wt. % of Cesium has been developed in BARC. The stability of the material has been studied by variable temperature XRD, neutron diffraction and thermal analysis techniques. It was observed that the sample undergoes melting at around  $772^\circ\text{C}$  without any loss of Cs. No structural transition is observed between 15K and melting temperature, while it undergoes a magnetic transition below 15K.

Iron Phosphate Glass (IPG) is emerging as an alternative to the more commonly used borosilicate glass for immobilization of highly volatile fission products such as Sb and Te in the nuclear waste. Several glass compositions containing different amounts of Sb and Te have been prepared by melt-quenching procedure and their glass stability parameters have been evaluated. It was observed that

the Sb and Te loaded IPG has comparable glass stability parameters and superior glass forming ability.

Phase behavior of binary alloys in zirconium-iron (Zr-Fe) system and Zircaloy-steel system has been investigated to develop metallic matrix for immobilization of zirconium-based metallic nuclear waste originating from thermal nuclear reactors. Diamond films having thickness varying from 13 microns up to 500 microns have been synthesized for their application in indigenous development of radiation detectors. Surface morphology and topography studies have been carried out on a range of uranium precursors such as Ammonium Di-Uranate (ADU), Sodium Di-Uranate (SDU), Ammonium Uranyl Carbonate (AUC), uranium trioxide ( $\text{UO}_3$ ), etc., to optimize the process for uranium production. An indigenous facility for measurement of high temperature electrical properties of ceramics and alloys has been designed and fabricated.

Protein conjugated glutaric acid functionalized Magnetic Nanoparticles (MNPs) were developed for hyperthermia therapy. The prepared MNPs are biocompatible towards normal cells and showed substantial cellular internalization in cancerous cells, suggesting their potential application in hyperthermia therapy. Hyperthermia using MNPs has been introduced clinically as an alternative approach for local treatment of tumors.

Highly monodispersed upconversion nanocrystals functionalized with folic acid for targeting tumor cells were prepared and tested for cellular imaging under UV light and NIR excitation. Nanocrystalline materials emitting a single band red light under Near Infrared excitation has advantages in terms of cellular imaging in biological windows, as agents for photodynamic and photothermal therapy.

Multi-scale simulations were carried out to understand the binding and selective extraction of actinides through Lanthanide Binding Tags (LBTs). Technical information related to Solvation dynamics has been obtained, which can offer solutions and opportunities in bio-speciation of actinides.



*Dissolved oxygen (DO) monitor*

A Dissolved Oxygen (DO) monitor with linear dynamic range of 1 ppb ( $\mu\text{g L}^{-1}$ ) to 20 ppm ( $\text{mg L}^{-1}$ ) was developed based on the redox coupling of two metals with difference in redox properties. The reduction current of oxygen is the measurable parameter for the determination of dissolved oxygen. The resolution of the system is 0.1 ppb at 2 ppm level.

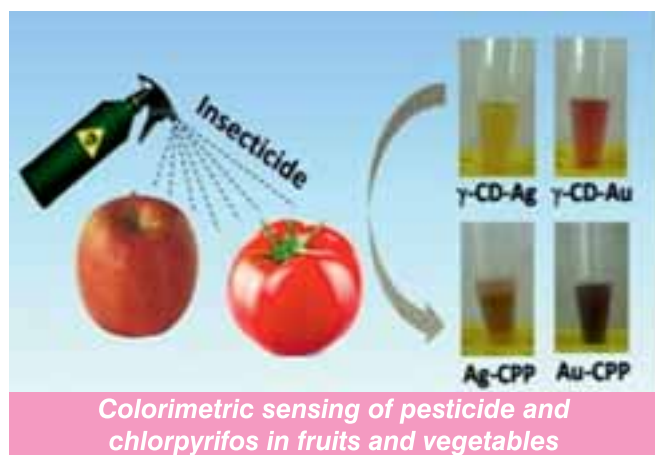
Modified stainless steel (SS) electrodes, showing bi-functional catalytic activity towards water oxidation (OER) and Hydrogen Evolution (HER), were developed. Among the different synthesis routes adopted, electrochemical deposition was found to provide an efficient Ni modified SS based electrode with lower Tafel slopes both for OER ( $39.5\text{mVdec}^{-1}$ ) and HER ( $125.8\text{mVdec}^{-1}$ ) activities. The over-potential required to generate current density of  $10\text{mAcm}^{-2}$  were 210 mV and 240 mV for OER and HER, respectively. The developed electrodes showed no change in electrocatalytic activity after 10 hours of continuous operation, indicating good stability during electrochemical reactions. These SS electrodes can replace costly conventional electrodes in electrolyzers without compromising the efficiency.

Imidazolium ionic liquids were investigated for developing potential antimicrobial formulations for biofilm prevention. The imidazolium ionic liquids containing dodecyl to hexadecyl alkyl group on cation effectively prevented biofilm formation in natural freshwater and seawater used in the tertiary Cooling Water System (CWS) of power plants. The ionic liquid was also evaluated for applications in disinfection of environmental surfaces. The chosen antimicrobial ionic liquid and its formulation prepared in ethanol were found to be suitable for disinfection of environmental

surfaces such as wood, steel and glass. The effective killing and removal of bacteria from surfaces shows potential use in sanitizers. The results indicated that ionic liquids are promising for effective antimicrobial formulations.

The clinical grade oral formulation of DSePA, a potential drug candidate molecule for treatment of radiation pneumonitis and lung cancer, has been developed in BARC. Its deuterated derivative, D-DSePA, was also evaluated for various biochemical properties. The D-DSePA exhibited better therapeutics index than parent DSePA, in terms of differentiating between normal and tumor cells, mainly due to slower metabolism in the former. Currently, the method of preparing DSePA formulation is being scaled up for phase I (safety) study in humans under DBT sponsored "Early Translation Accelerators Agreement".

Studies have been carried out to demonstrate the applicability of silver and gold nanoprobe for the detection of pesticides. A facile one-step green synthetic approach using  $\gamma$ -cyclodextrin ( $\gamma$ -CD) was employed to synthesize  $\gamma$ -CD-Ag and  $\gamma$ -CD-Au nanoprobe. The noble metal nanoprobe served as a platform for colorimetric and Raman sensing of chlorpyrifos (CPP). The colorimetric changes as well as enhancement in the Raman bands of CPP resulted due to the interaction of the metal particles primarily through the amine and phosphorothioate functional groups of CPP. The applicability of the nanoprobe was tested on apple and tomato. The methodology developed for pesticide detection is simple, fast, cost-effective and highly reproducible.



A rapid, easy, sensitive and highly selective fluorescence "Turn-On" probing system or biosensor based on Aggregation Induced Emission (AIE) was developed for monitoring ALP concentration in blood. The sensing units of the probing system are made up of an AIE active dye and polycationic Protamine Sulphate (PrS) that electrostatically interact with each other to make a highly fluorescent supra-molecular complex. Subsequently, the fluorescence of the complex is quenched by the addition of sodium hexametaphosphate,  $(\text{NaPO}_3)_6$ . A rapid recovery in the fluorescence (turn-on) is obtained by adding ALP in the basic buffer conditions.

About 250 gm of dibenzo-18-crown-6 functionalized Chloromethyl Polystyrene (CMPS-DB18C6) resin was prepared for  $\text{Sr}^{2+}$  ion adsorption. This material exhibits a high adsorption capacity of 141.37 mg/g with good selectivity and radiation stability. The regeneration of the used CMPS-DB18C6 was accomplished by 0.5M  $\text{HNO}_3$ . Breakthrough curve analysis showed 99.6% adsorber performance with bed capacity of 147.56 mg/g and 1.38 mbar pressure drop across the adsorber bed. Further, the high adsorption and selectivity of  $\text{Sr}^{2+}$  ion was complimented by performing density functional theoretical calculation.

The interaction and dynamic behaviours of hydrogen isotopes in Cr lattice were studied employing plane wave-based density functional theory. Nudge elastic band methods were used to determine the activation barrier and phonon calculations were performed to investigate the isotope effects. The diffusion of H atom from one tetrahedral hole to the adjacent tetrahedral hole has been established to be the most favoured pathway. The lighter H atom was shown to have higher diffusion coefficient, permeability coefficient, solubility and rate constant than heavier D and T atoms. The computed values of diffusion, permeability and solubility of H in Cr follow the experimental prediction.

The temperature-dependent diffusion coefficients of interstitial hydrogen, deuterium, and tritium in Fe were computed using classical and Transition State Theory (TST). The coefficient of thermal expansion, Helmholtz free energy of activation, jump

factor of the diffusion coefficient were obtained from activation energy and phonon calculations. The present computed results followed the similar trend of experimental findings. The path and kinetics of dissociation and reassociation of  $H_2$  molecule were established on Fe (100) surface at 0.5 and 2.0ML coverage. At low coverage (0.5ML), dissociation of  $H_2$  molecule was favoured, whereas at high coverage (2.0ML), reassociation of  $H_2$  molecule was favoured.

Density functional theory-based computation was performed to investigate the micro-adsorption of hydrogen and its isotopic molecules on uranium atom. The geometrical configurations of  $UX_n$ ,  $U(X_2)_n$ ,  $UX_4-(X_2)_n$  ( $X=H, D, T$ ) systems were analyzed from  $n = 1$  to 9. The interactions between U and  $H_2$  isotopic molecules were confirmed to be of Kubas type. Predictions using Structural and binding enthalpy (BE) analyses confirmed  $UH_4-(H_2)_8$  polyhydride is predicted to be the largest super polyhydride. To the best of our knowledge  $UH_4-(H_2)_8$  is the largest metal polyhydride ever been reported with twenty hydrogen atoms displaying high gravimetric density of 7.80, 14.47 and 20.21 wt% for  $H_2$ ,  $D_2$  and  $T_2$ , respectively.

Molecular dynamics simulations of  $TiO_2$  doped silicate and sodium borosilicate glasses were performed. The modification in the intermediate and long-range order of Ti containing glasses was noted by structure factor, ring statistics, and vibration density of state profiles. Emergence of smaller rings and disappearance of larger rings with  $TiO_2$  addition, resulted into higher  $T_g$ , improved chemical and mechanical durability. In addition, the impact of  $TiO_2$  addition on surface creation was analyzed, and results showed that addition of  $TiO_2$  in the glass matrix would control the increasing  $R$  ( $Na_2O/B_2O_3$ ), lowering  $K$  ( $SiO_2/B_2O_3$ ) and reducing  $BO_4$  fraction at glass surface, which make transform the surface to become less susceptible to leaching compared to bare NBS glass.

Mass spectrometric investigations on a range of metal and metal oxide clusters such as  $LaO$ ,  $Al$ ,  $AlO$ ,  $Co$ ,  $Co.NH_3$  using indigenously-built metal cluster set-up proved that lanthanum clusters containing up to 50 atoms are stable. The geometrical structures of 2 to 10

atom lanthanum clusters could be established through experimental and theoretical investigations.

The Supersonic molecular beam set-up established in BARC was used to investigate electronic structure of  $ScO$  molecule in visible/ultraviolet region using laser-induced fluorescence spectroscopy. Investigations confirmed severe perturbation among the various states of  $ScO$ , revealing the complexity in the electronic structure of the molecule, which has astrophysical importance.

### **In-situ regeneration of cold trap of HEXAMINI bench top sodium loop**

HEXAMINI bench top Sodium Loop (HSL) is being used for testing and calibration of Electrochemical Hydrogen Meters (ECHM). HSL has a Cold Trap (CT) which controls the hydrogen and oxygen impurities in the HSL by trapping the impurities as hydrides and oxides. Continuous operation of HSL, injection of hydrogen for testing and frequent opening of HSL for various purposes has led to the saturation of CT and it needed regeneration for further usage. At IGCAR, in-situ CT regeneration was carried out by thermo-vacuum process in which the  $NaH$  decomposed to sodium and hydrogen according to equation:  $2NaH \rightarrow 2Na + H_2$ . As hydrogen forms explosive mixture with air beyond 4%, Hydrogen Mitigation (HM) during the process is the key concern. HM was carried out by Online Hydrogen Monitoring (OHM) and maintaining below 2% during the process. In-house developed  $H_2$  sensors like ECHM, Polymer Electrolyte Membrane based Hydrogen Sensor (PEMHS) and Semiconducting Metal Oxide based Hydrogen Sensors (SMOHS) were deployed simultaneously for the first time towards simultaneous monitoring of hydrogen levels in sodium and argon gas plenum during the regeneration process. HCT Regeneration (HCTR) set-up was made by integrating Gas purging system to cover gas space of HSL; vacuum pumping system and online hydrogen sensors.

UHP argon gas was purged in to HSL by using mass flow controller and needle valve. Diaphragm vacuum pump was used to maintain the vacuum level of cover gas volume and the same was measured by

digital vacuum transducer. The sample gas from pump outlet was passed through suitable mass flow controller to measure the flow rate of released  $H_2$  gas and fed to the sensors after diluting with Ar. The regeneration process was carried by simultaneous heating of CT from 250 to 400°C in steps at 50 mbar vacuum level.

### **Chemical characterization of MOX pellets by various analytical techniques**

Estimation of uranium and plutonium in dissolver solution by potentiometry results in generation of acidic waste solution mainly containing phosphoric acid, sulphuric and nitric acids. Recovery of Pu from such acidic waste is a challenging task. The methods reported in literature for the quantitative recovery of plutonium from acidic waste solution are limited. Therefore, it is important to examine and employ alternate methods for determination of uranium and plutonium which minimizes acidic waste generation. In this context, non-destructive techniques such as K-Edge Densitometry (KED) and Energy Dispersive X-Ray Fluorescence (EDXRF) were examined for the determination of high concentrations of Uranium (U) and Plutonium (P) in acidic solutions. In this study, MOX pellets were dissolved in concentrated  $HNO_3$  (16 M) acid containing small quantities of HF (0.05 M) under IR lamp. U and Pu contents in the solution were estimated using non-destructive techniques such as KED and EDXRF methods and compared with the results of conventional potentiometry. The study established that U and Pu in dissolver solutions of MOX can be determined by KED and EDXRF methods. Hence, in order to avoid large quantity of acidic radioactive waste, these non-destructive methods can be used as an alternative method for the routine assay of actinides.

### **Direct preparation of Uranium – Titanium ( $U_2Ti$ ) intermetallic compound by DOER method**

Uranium alloys are proposed as a fuel for liquid metal FBRs. Moreover, uranium alloys are considered as a potential candidate for storage of tritium in fusion reactors. In this context,  $U_2Ti$  intermetallic compound has gained considerable attention for the application of safe and high capacity storage material for hydrogen and tritium. This intermetallic is usually prepared by arc

melting of a mixture of stoichiometric amount of uranium and titanium metals. The method involves two steps i) independent preparation of metals and ii) mixing of both metals by arc melting. Nevertheless, repeated arc melting and annealing is essential to achieve homogeneity of the sample. Direct Oxide Electrochemical Reduction (DOER) is a promising technique in which metals or alloys can be prepared from the corresponding metal oxides or a mixture of metal oxides respectively. This single step process can directly yield alloys from its constituent metal oxides. The applicability of DOER towards the preparation of  $U_2Ti$  intermetallic from mixed  $UO_2$ - $TiO_2$  oxide in  $LiCl$ - $Li_2O$  melt has been investigated. Mixed oxide pellet was prepared from the required quantity of  $UO_2$  and  $TiO_2$  and the pellet was sintered at 1500°C under  $Ar$ -8% $H_2$  atmosphere for 4h. The sintered pellet was characterized by XRD and SEM. It is noteworthy that  $TiO_2$  can react stoichiometrically with  $UO_2$  at high temperature and form  $UTi_2O_6$ . The study confirmed the feasibility of preparation of  $U_2Ti$  intermetallic by direct oxide electrochemical reduction method.

Metalloproteins are an important class of proteins involved in metal uptake, transport, and electron-transfer reactions. At TIFR, the researchers synthesized peptides - mini-versions of a protein (azurin) from soil-dwelling bacteria that are important for nitrogen fixation. It was found that these small peptides exhibit novel metal-binding properties. These peptides provide a platform for studying metal-induced structural and spectroscopic properties using transition-metal ions. These novel properties can be used in solar-energy harvesting and in making novel biomaterials for material science and medicine. Converting  $CO_2$  directly from the air to fuel at ambient conditions is a huge challenge. Researchers employed magnesium (nanoparticles and bulk), an inexpensive and eighth-most abundant metal, to convert  $CO_2$  to methane, methanol and formic acid, using water as the sole hydrogen source. The conversion of  $CO_2$  took place within a few minutes at 300 K and 1 bar, and no external (thermal, photo, or electric) energy was required.

At NISER, in addition to traditional organic, inorganic, physical and theoretical chemistry areas, the school continued to embark on teaching and research

activity in the interface areas of Biology, Material Sciences and Medicine.

## BIOLOGY

At the Indus-2 BL-21 computation facility, Protein Sequence Analyzer (PSA) software PSA was installed for understanding physico-chemical properties of proteins of different organisms. PSA has been used to analyze evolutions of various mutant proteins of SARS-CoV-2 in India and UK. The co-evolving sites in the sequence of various proteins of SARS-CoV-2, which could play important functional role, have also been identified using it.

At BARC the major R-loop resolving enzyme, RNase H1 is shown to exist as phase-separated assemblies in association with elongating RNA Polymerase II during active transcription. RNase H1 nucleation at the R-loop sites by interacting with elongating Pol II in LLPS dependent manner during transcription was hypothesised. A new evidence for a cross-talk between transcription and RNase H1 function in the cell has been provided, which opens-up path for further exploration.

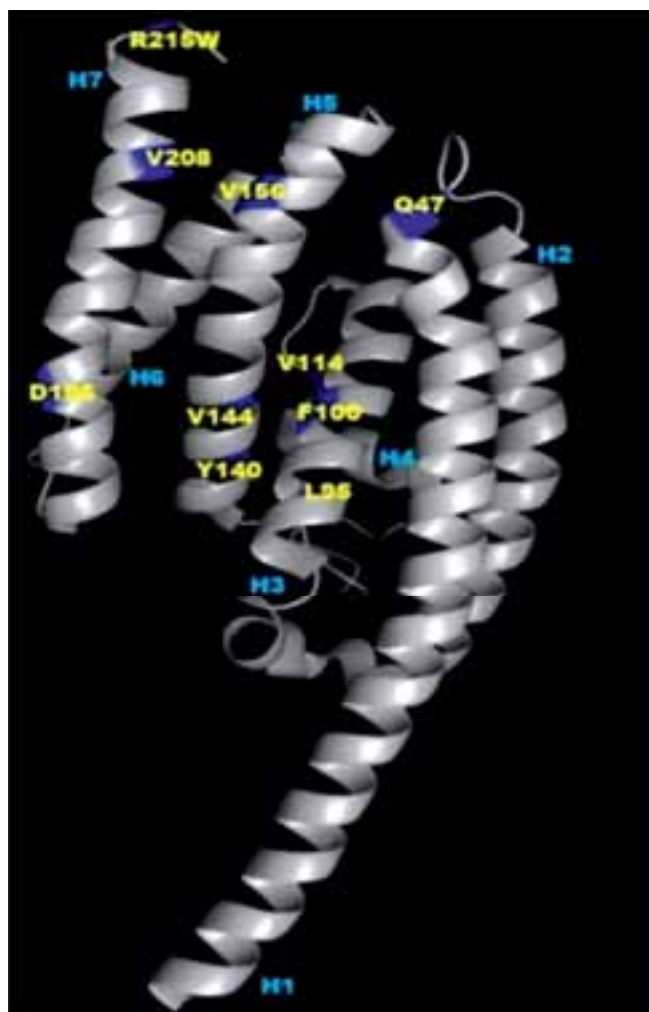
*Deinococcus radiodurans* is known for its extreme resistance to lethal doses of gamma radiation. Molecular basis of resistance to gamma radiation has been studied at various levels. The new findings highlight the existence of a new type of DNA damage response and cell cycle regulation that is similar to eukaryotic mechanisms and distinctly different from known mechanism in other bacteria, and role of non-canonical secondary structure of DNA in radioresistance and regulation of gene expression in response to gamma radiation exposure.

N-terminal residues influence structure /function of Mn-catalase, widening the scope for amino acids that can be targeted for rational protein engineering. The roles of N-terminal residues in structure/function of cyanobacterial Mn-catalase KatB has been demonstrated.

To decipher roles of genes and molecular mechanisms important for regulation of gene

expression in different conditions and protection against stress-induced oxidative damage, in silico and wet-lab analysis were employed. During the year, studies were done on bromodomain homologs in plant and their potential roles in epigenetic regulation of gene expression and protein diversity in rice and arabidopsis.

Ten variants (found in different cancers) of Translin - an evolutionarily conserved nucleic acid interacting protein were addressed and the biophysical and biochemical properties were studied.



**10 variants (found in different cancers) of Translin protein**

Heavy metal pollution has become a significant environmental concern. In continuation of earlier efforts in exploiting the remediation capability of microorganisms, *Deinococcus radiodurans* is genetically engineered by expressing a cell-surface localized metallothioneine (MT) and demonstrated that

the recombinant bacterial cells can efficiently sequester Cadmium metal. Additionally, a cell-free matrix immobilized with a phosphatase-S-layer fusion protein is constructed to show its ability to precipitate Uranium.

As a step towards understanding the DNA repair network of the highly radioresistant cyanobacterium, *Nostoc*, the regulatory mechanisms involved in the expression of the core DNA repair proteins RecFOR were identified. A new physiological role for one of the DNA kinase, Thymidylate kinase, in photosynthesis was discovered.

Iron (Fe) is a key inorganic micronutrient for all living organisms. Physiological characterisation of Fe uptake in *Synechocystis* 6803, a well-studied cyanobacterium has been performed.

Novel agents were synthesized for detection and mitigation of intracellular iron in human bodies. A BODIPY based novel fluorescent probe to selectively detect  $\text{Fe}^{+2}$  in active cells, based on a selective chemical reduction, has been developed, and has been validated in-vitro. The triplet, profluorescent nitroxide probe showed a turn-on sensing with a low limit of detection and high sensitivity.

SINP remained focused on rational design of 'artificial enzymes' for applications in energy, healthcare and environmental sectors. Works on the two most efficient artificial enzymes, namely Ir(Me)-PIX-Cyp119-Max and de novo retro-alodolases to understand the underlying reasons for their remarkable efficiency were continued.

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.

At TIFR, a study uncovered hitherto unknown mechanisms that regulate robustness of information flow through insulin signaling. In addition to highlighting the importance of normal insulin cycles (during feeding and fasting), it identified components that could perturb the signaling cascade under situations of hyper-insulinemia as in diabetes and clinical insulin administration. The study also raised the possibility of re-evaluation of insulin dosing (amounts and frequency) to ascertain its impact on molecular components that protect tissues from damage, beyond maintenance of blood glucose levels.

Most endangered species exist today in small populations, many of which are isolated. Evolution in such populations is largely governed by genetic drift. Empirical evidence for drift affecting striking phenotypes based on substantial genetic data are rare. Whole-genome data and pedigree-based association analyses from captive tigers revealed that pseudomelanism cosegregates with a conserved and functionally important coding alteration in Transmembrane Aminopeptidase Q (Taqppep), a gene responsible for similar traits in other felid species. The study at TIFR's National Centre for Biological Sciences, Bengaluru highlighted an unusual evolutionary trajectory in a small and isolated population of an endangered species. Phosphorylation is a post-translational modification that is utilised across all clades of life, and acts as an important signalling switch, regulating several cellular processes. Tyrosine phosphatases, which are found predominantly in eukaryotes, act on phosphorylated tyrosine residues and sometimes on other substrates. The investigators looked for sequences of the cysteine-based tyrosine phosphatase superfamily in thirty mammalian genomes from all across Mammalia and validated the sequences with the presence of the signature catalytic motif.

At NISER, the school of Biological Sciences continued to offer 5-year integrated M.Sc program, Ph. D program and Post-Doctoral program to motivate and train students. It continued to provide effective interdisciplinary learning ambience through extensive subject coverage in all fields of modern biology and inter-phasing with other scientific disciplines.

## CANCER

Characterization studies were done on Topoisomerase-1 enzyme to understand the role of kinases during phosphorylation for possible applications in targeted cancer therapy.

Studies on DNA repair in homologous proficient breast cancer were done with pharmacological drugs made from naturally available sources as well as those from synthesized route.

To evaluate the efficacy of the combination of 4, 4'-Dihydroxystilbene and talazoparib in reducing tumour volume in ovarian cancers, a pre-clinical study in immuno-compromised nude mice was carried out. While the drug combination showed appreciable results in reducing the tumour volume, the change in relative body weight of the mice, an indicator of toxicity of the drugs remained within the permissible limits. It was identified that DHS induces contextual synthetic lethality when combined with talazoparib in ovarian cancers by multiple PARP-targeted pathways. These pathways included induction of extensive oxidative stress thereby increasing the reliance of PARP-mediated base-excision repair, downregulation of HR leading to cell death when combined with PARP inhibitor and increasing occupancy of PARP on chromatin and increased trapping of PARP on DNA.

A nanoreactor, comprising of an enzyme and a peroxide incorporated into a metal-organic framework, has been developed in an endeavour to promote Fenton reaction in the acidic microenvironment of tumour, generating cancer cell-killing Reactive Oxygen Species (ROS). Initial screening showed high potential for such nano-platform with a selective anti-proliferative effect towards cancer cells compared to normal cells.

Whole blood transcriptome sequencing was carried out on 50 samples (12 Healthy, 38 Neuroendocrine Tumours (NETs)) to evaluate potential biomarkers. Among 4000 genes that were differentially expressed between the 2 sets (Healthy versus NETs), top 30 genes could segregate the samples correctly into healthy or NET groups. This study was piloted in collaboration with Radiation Medicine Centre.

At SINP, the research is on-going which aims at the understanding of the cell biological phenomena that govern extensive cellular dysfunction and death in late-on set neurodegenerative diseases. Investigations are carried out to understand the rationale behind the involvement of several membrane proteins like Receptor Tyrosine Kinases (RTKs), Water Channels etc in neurodegenerative signalling, which are otherwise highly implicated in cancer. Special focus is given on the regulatory mechanisms by oncogenic long non-coding RNAs (lncRNAs) that drive the expression and activity of these proteins. Research is on-going in metabolomic area to analyze the metabolic reprogramming associated with stress response in cancer and normal cells. Mass spectrometry-based methods for analysis of Ribonucleic acid (RNA) modifications has been developed, which is being used to unravel the role of RNA methylation in controlling metabolism and cell fate.

## SYNCHROTRON & THEIR UTILISATION

The Indus synchrotron radiation sources, Indus-1 and Indus-2 were operated as national facility for the synchrotron radiation (SR) user community in round-the-clock mode for 189 days during the period April to December 2021 (expected 274 days in FY 2021-22). The facility could not be operated during lockdown period. The availability of SR beam for users has been 3855 hours (~21 hours/day) in Indus-1 and 3009 hours (~16 hours/day) in Indus-2 till Dec 2021. With this performance, the beam availability for the year 2021-22 is expected to be ~5700 hrs for Indus-1 and ~4350 hrs for Indus-2. The number of user experiments at Indus-1 and Indus-2 beamlines from April to December 2021 is 365 and expected to cross 575 in FY 2021-22. There has been continuous effort for the upgradation of various sub-systems by way of developing and deploying improved technologies which are mostly based on indigenous efforts. In this year, the following development activities have been carried out with an aim of their deployment in the machine in future. Design and development of a high stability current controlled orbit correction power supply for microtron in Indus facility has been developed. The existing power converters for LS2Q2F magnet in Indus-2, developed

about 20 years ago, is replaced with the upgraded new power converters. A VME based three-layered modular test and simulation setup for Indus control system, has been developed to test software as well as hardware for various sub-systems of Indus-1 & Indus-2 control system. A horizontal pinger magnet, which is a beam diagnostic tool for measuring various beam dynamical parameters of particle accelerator, was designed, developed and characterized and has been installed in Indus-2. Upgraded BPIs have been developed, and installed in Indus-2 for the measurement of electron beam position at 56 locations.

A horizontal pinger magnet, which is a beam diagnostic tool for measuring various beam dynamical parameters of particle accelerator, was designed, developed and characterized. It has been installed in Indus-2, the 2.5 GeV Indian Synchrotron Radiation Source. It can deflect the 2.5 GeV electron beam by 1.5 mrad in horizontal direction. The pulsed magnetic field uniformity along pole width and pole gap is less than  $2 \times 10^{-3}$  within  $\pm 10$  mm of the centre of pole aperture. Indus-2 timing control system has been augmented to provide remote control for horizontal pinger magnet with 0.5 ns resolution and sub nanosecond ( $< 1$  ns) timing jitter.



**The horizontal pinger magnet under magnetic measurement**

Four nos of 20 V/ 6 A orbit correction coil dc power supply to energize the orbit corrector magnet of microtron in Indus facility has been developed. The stability of output current achieved is better than 50 ppm and the setting resolution is of the order of 10 mA.

Six numbers of upgraded Beam Position Indicators (BPIs) have been developed, and installed during the December 2021 shutdown. These BPIs are



**Power supplies**



**Upgraded beam position indicators (BPIs) installed in Indus-2 SRS**

used in Indus-2 for the measurement of electron beam position at 56 locations.

An electron beam radiation processing facility ARPF (Agricultural Radiation Processing Facility) has been set up by DAE at Indore. The facility is based on indigenously developed 10 MeV, 6 kW electron linacs. This is the first 10 MeV electron beam facility in the country licenced by AERB and FDA with ISO certifications for radiation processing of medical devices (Risk Class-A). A quality assurance program has been implemented at the facility. Dosimetric qualification of various medical devices (Petri-dishes, COVID-19 Self standing VTM tubes, Blood vacutainers, Cotton gauze pieces, Surgical gloves, Collagen skin Temp sheets) for bulk processing has been carried out. The facility was operated for carrying out a large number of irradiation experiments on various research samples including seeds for mutation breeding, rice for insect disinfestation, active pharmaceutical ingredients for sterilization dose standardization, gem stone for colour modification. A large size batch (125 boxes) of VTM tubes and Petri dishes was successfully radiation



**Bulk sterilization of medical devices with electron beam carried out at ARPF (a batch of 125 boxes); Client: M/s Adge Industries, Ahmedabad, Gujarat**

processed for sterilization at ARPF. The sterility testing of irradiated products has been carried out at NABL certified lab. & the results confirmed the successful achievement of desired sterility assurance level.

RRCAT has developed 9.5 MeV electron Linac with beam power of 10 kW for food irradiation applications. The linac has an energy limiting system to remove electrons above 10 MeV to meet the regulatory requirements for food irradiation. High power operation of linac at beam energy 9.5 MeV and beam power 10 kW has been established. Preparations are underway to do the dosimetry of food products.

Indus-1 and Indus-2 are national facilities with 17 beamlines in Indus-2 and 7 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. However, due to issues related to the Covid-19 related lockdown, there has been a significant reduction in the number of user experiments. After the resumption of operation of Indus machine and the restarting of the user experiments at the beamlines, users have not been able to come to Indus beamlines for their experiments. User samples are thus being received only by post for experiments. Within these constraints, there have been 477 user experiments carried out in the period January 2021 to December 2021. The Angle

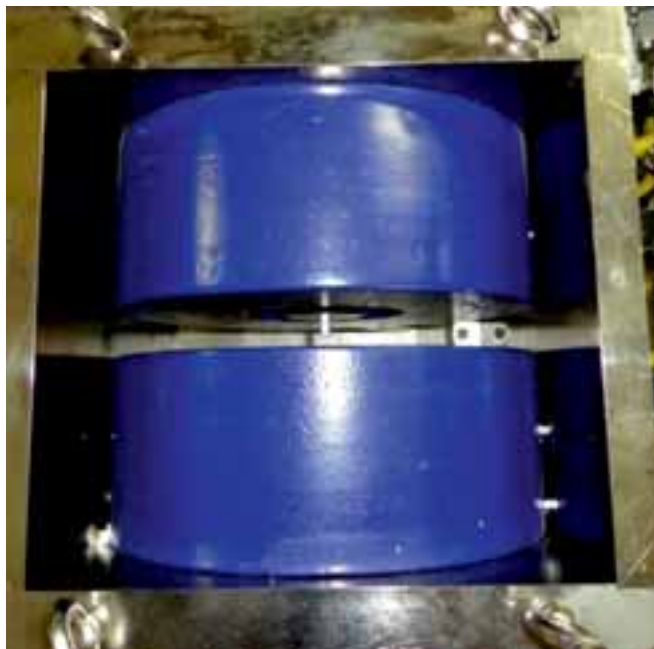
resolved photoelectron spectroscopy beamline (BL-10) which is the first undulator based beamline in Indus-2, has been commissioned and is available to users for experiments.

An in-vacuum heater capable of operation in a high vacuum level of  $10^{-5}$  mbar, has been developed. The heater was designed to be compatible to the sample mounting stage of the available goniometer in the Engineering applications beamline BL-02 at Indus-2. The heater has been tested for a maximum temperature of 600°C on a sample of 25 mm diameter and 1 mm thickness. The temperature accuracy achieved at the sample surface is of the order of  $\pm 0.5$  C. This setup will enable users to determine thermal characteristics of materials, strain in samples as a function of temperature.

To improve spectral purity at Indus-2 soft x-ray reflectivity beamline (BL-03) a three mirror based Higher Order Suppressor (HOS) system was custom designed, fabricated and commissioned. The three mirror assembly of this HOS setup moves simultaneously in a synchronized way, in ultra-high vacuum environment, such that the beam exit remains fixed during the HOS operation. All the three mirrors are coated with with four stripes of Ni, Cr, Si and Carbon, which are used to suppress the higher harmonics in the complete energy range of 100-1000 eV.

Work related to the development of two beamlines: a) Multi-Investigations of Radio Actinide beamline (MIRA) beamline BL-19 and b) Atomic Molecular and Optical Sciences (AMOS) beamline BL-05 have been carried out. At BL-19, the various components of the frontend have been fabricated tested and installed. Testing and commissioning of water-cooled beam viewer, water-cooled mask, horizontal and vertical scanning wire monitor with synchrotron beam from the undulator U1 is carried out in BL-05.

The Experimental Chamber for Matrix Isolation (MI) spectroscopy at Photo-physics beamline at Indus-1 was replaced with an Ultra High Vacuum (UHV) Chamber having eight ports CF flanges and compatible rotary feedthroughs for deriving large sets of quality data. The Chamber has been qualified for Helium Leak Test with leak rate in order of  $10^{-10}$  Pa.m<sup>3</sup>/s.



*2 Tesla compact electromagnet for X-ray Magnetic Circular Dichroism (XMCD) experiments at INDUS-II*

A 2 Tesla compact electromagnet is undergoing installation at BL-09 (Scanning EXAFS Beamline) of INDUS-II synchrotron for X-ray Magnetic Circular Dichroism (XMCD) experiments. The magnet generates 2T magnetic field in an air gap of 25mm. The Magnetomotive Force (MMF) required for the electromagnets was generated using water cooled coils. To achieve high magnetic field, high magnetic saturation material (FeCo alloys) was selected for magnetic poles.

Scientists of SINP are actively involved in research using X-ray synchrotron beamlines and also in the development and maintenance of beamlines. Currently two beamline projects are active: (1) Grazing Incidence X-ray Scattering beamline (GIXS) at BL-13, Indus-2, RRCAT, Indore, (2) Indian Beamline at Photon Factory, KEK, Japan.

### **Grazing Incidence X-ray Scattering beamline (GIXS) at BL-13, Indus-2, RRCAT, Indore**

After successful commissioning of GIXS beamline (BL-13) at Indus-2 synchrotron radiation facility, the beamline has been running under trial permission. All safety measures are in place, and an application has been made to AERB in February, 2021,

for the safety approval. A comprehensive users' manual has been prepared. Daily maintenance work, operation and users' support for the beamline is provided by RRCAT and SINP.

### **Indian Beamline at Photon Factory, KEK, Japan**

The Indian beamline at the X-ray synchrotron source Photon Factory, KEK, Japan has been fully operational. It offers different experimental facilities like diffraction in various samples (high and low temperature, high pressure), X-ray reflectivity-diffuse scattering from solid and liquid surfaces, small-angle X-ray scattering, and single-crystal diffraction. Daily maintenance work and users' support are given to Indian Nationals under India-Japan collaborative research program.

## **CYCLOTRONS & THEIR UTILISATION**

### **Design and Development of High-Power RF Amplifier for 88-inch Room Temperature K130 Cyclotron**

A tetrode based high power RF amplifier has been designed, developed and commissioned at Variable Energy Cyclotron Centre (VECC), Kolkata, India for 88-inch Room Temperature K130 Cyclotron. K130 cyclotron has been operational since its inception in 1977 facilitating various institutions from all over the country to carry out experiments. The RF resonator is fed by a tetrode based high power RF amplifier. The requirement of RF amplifier is to develop the required accelerating voltage in the accelerating electrode (called "Dee") for particle acceleration. The previous amplifier design was based on 4648 tetrode manufactured by RCA/Burle/Photonis and it was operational for more than three decades in our centre. The 4648 tetrode tube became exorbitantly expensive, difficult to procure due to long lead time and finally became obsolete. There was a serious need to design and develop a similar amplifier in short period of time to keep the cyclotron running. The RF amplifier was successfully designed, developed and commissioned. During the installation amplifier minor mechanical



*A-Installed RF Amplifier, B- Modified Tube socket, C- Anode blocking capacitor*

alignment was done for coupling with the resonator input port. The RF clamp circuits and modulator gain in voltage regulation module was adjusted accordingly. The input driver power and biasing point was adjusted to achieve Dee voltage in the range of 40kV to 58 kV in different frequencies between as required by researchers. The RF system has performed round –the-clock without any major problem. VECC K130 cyclotron successfully accelerated various ion beams at required energies with the new RF amplifier.

### **New beam development and improvement of beam transport in the extraction beam line of Superconducting Cyclotron**

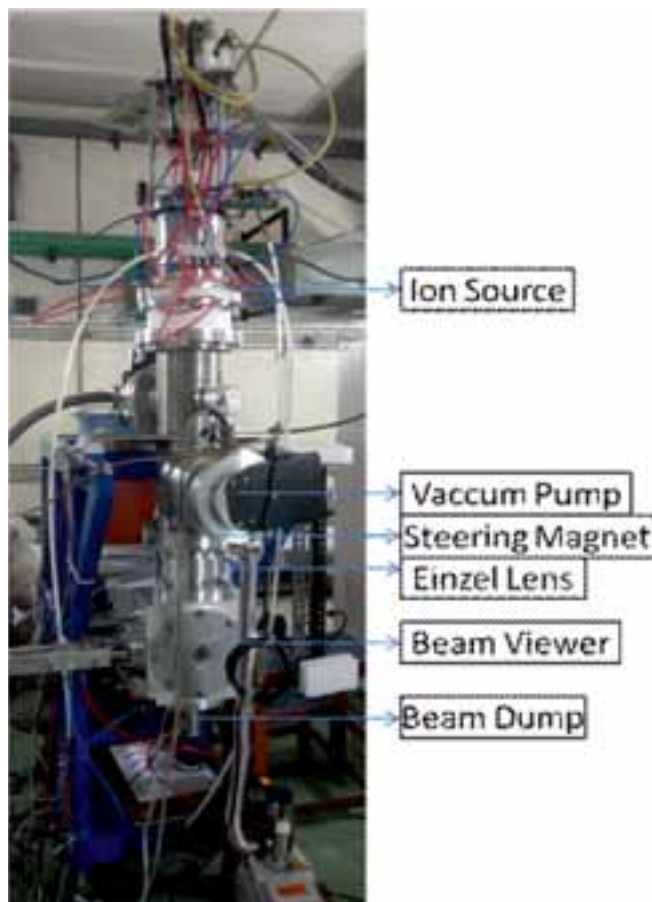
252 MeV  $N^{4+}$  beam has been successfully extracted from VECC K500 Superconducting cyclotron during last year. This year it is planned to extract Neon ( $Ne^{6+}$ : 360 & 380 MeV) and oxygen ( $O^{5+}$ : 309 & 331 MeV) beams and transport it to the experimental area. Preparatory steps (deflector and RF conditioning) for acceleration and extraction of these beams are being perused at present.

### **Indigenous Compact Medical Cyclotron (MC18) Project at the Variable Energy Cyclotron Centre**

Some of the major activities and achievements about the above project are mentioned below:

#### **• Ion source and Injection beam line components – development and testing**

The H– ion source in development will be used in 18 MeV Medical cyclotron Project. It is a multicusp



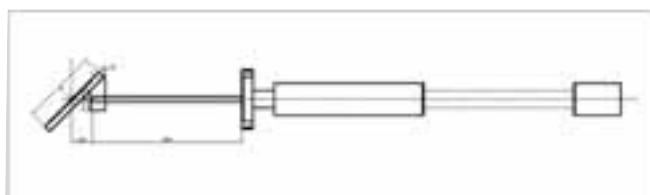
*Test Bench for H- Ion Source*

field design, biased at negative potential compared to the ground electrode for the extraction of negative ions. The H– multi-cusp ion source is divided into two chambers by a magnetic dipole filter, a source chamber and an extraction chamber. In the source chamber, hot electrons ( $>45$  eV) emitted by high temperature filament collide with  $H_2$  molecules to generate the vibrationally excited  $H_2^*$  molecules. When these excited  $H_2^*$  molecules collide with low energy electrons ( $\leq 1$  eV), they split into an H atom and an H– ion through dissociative-attachment. To increase the chance of collision and confine the plasma, and to improve the plasma density in the center, the multi-cusp magnetic field configuration is adopted. The test Bench consists of an ion source, steering magnet, Einzel lens, low wattage faraday cup, Beam Viewer and Beam dump is installed. The steering magnets allow moving the beam in transverse plane of injection axis. The beam is weakly focused by electrostatic Einzel lens at the centre of the Beam viewer. Faraday cup and Beam dump with a water-cooled copper plate allows stopping the beam

and measures the beam current. Ion source is tested for different configuration of Cusp Field and filter magnet. Profile of Magnetic field plays an important role in improvement of Beam current and Beam quality.

- **Development and testing of Beam Viewer for injection beam line**

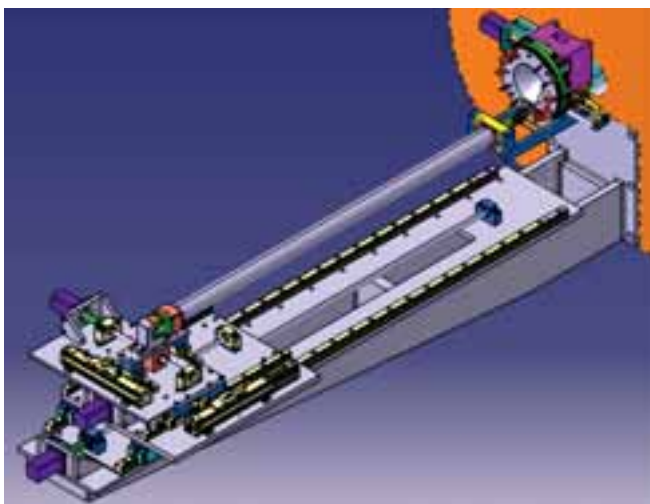
Beam Viewer in 18 MeV Medical Cyclotron will be used to view and measure the beam size in injection beam line. The Beam viewer will be placed at the centre of the beam line whenever beam view is to be taken. The top layer of beam viewer is coated with potassium bromide to get fluorescence effect since initial energy of inject H<sup>-</sup> beam is very less. Beam viewer is tested in Ion source test stand and a good beam spot obtained. Engineering drawing of Beam Viewer for injection beam line is shown below.



*Engineering Drawing of Beam Viewer*

- **Engineering design of stripper driving system**

Extraction in MC-18 cyclotron is obtained by stripping the negative ions. The radial position of the stripper determines the extraction energy. The extraction energy can be varied by moving the stripper



*3D design of stripper with Automatic stripper foil holder*

radially inside the vacuum chamber. H<sup>-</sup> ions are accelerated up to the stripper position and then protons are extracted through a carbon stripper. The stripper with carbon foil is horizontally movable between the hill-gap from 16 MeV to 20 MeV. When the stripper is at R=578 mm,  $\omega = 102.5\omega_0$ , almost 4 turns are falling on the stripper. Detailed extraction study and effects of various parameters on extracted beam like broadening of phase width due to slight deviation of Main Magnetic field, accelerated orbit shape and effect of transverse space charge effect also studied. 3D design of Stripper system is shown.

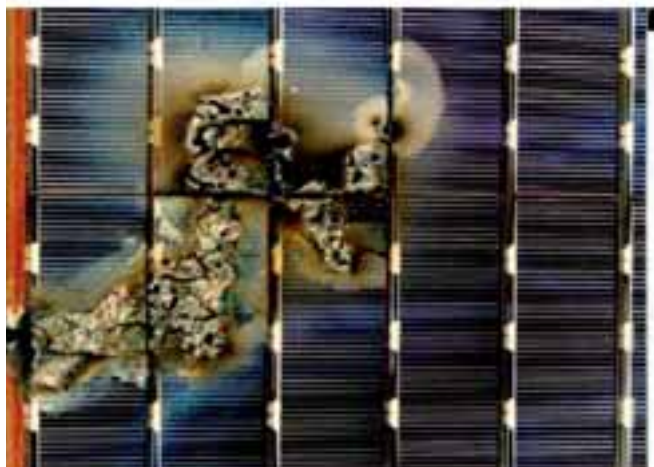
### Room Temperature Cyclotron (RTC) Utilisation

At VECC, the K130 room temperature cyclotron has been operating round the clock and delivering light and heavy ion beams for various types of experiments. The K130 cyclotron has two ion sources (internal PIGIS and external ECRIS) to produce light and heavy ions. Presently PIGIS is in use to produce light ion beams like proton and alpha for conducting the research program. Alpha beams having energy 26 to 52.4 MeV have been provided to the users and as a special requirement alpha beam in the energy range 5.5 to 6.5 MeV have also been delivered using higher harmonic mode of operation. Proton beams in the range 7 to 14 MeV are also delivered regularly for physics experiment. The above-mentioned beams are regularly being used to produce isotope production, irradiation, rare ion beam (RIB) production, radiation damage studies and nuclear physics experiments etc. The facility has been utilised by the experimentalists of VECC, SINP, ACD/BARC, RCD/BARC, HPU/VECC, Banaras Hindu University, Viswa Bharati University, University of Calicut etc. The K130 cyclotron is regularly fulfilling its target for beam availability and for the year 2021-21, the beam availability has been 2225 hours till December 21, 2021.

## PLASMA & FUSION TECHNOLOGIES

### An Import Substitute Plasma Source for Ground Testing of Satellite Solar Panels

The increasing power requirement in satellites requires operation at progressively higher bus voltages.



*An image of satellite solar panel damaged due to arcing*



*An indigenously developed SPIX facility with ECR plasma source for the ground testing of satellite solar panels before launching into space.*

This can lead to arcing on the satellite solar panel and may limit the operational lifetime. To study this effect, IPR had set up an indigenous Spacecraft Plasma Interaction eXperiment (SPIX) facility, where the plasma source resembles Low Earth Orbit (LEO) and Geosynchronous Equilateral Orbit (GEO) like space environment. An imported ECR Plasma source was being used so far. An ECR plasma source has now been indigenously developed and integrated with SPIX, yielding performance on par with imported systems. This is a contribution to Atmanirbhar Bharat.

### **Patent granted on “Apparatus for Production of Microwave Plasma”**

IPR has developed a novel apparatus for production of atmospheric-pressure plasma using microwaves, and this has been granted an Indian



*Microwave plasma arc at atmospheric pressure fluorescent tube*



*Microwave plasma coupled to low pressure*

patent. This low-cost system is also simpler than conventional systems, since there is no need for matching components like isolator, circulator and stub-tuner for matching the source to the plasma. This system can be used in a variety of industrial applications, such as microwave plasma arc in coal gasification, waste disposal, diamond synthetization, and sterilization of biomedical tools/equipment.

### **Use of Plasma Activated Water for food sector**

Chemicals like Alcohol,  $H_2O_2$ , Chlorine and Chlorine compounds etc. are commonly used as disinfectants. These chemicals can pollute the environment and are relatively costly. Plasma activated water (PAW) is an alternate solution. IPR has developed a technology to produce PAW with properties optimized for different applications. In a joint study with an external agency, PAW was used for sanitization of milk cans,

dump tank etc. during dairy operations. A significant reduction in the microbial load was observed when PAW was used for final cleaning of containers.

### **Indigenous development of Helicon Plasma Thruster at IPR**

A helicon plasma thruster and its characterisation facility has been indigenously developed at IPR, based on IPR's in-depth understanding of helicon plasmas. Such thrusters offer higher specific impulse and long lifetimes as compared to many other thrusters for space applications. The facility uses a 5 kW 13.56 MHz RF source coupled to the plasma using a helicon antenna. Thrust measurement is done using an indigenously-developed & calibrated Strain Gauge thrust sensor. Using an electromagnet with an axial magnetic field of 1.5 kG, Argon gas feed and a 50 mm dia plasma source, the thruster has so far yielded 70-80 mN thrust, with thrusts above 90 mN achieved at 2 kG. A permanent magnet with higher fields and a different configuration appears to be yielding higher thrust and is being studied. A variety of plasma diagnostics are under installation & testing, for measuring axial profiles of plasma density and temperature, Mach probe for velocity, ion energy distribution and optical emission spectroscopy. A new 10 kW helicon source device is now under development.



*Indigenous development of Helicon Plasma Thruster at IPR*

### **Anode material erosion characterisation for Plasma Thrusters**

Plasma Thrusters are used in satellites for changing orientation, changing orbits, etc. Currently

used thrusters are coated with Boron Nitride ceramic. Ceramic erosion by ions alters magnetic field profiles and changes beam divergence, resulting in lower thrust efficiency, spacecraft charging, arcing, and coating of eroded material on solar panels. Hence a material erosion study was crucial. This requires in-depth understanding of Plasma Physics and Material Science. Under an IPR-VSSC MoU, IPR set up a low-energy ion beam facility. A large number of long duration experiments were performed, and erosion behaviour & sputtering yield was noted along with other surface characterisations at various ion energies, angles of incidence, temperature & fluence for various materials developed by VSSC/ISRO. This helped validate & qualify the developed material for indigenously developed plasma thrusters by ISRO, which will be used in forthcoming missions.

### **Aditya-upgrade tokamak**

Both the top and bottom Divertor coils have been operated simultaneously with driving 15 – 20 kA-turn in these coils. Furthermore, the Auxiliary Divertor coils are also added to these main divertor coils. The effect of these shaping coils on plasmas has been studied. The current in both the top and bottom divertor coils are driven by separate capacitor-bank based power supplies. It has been observed as the divertor is powered on, the soft-X-ray intensity increases and the HA emission intensity decreases suggesting an improvement in the discharge characteristics. Along with increase in the soft-X-ray emission the magnitude and period of the saw-tooth activity also increases during the charging of the divertor coils. These studies are being continued in the ADITYA-U.

### **100 GHz Quadrature based Heterodyne Interferometer system for Aditya – Upgrade Tokamak**

A 100 GHz quadrature based (IQ) heterodyne interferometer is indigenously developed and commissioned for ADITYA-U tokamak for real-time electron density measurement during plasma discharges. A quadrature detector is used for down conversion of the received signal and reference signal. The down converted signal is amplified and filtered with

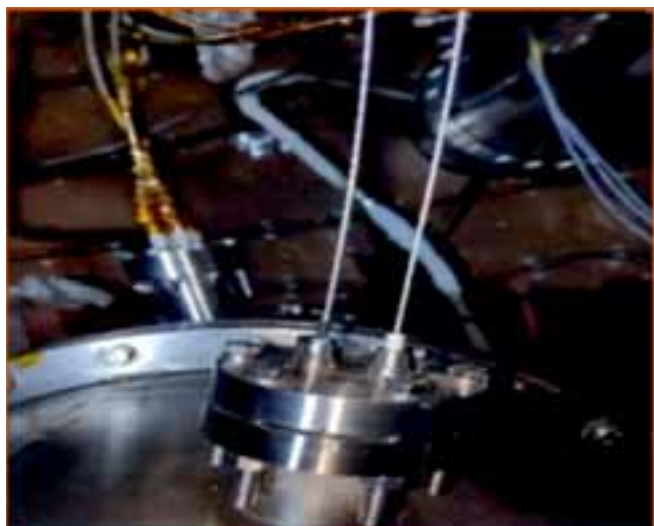


*100 GHz quadrature based (IQ) heterodyne interferometer*

offset block. Those signals are acquired in the digital domain using the Field-Programmable Gate Array (FPGA)-based Data Acquisition (DAQ) module which transform the signal in real-time domain.

### **Steady-State Superconducting (SST-1) Tokamak**

To perform SST-1 tokamak with Poloidal field coils to produce shaped plasmas for more than a second, certain modifications and improvements are required and therefore machine was under maintenance during the FY 2021. For integration of new power supply to the Lower Hybrid Current Drive system, required to push the plasma current to more than a



*Optical feed through with optical fibers mounted at Current Feeders System (CFS) for detecting arcs / flashes*

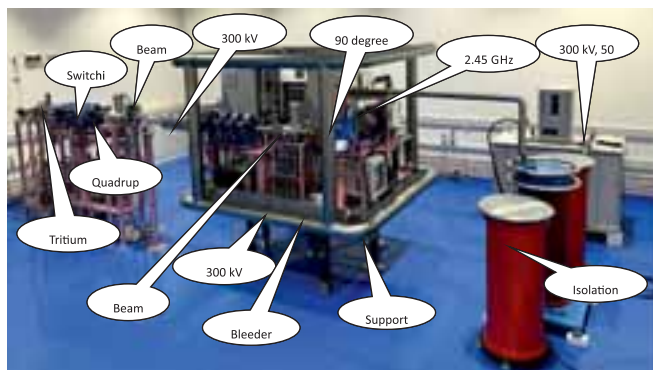
second (a targeted goal of the existing DPR), power and control cables were also laid out from the ITER-India lab to SST-1 hall. Two other main tasks have been carried out, namely the Vacuum Barrier for PF-3 coils and arc detection system inside the Current Feeders System (CFS). It is very crucial to detect arcs occur either due to Paschen discharges or any electrical faults inside the CFS in SST-1.

A novel technique using optical fibers has been developed to detect and alert the operators in advance, so as to mitigate any potential damages inside the CFS. This arc detection system would not only detect the vacuum arcs but also any reflected light from the cold surfaces (such as 77 K surfaces of cryostat duct inside CFS in which superconducting (SC) magnet bus bars are connected with SC current feeders or current leads). Optical fibers are mounted inside the vacuum chamber using the vacuum compatible optical feedthroughs onto the PF ducts of Cryostat inside CFS and routed in vacuum through optical window. Test experiments have been carried out to detect flash /arc created inside a vacuum chamber.

A Multi-point Thomson Scattering System with 6 Nd:YAG lasers (1.6 J energy, 8 ns pulse width) has been installed and calibrated on the SST-1 Tokamak. It measures temperature and density from 8 spatial channels. Indigenously designed and developed filter poly-chromators are used for the spectral dispersion and detection of the Thomson scattered spectrum. The system operates with a spatial resolution of 10 mm and temporal resolution of 5.3/ 33 ms depending upon the plasma parameters. The figure shows the temporal evolution of plasma density and temperature for shot no 9721 in the recent SST-1 campaign in which the temperature estimated is found to be matching well with the same estimated from the Electron Cyclotron Emission by Reflectometry

### **Commissioning of accelerator-based 14 MeV Deuterium-Tritium neutron generator facility**

An accelerator-based neutron generator has been commissioned at IPR. Initial trial operations have produced a neutron yield of  $7 \times 10^{11}$  n/s, which is expected to go up to  $5 \times 10^{12}$  n/sec during full operation.



**14 MeV Deuterium-Tritium neutron generator**

The source consists of an 2.45 GHz Electron Cyclotron Resonance Ion Source (ECRIS), Low Energy Beam Transport (LEBT) system, Electrostatic Acceleration, Medium Energy Beam Transport (MEBT) system, a 300 kV – 50 mA High Voltage Power Supply (HVPS), Beam diagnostic system (BDS), Switching Magnet (SM) and Rotating tritium target. The LEBT system is to transport the 20mA, 40keV deuterium beam from ECRIS to the Entrance of the acceleration column. The MEBT system transports the 300 keV beam from the acceleration column to the target assembly. The accelerated deuterons impinge on a Titanium tritide (TiT) thin-film target. The 14 MeV neutrons so produced can be used to study the effect on different materials to be used in a fusion reactor blanket, benchmark experiments for Fusion Evaluated Nuclear Data (FENDL), neutron spectroscopy measurements, double differential cross-section measurements, and other plasma-facing components of fusion machines.

### In-Vessel Inspection system for tokamaks

Plasma Facing Components (PFCs) in a tokamak are subjected to high heat flux and erosion, hence their periodic inspection is essential for health monitoring. An In-Vessel Inspection System (IVIS) has been developed at IPR to perform remote in-service inspection inside a toroidal vacuum vessel without breaking the vacuum. IVIS consists of a 6-degree-of-freedom articulated arm mounted on a linear guide and having a vacuum storage chamber. It can be deployed in a toroidal chamber through a port connected with a vacuum gate valve. The system can deploy up to 1 kg camera payload at a maximum reach of 4 m with a precision of 2 mm. It is compatible with an ultra-high vacuum system down to  $10^{-7}$  mbar pressure, and at

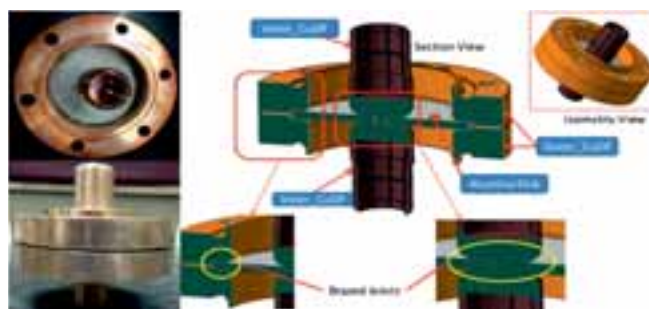


**In -Vessel Inspection System**

temperatures upto  $100^{\circ}\text{C}$ . It makes use of UHV-compatible motors with gearboxes, absolute encoders, cables and hybrid bearings. IVIS is now being integrated with a virtual reality system, which will permit remote control and monitoring over a high-speed network.

### RF technology: Indigenous development of Vacuum Barrier

A vacuum barrier is used in fusion machines and accelerators to deliver RF power from generators to systems operated in high vacuum. It also provides high voltage isolation between the inner & outer conductors of RF coaxial conductors. Such barriers, used in a brazed configuration with Alumina as an isolator, are not commercially manufactured in India as they must be made to specific design & functional needs. This



**Configuration of Indigenously developed Vacuum Barrier**



**Qualification checks for vacuum and electrical compatibility**

necessitates import of costly barriers (~10-12 Lakhs/piece). Such a barrier, developed indigenously in association with NFTDC, comes at half the price of the imported product. Additionally, this development provides confidence in achieving the similar brazed ceramic-to-metal assemblies in other applications like accelerators.

### Development of Indigenous State-of-the-Art Code Suites for Nuclear Activation Analysis

Rigorous and accurate nuclear analysis is necessary for nuclear fusion machines from design, safety, maintenance, material damage, de-commissioning and radiation waste (rad waste) disposal considerations. Two classes of codes are needed, viz., neutron transport codes and nuclear activation codes. Indian labs have limited access to nuclear activation codes. Hence to make us self-reliant, a state-of-the-art computer code suite for nuclear activation analysis called ACTYS family of codes have been developed. ACTYS performs nuclear activation calculations with one material and one neutron spectrum, ACTYS-1-GO is for a complete geometry with many materials and spatially varying neutron field with an option for first-level material composition optimization, and ACTYS-ASG is for activated gamma source generation. All the codes are well validated at various levels. ACTYS has been found to be superior to the well-known FISPACT-2007 in some respects. Recently ACTYS has been qualified and approved by the Nuclear Integration Unit, ITER for all ITER related nuclear activation calculations, which include calculations that lead to nuclear safety related reports.

At BARC, a novel strongly effective environmental barrier coating of  $\text{YPO}_4$  is being developed. This coating material is effective against highly corrosive environment prevailing during the processing of molten uranium.

Regular waste incineration is being carried out at the experimental incineration/ gasifier facility at PRIP Shed site, BARC. A 1 ton per day capacity new air plasma-based waste incineration plant at Gamma Field site, BARC was installed and commissioning trial runs have commenced.



*Air Plasma incinerator under commissioning at Gamma Field, Trombay*

## MATERIAL SCIENCE

Infra-Red Free Electron Laser (IR-FEL) is developed earlier at RRCAT, Indore. This year the continuous wave average power output achieved from the IR- FEL was 19 mW (more the double achieved last year), which corresponds to peak power of 5MW. The power stability is within  $\pm 5\%$ . Wavelength tuning over a range 12.5 to 40 micrometer has been achieved. The IR-FEL radiation has been transported up to the user area over a distance of around 45 m and an experimental facility for the utilization has been established using a custom-built experimental set-up for doing frequency domain spectroscopy in transmission and reflection modes.



*Set-up for doing frequency domain spectroscopy at low temperatures (5- 300 K) and high magnetic fields (up to 7 T) using FEL and laboratory-based sources*

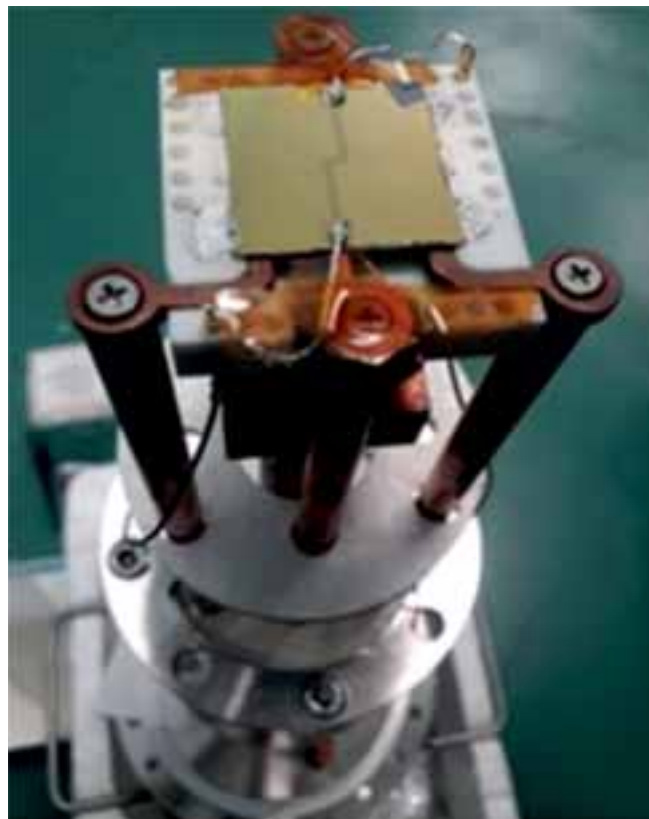
The gamma-ray and x-ray detectors are widely used in nuclear detectors, synchrotron facilities, medical and space applications. The performance of such detectors mainly depends on the semiconductor material properties. In the last few decades, III-V compound semiconductors like GaAs, CdTe, and GaN have emerged as promising materials for such

applications due to their superior radiation tolerance compared to their elemental semiconductor counterparts. Prototype scintillator CsI (Tl) coupled GaAs PIN junction-based radiation detectors have been developed for  $\gamma$ -ray detection at room temperature. The developed detector along with custom made preamplifier can also be used in  $\gamma$ -ray and x-ray spectroscopy and also for the detection of high-energy charged particles.

Au nanoparticles and Si nanowire-based Surface Enhanced Raman Scattering (SERS) substrates were prepared using a cost-effective chemical synthesis for trace detection of Methylene Blue (MB) dye, thiram and thiabendazole (ThB) pesticides up to 100 nano molar (100 ppb). These cost-effective SERS substrates along with portable Raman system has potential for trace detection of various harmful organic molecules for food safety and other on-site SERS applications.

Cerium doped YAG ceramic disc of diameter 20 to 30 mm and thickness 0.5 to 1.5 mm were fabricated by nano-powder technology and vacuum sintering technique and one of these ceramic discs (diameter: 30 mm; thickness: 0.5 mm) was used as a scintillator screen to characterize the hydrogen negative ion beam at Ion Source Development & Diagnostics Section, RRCAT and also to detect electron beam. The scintillation generated from ceramic disc was captured using a coloured CCD camera. For electron detection the sample was exposed to different combination of electron energies in the range of 5 to 35 keV and electron current 10 to 46 mA.

The process of micro-trapping of atoms on an atom-chip started with laser-cooling of atoms in the U-Magneto-optical trap (U-MOT) near the chip-surface (6 mm below the chip surface). An atom-chip with around  $4 \times 10^6$   $^{87}\text{Rb}$  atoms trapped at a height of 550  $\mu\text{m}$  from the surface in an Ioffe-Pritchard trap has been demonstrated. The estimated life-time of atoms in micro-trap is found to be  $\sim 60$  ms. Trapping of atoms on atom-chip can be useful in developing compact cold atoms based sensors for high precision measurement of time, magnetic field and inertial parameters (such as gravity, acceleration and rotation).



*The photograph of in-house developed atom-chip fixed on chip mount. The Z-shaped gold wire on the atom chip surface (yellow color) is visible in the photograph*

Dixon ring-based platinum loaded carbon aerogel (Pt-CA) catalyst has been developed in collaboration with HWD, BARC for heavy water decontamination application. The indigenously developed catalyst displayed stable performance under accelerated test conditions. A total of 12,000 Dixon ring catalysts have been supplied to BARC for testing in the pilot plant.

Single crystals of Cr (1.0, 1.2 and 1.5 at.%) co-doped Nd (0.5 at.%)GdVO<sub>4</sub> were grown for self Q-switched pulsed laser. Using laser element fabricated from the 1.0 at.% Cr co-doped crystal stable pulsed laser output was obtained at 1066 nm with power 105 mW, pulse width 477 ns and repetition rate 550 kHz.

Technology for the bonding and packaging of high-power laser diode arrays is developed by RRCAT. Using this technology, the non-working commercially available solid-state lasers pumped by high power laser diode modules were refurbished. The characteristics of

individual laser diode arrays, extracted from refurbished laser diode modules, were evaluated and used for the selection of the failed devices. Subsequently, laser diode arrays in working conditions were taken out and remounted on the indigenously developed mechanical mounts. Efforts are now in progress to develop the high-power laser diode modules via RRCAT Incubation Centre.

At BARC, Ti<sub>2</sub>CrV alloy samples were prepared for deployment in the bench scale hydrogen storage device of integrated hydrogen production and storage test facility. The alloys were characterized by EDS & XRD to confirm uniformity in composition & microstructure. The alloy has been tested for 50 hydrogen absorption-desorption cycles. Neutron diffraction study of the deuterated alloy reveals that D atoms occupy only the tetrahedral sites of the FCC lattice of the deuteride. D atoms are double in occupancy as compared to cations indicating a D/M value > 2 which matches well with the hydrogen uptake value of the alloy by gas sorption method.



*Ti<sub>2</sub>CrV alloy samples prepared using arc melting technique*

Efforts have been made to develop materials for high energy and power density, enhanced safety and low-cost Lithium and Sodium Ion Battery (LIB and SIB). Mo<sub>2</sub>C nanoparticles dispersed over rGO electrode have been prepared and evaluated for use in SIB. The unique design of Mo<sub>2</sub>C/C/rGO nanosheets exhibits specific capacity of 498 mAh/g at 50 mA/g current density against sodium electrode.

A novel Nickel based alloy with Mo, Cr and Ti as the principal alloying elements has been developed in-house as a candidate structural material for the Indian Molten Salt Breeder Reactor (MSBR). A unique glove box coupled Molten Salt Corrosion Test Facility (MSCTF) was developed and commissioned with

FLiNaK salt. Results of the studies done at this facility indicate that the presence of Cr is not desirable from the fluoride ion point of view.

High-Cr steels like ferritic/martensitic steels and ODS-alloys are important for applications in nuclear reactors. However, one of the major limitations of these steels is nanoscale Cr-rich phase (A/) separation that leads to embrittlement and potentially endangers safe operation and life time management of nuclear power plants. In the present work, by using complementary tools phase separation tendencies have been determined up to the resolution of atomic level. For the first time, key features of SANS profiles have been identified that can unambiguously distinguish Spinodal Decomposition (SD) from Nucleation-Growth (NG)) in Fe-Cr system.

Hastelloy X, a Ni-based super alloy, is used in various critical engineering applications due to its attractive combination of properties such as high strength, good oxidation and corrosion resistance under high temperatures. Detailed characterization of the oxide layer has been carried out at 1223 K in ambient air for duration ranging between 60 min and 1080 min. The growth kinetics of the oxide layer was found to follow a parabolic nature. The layers of oxide on the outer side were rich in Cr while those near the alloy/oxide interface were rich in both Cr and Ni. The oxide layer on the outer side contained 36.4 at. % Cr, 1.1 at. % Ni and 62.5 at. % O and hence was assumed to be Cr<sub>2</sub>O<sub>3</sub>.

Nb-Mo-Zr-C alloys were developed for high temperature nuclear applications. Present work is on the development of new fabrication route.

In continuation with previous work on the development of carbide free nanobainitic steel, where a steel ingot of composition 0.23C-2.06 Mn-1.03Ni-1.24Si-0.21Mo-0.38Cr-0.025V (wt.%) was melted and forged at 1200°C to achieve 50% deformation, detailed microstructural investigation is reported in the present work.

In-house made Silicon Carbide (SiC) coated carbon fibre mat was used successfully to prepare >80% dense fully converted SiC fibre matrix composite.

The Fibre was extruded from solid Polycarbosilane (PCS) polymer precursor by spinning the molten PCS under nitrogen pressure through a single hole spinneret of a melt spinning unit. A continuous fibre of about 5 m length was obtained without any surface defect. Different range of fiber diameters were produced by varying the spinneret orifice diameter, nitrogen pressure, winding speed and melt viscosity. It was subsequently cured by slow heating of fibre in a flow of dry air in an oven at a temperature of 200°C. Heat treatment of cured fibre at 1250°C for 30 minutes converted it in to defect free SiC fibre.

Ab-initio simulations have been carried out to assess the potential of Fe-Zr alloy based intermetallic to incorporate s-, p- and d-block Fission Metals (Fms). The calculated solution energies of the fission metal in intermetallics suggest that Zr-rich phases, viz.,  $\text{FeZr}_2$  and  $\text{FeZr}_3$  are more preferable over Fe-rich  $\text{Fe}_2\text{Zr}$  phases.

Hydroxyapatite (HAP)/bioglass (45S5) composite specimens were prepared using polyurethane foam as a template. The composites were prepared by sintering at maximum temperature of 950°C. The pure HAP specimen was quite fragile; however, with addition of bio-glass improves the mechanical integrity. These composites were characterized for optimized bio-mechanical properties as an alternate treatment of cancer.

Graphene Oxide (GO) cement composite concrete has been developed that has shown up to 40% improvement in compressive strength over pristine M30



*The developed Concrete-Graphite Oxide cubes and their compressive strength*

concrete. Fine cracks with few branches instead of a clean crack was observed in GO cement composites, implying that GO can delay the propagation of cracks by densifying the microstructure.

$\text{Cr}_2\text{AlC}$  MAX-phase is a high temperature oxidation resistant material, which shows a unique combination of metallic as well as ceramic properties.  $\text{Cr}_2\text{AlC}$  MAX-phase has been reported to be stable up to 1550°C under protective atmosphere and shows very good oxidation resistance up to 1400°C.  $\text{Cr}_2\text{AlC}$  MAX-phase is one of the potential candidate materials for oxidation resistant coating on Zr-based Accident Tolerant Fuel (ATF) clad tubes.

Hot working is one of the important steps in the processing route of newly-developed Titan-24 alloy. Optimum hot working condition for the alloy has been determined by construction of a processing map.

Alloy 690 is a Ni-based superalloy, which exhibits excellent corrosion resistance under harsh environment such as marine and acidic environments. Absence of Co makes it more attractive for nuclear applications such as steam generator, reprocessing plants etc. However, its high cost inhibits its large-scale engineering use. In this context, clad steel having Alloy 690 as corrosion protection layer over a cheaper carbon steel such as ASTM Gr.60 reduces the total requirement of Alloy 690 and overall cost of the component.

Split Hopkinson Pressure Bar is used to carry out mechanical testing at high strain rates  $1000^{\text{s}^{-1}}$ . A Split Hopkinson Pressure Bar facility has been developed for carrying out compression tests in the temperature range of -100 to 800 °C.



*Split Hopkinson Pressure Bar*

In Metastable austenitic steels, martensite treatment is one of the thermo-mechanical processes that can be used for the grain refinement. In this method, cold deformation was given to the specimen to form

martensite and subsequent reversion treatment to austenite phase, leading to ultra-fine grains. Fracture and Fatigue crack growth behavior of the ultrafine grained (Ufg) SS304L steel have been determined.

Among various Nb alloys, the Nb-1Zr-0.1C alloy composition is considered as one of the most promising candidates with optimum composition for high temperature reactor applications. At NFC, low temperature thermo-mechanical processing flow sheet developed in BARC was implemented to fabricate the Nb alloy tubes for Pb-Bi liquid metal loop. Molybdenum has been added in the alloy in order to further increase the mechanical properties of Nb alloy. To avoid low temperature deformation, a new room temperature deformation processing route has been developed. The developed room temperature deformation thermo-mechanical processing flow sheet can reduce oxidation, decarburization and loss of material due to surface machining to increase material surface quality during fabrication of materials.

A technique for brazing Zircaloy-4 using multilayer coating of Zr and Cu was developed. Pieces of Zircaloy-4, coated with Zr-Cu multilayers having total thickness of around 2 microns, were brazed in a vacuum furnace at 1263 K with soaking time of 3 minutes. The coated Zircaloy-4 pieces were successfully joined with each other in vacuum brazing, where the multilayer coating acted as the filler alloy. The width of the braze zone was around 200 microns with distinct microstructure compared to the base alloy. Moreover, the interface between the braze zone and the base materials was diffuse and devoid of any defect or discontinuity, the microchemical analysis of the joint interface revealed the formation of Zr-Cu melt which spread along the grain boundaries of Zr leading to a desirable uniform microstructure at the interfacial region. Finally, a two-phase eutectoid type microstructure developed in the Cu-rich regions owing to the low solubility of Cu in Zr at low temperature.

### **Development of Portable Cadmium Zinc Telluride (CZT) based Gamma Radiation Detector**

Research and development of radiation

detectors are vital for achieving self-sufficiency in the indigenization of different radiation monitoring devices used in nuclear facilities. In this regard, CdZnTe (CZT) based detectors with a wide bandgap ( $\sim 1.57$  eV) and high atomic number are ideal candidates for room temperature radiation detection. However, the growth of high-quality CZT single crystals involves several challenges due to inherent materials properties. In IGCAR, the traveling heater method (THM) to grow detector-grade CZT crystals has been indigenously designed and fabricated. Detector grade CZT single-crystals were successfully grown in-house. Further efforts to improve the sensitivity and resolution of the detector by optimizing growth parameters, device fabrication process and developments of signal processing electronics are in progress.

### **Magneto-cardiography with a non-magnetic bicycle ergometer to conduct stress measurements**

A facility to record weak magnetic fields associated with the electrical activity of the heart, namely, the Magneto-Cardiograph (MCG) setup using Superconducting Quantum Interference Device (SQUID) sensors have been setup at IGCAR, Kalpakkam. Several physiological investigations have been performed in collaboration with hospitals and medical institutions in the neighbourhood to unravel the diagnostic efficiency of MCG. As a part of this initiative, the sensitivity of MCG in detecting electrical signals associated with the blocks in the coronary arteries of the heart leading to ischemic heart diseases was assessed.

### **Thermodynamic properties of bcc uranium with point defects studied through ab initio molecular dynamics simulations**

Thermodynamic properties of bcc uranium with point defects have been studied through ab initio Molecular Dynamics (MD) simulations at 1100 K. This work demonstrates that the computational scheme adopted gives reliable formation and binding energies of atomic defects in bcc uranium compared to conventional density functional theory calculations. The equilibrium volume, bulk modulus, and thermal expansion coefficient of pure bcc uranium obtained

from our MD simulations compare very well with corresponding experimental results.

#### **Development of SnO<sub>2</sub> quantum dot-based methane sensor**

Chemical sensors are essential part of many smart devices involved in monitoring environmental pollutants and domestic gas leaks. The use of nanotechnology in the sensor material fabrication processes has enabled the devices to reduce the power consumption, cost and complexity of detection. In this regard, a chemical sensor using SnO<sub>2</sub> quantum dots (diameter 2.5 nm) for detection of methane (CH<sub>4</sub>) for industrial and environmental applications has been developed. The performance of the gas sensor was studied at various temperatures and the optimum temperature for maximum sensitivity was found to be around 100-110°C. Development of a prototype self-standing sensor module is currently underway.

#### **Optically sensitive isolated silver nano-dots on nitrogen ion-induced pre-patterned silicon nano-templates**

Silver nano-dots have been synthesized by implanting 6 keV silver ions on silicon nano-templates that were formed by the bombardment of 14 keV molecular nitrogen ions at an oblique angle. It is shown that the subsequent implantation of nitrogen and silver ions on silicon surface tailors the optical band gap, which is applicable for tuning the electrical and optoelectronic properties of silicon. Also, the presence of silver dots in the nano template shows significant enhancement of the Raman signal. Such nano-templates are useful as reusable SERS (Surface Enhanced Raman Spectroscopy) chips with potential applications in biological research. Also, silver nano-dots lead to enhanced surface absorption of light which is useful in applications involving anti-reflectance coating and photovoltaic devices. The experiments were performed at RIB beam-line and Atomic Force Microscope (AFM) facility at VECC was used for sample characterization. The X-ray Photo-electron Spectroscopy (XPS), Transmission Electron Microscope (TEM) analysis and Surface Enhanced Raman Spectroscopy (SERS) measurements were

carried out using the facilities at Saha Institute of Nuclear Physics (SINP) and Bose Institute, Kolkata.

#### **Investigating the effect of applied bias on methylammonium lead iodide (MAPbI<sub>3</sub>) perovskite by electrical and positron annihilation spectroscopic studies**

Methylammonium Lead Iodide (MAPbI<sub>3</sub>) is a multi-functional organic-inorganic hybrid perovskite material that has shown photo conversion efficiency > 27 %. The formation of point defects in crystal lattice of MAPbI<sub>3</sub> is detrimental to the long-term stability of perovskite-based solar cell. In our earlier study we observed Piezo-electric effect, and were also first to report that room temperature ferromagnetism can be induced in this material. The formation of point defects in the crystal lattice of MAPbI<sub>3</sub> is detrimental to the long-term stability of the perovskite-based solar cell. The observed hysteresis during photocurrent measurement is believed to be consequence of defect-mediated ion migration in such perovskites. Therefore, understanding the formation and evolution of point defects is very crucial for designing improved device performance and stability of the solar cells. Electric field-induced defect formation in MAPbI<sub>3</sub> through in-situ positron annihilation technique using the PAS (positron annihilation spectroscopy) setup at VECC was studied. Electrical measurement in Ag/MAPbI<sub>3</sub>/Ag lateral devices showed extensive poling with the creation of junction at the respective MAPbI<sub>3</sub>/Ag interfaces. This leads to p-i-n or n-i-p device structure due to formation of lattice defects at the interfaces. It has been shown that stability of ionic vacancy also depends on the applied voltage.

#### **Irradiation Studies of indigenously developed Reactor pressure Vessel Steel**

It is important to assess the mechanical stability of Reactor Pressure Vessel under irradiation to ensure safe operation of the reactor. The primary pressure barrier suffers from neutron damage resulting in generation of point defects, dislocations, radiation induced segregation etc. which causes irradiation induced embrittlement in the material. The pressure vessel made of RPV steel is being indigenously developed by BARC. During the life time of the reactor,

the RPV is expected to get exposed to neutron damage of 0.05-0.1 dpa. Therefore, it is necessary to test the materials before it is actually used in reactor environment. Proton irradiation is being used as a surrogate for understanding the neutron induced damage in the nuclear structural materials. Hence, in order to bench-mark the newly developed indigenous materials, a program was carried out to compare the irradiation response of these materials with respect to the imported material of equivalent grade using the proton beam from the Variable Energy Cyclotron. Microstructure (10mm x 10mm x ~125-128 mm thick) samples and miniature tensile coupons of the material were irradiated using 7.5 MeV proton beam after appropriately degrading the energy, so that the Bragg peak occurs at the back-surface of the sample. The microstructure samples were irradiated to a dose of  $7.4 \times 10^{17}$  p/cm<sup>2</sup> which resulted in an average dose of 0.1 dpa from the back-side of the sample in a depth probed by the Co K <sub>$\alpha$</sub> - X-ray for the microstructural characterization. The miniature tensile samples were irradiated from both sides so that the gauge length is exposed to an average dose of 0.1 dpa. These samples will be characterized at VECC using XRD and will be sent to BARC for further studies. This is a collaborative study with BARC.

### Radiation damage studies of Nb and its alloys

The microstructural evolution and corresponding changes in mechanical properties of proton irradiated Nb-1Zr-0.1C alloy have been studied as a function of irradiation dose. Different XRD Line Profile Analyses (XRD/LPA) have been carried out using synchrotron XRD data to evaluate the microstructural parameters. Contradistinction of the findings of Nb-1Zr-0.1C with those of pure Nb contemplated the role of the alloying additions, especially carbon, in governing the irradiation behaviour of the alloy.

The phenomenon of Quantum Hall Effect (QHE), which is elusive in bulk materials, has gained renewed interest from the recent studies on bulk systems like ZrTe<sub>5</sub>, EuMnBi<sub>2</sub> etc. Researchers grew the single crystal of CaCuSb single crystal, which crystallizes in a hexagonal lattice with a layered crystal structure, where the Cu-Sb atoms and Ca atom

constitute the different layers. From a detailed transport, high magnetic field measurements (up to 45 T) and band structure calculations, researchers unequivocally confirm the observed step-like feature as QHE. Superconducting circuits are one of the leading platforms for quantum computing and information processing. Researchers demonstrated a novel design that significantly improves qubit connectivity compared to most state-of-the-art superconducting architectures. The study used a ring resonator as a coupling element mediating interaction between several qubits distributed around the ring resonator. The invention may find several interesting applications in quantum computing, quantum simulation and quantum annealing.

## INTERDISCIPLINARY AREAS

For providing a realistic assessment of air borne infection transfers in indoor environment, Poissonian fluctuations were studied to develop the theory of residence time of virus-laden droplets (virusols). Studies showed that the mean residence time of virusols was found to increase nonlinearly with the viral load in the ejecta, ranging from about 100 to 150 s at low viral loads ( $<10^4$ /ml) to about 1100–1250 s at high viral loads ( $>10^{11}$ /ml).

In comparison to inorganic semiconductors, organic materials still lag in electrical conductivity. Dopants are often used to increase the conductivity of the semiconductor films. At TIFR's Centre for Interdisciplinary Sciences, Hyderabad, researchers showed the first example of a dimethyl sulfoxide based molecular adduct system for organic semiconductors, where the dopants do not leave behind any side products and work better than the existing class of dopants. Using solar energy to successfully charge electrochemical energy storage devices such as batteries would lead to exciting developments in energy technologies. In another study, researchers assembled a two-electrode photo rechargeable Li-ion battery using nanorod heterostructures. Low band gap, high efficiency photo-conversion and efficient electron-hole separation help the battery to fully charge within a few hours using solar light. The proposed concept and materials can enable next generation stable photo-

rechargeable battery electrodes, in contrast to the reported materials.

## INTERNATIONAL RESEARCH COLLABORATION

The Experimental High Energy Physics & Applications (EHEP&A) group of VECC has been working in the field of instrumentation and performing experiments in the field of high energy heavy ion collisions for creation and characterization of the Quark Gluon Plasma (QGP), a de-confined phase of the strongly interacting matter. VECC is involved in the areas of creation of such media at high temperature at LHC-CERN and at high density at the upcoming FAIR facility at Darmstadt, Germany. VECC is taking the lead role in building the muon chambers (MuCh) of the Compressed Baryonic Matter (CBM) experiment at FAIR using advanced gaseous detectors i.e., GEM and high rate RPCs. VECC has built and tested two types of real-size and sector-shaped triple-GEM chambers for the 1st and 2nd detector stations of MuCh with length of 80 cm and 120 cm respectively. A real-size RPC for the 3rd station of MuCh has been tested with cosmic muons. Both GEM and RPC modules have been tested at the GIF++ facility at CERN with muon beams in presence of high photon flux. An efficiency >95% for muons have been measured for RPC. The RPC module and the two GEM chambers with modified high voltage distribution

circuitry have been installed at the mini-CBM setup at GSI-Germany for testing with high intensity beams. Detailed performance simulation of the di-muon system with realistic geometries of the setup including those of beam-pipe, absorber are underway. On the area of the applications of these detectors, a prototype muon tomography setup using 6-RPC layers have started taking data with cosmic muons at VECC.

At HRI, in the High Energy Phenomenology the focus remained on searching for signals of Beyond the Standard Model (BSM) physics at present and future colliders, various neutrino physics and Dark Matter (DM) experiments, and gravitational waves interferometers. Multiple new BSM models predicting the existence of light  $Z\tilde{\epsilon}$  bosons, a light scalar that can induce neutrino self-interaction, and self-interacting and freeze-in DM candidates have been constructed. New ways of searching such particles at experiments by making use of multivariate/machine-learning techniques have been proposed. Such cutting-edge data analysis methods have also been used to study the jet substructure of boosted fat W-boson jets and non-standard interaction of the Standard Model (SM) Higgs boson with bottom quarks at the LHC. A detailed study analysing the effect of anomalous couplings on the spin-correlations and polarisation of a pair of particles involving the SM heavy fermions and gauge bosons was carried out. Impact of BSM physics on muon g-2 anomaly and lepton flavour violating observables have been studied.

The experimental high energy physics groups at IoP participated 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 CMS group at IoP contributed to the measurement of CP structure of the Yukawa coupling between the Higgs boson and tau leptons in proton-proton collisions at centre-of-mass energy of 13 TeV using the data recorded by the CMS experiment at LHC. Furthermore, its members are taking leadership roles in the development of CMS high-level trigger system for recording data during LHC Run-3, which will be starting in 2022. The high energy physics group of the institute remained actively involved in many areas such as formal field theory, string theory, heavy-ion



Picture of the upgraded mMUCH detectors (left)  
Picture of the RPC module (in large Aluminium enclosure) and GEM module placed back-to-back under test at GIF++ (right)

collisions, QCD, radiative corrections, neutrino physics, beyond the standard model scenarios and their phenomenology, and quantum information. In particular, the work was carried out on Hawking radiation from acoustic black holes, scattering amplitudes and asymptotic symmetry in asymptotically flat four-dimensional space-time. In addition, the phenomenology of radiative neutrino mass models, signatures and bounds on the parameters of the seesaw models, FIMP dark matter, sterile neutrinos, and muon anomalous magnetic moment puzzle related models, sub-leading BSM effects on the neutrino mass-mixing parameters at the future high-precision accelerator long-baseline neutrino oscillation experiments such as DUNE in USA and T2HK in Japan and atmospheric neutrino experiment at the upcoming India-based Neutrino Observatory (INO), determination of the Higgs boson couplings at hadron colliders, one-loop QCD corrections have been investigated.

SINP is responsible for the fabrication, maintenance and upgradation of the 2nd Muon Tracking station of ALICE. During the RUN-III of Large-Hadron Collider (LHC), the luminosity of the beams will increase substantially. The expected trigger rate in Pb-Pb collision will be 50 kHz. In order to handle this huge rate, both the High Voltage and the Readout chain of the Muon chambers have been upgraded on a surface laboratory at CERN.



*Phase-II Tracker module test setup*

The SINP-CMS group has made significant contributions in Higgs and BSM physics analyses using the  $135 \text{ fb}^{-1}$  of proton-proton collision data collected by

the CMS experiment during Run-II of LHC. During the long shutdown period, the group made significant contributions in tracker operations, hadron calorimeter calibration, electron-photon identification, research and development in several areas pertaining to the upgrade of the tracker, muon and calorimeter endcap (High Granularity Calorimeter) for future high luminosity runs. The work of the group has resulted in four publications related to physics analysis, upgrade of tracking, endcap calorimetry and muon system, several detector and analysis notes, a plenary talk in Beauty 2020 and a number of invited talks.

Adv-LIGO is presently operational with two second generation ground-based detectors at Hanford, WA and Livingston, LA in the USA. The third Adv-LIGO detector of similar capability has been planned (with in-principal approval from the Govt. of India) to be built at Aundha in Maharashtra, India. Several members of the LIGO-India community with different expertise and specializations studied the scientific rationale of LIGO-India as the third detector. In this context, a fully (Bayesian) numerical simulations of GW signals of inspiralling binary neutron star systems were performed. It was demonstrated that the addition of the LIGO-India detector at Aundha, Maharashtra will significantly enhance the ability to constrain the neutron star EOS. This analysis was complete by February 2021 and presented to the LIGO Scientific Collaboration (LSC) in early March 2021.

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. Based on the design and prototype development done at RRCAT, in all 127 power converters of two types have already been manufactured, tested and qualified at ECIL, Hyderabad and supplied to FAIR, Germany.

Based on the design, guidance and supervision from RRCAT, the first-of-series prototype of a four-quadrant power converter for HB.C2 magnet for FAIR, Germany, which is rated for  $\pm 400 \text{ A}$ ,  $\pm 90 \text{ V}$  maximum, was developed at ECIL, Hyderabad, and has qualified the factory acceptance test. Series production of 45 such power converters is in the advanced stage.

## 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.

Despite severe COVID conditions the construction and assembly activities at ITER continue in full swing with 75% of the activities getting completed this year as ITER surges ahead to meet the first plasma target in 2025. India has ensured this progress with the timely supply of all the components required for the first plasma which include the cryostat, the cooling water system, the in-wall shields and the Cryolines and cryodistribution systems which interface the cryoplat with the machine components. 100 % supplies of these component as per the desired norms of quality and safety has been effected from various Indian industries and their sub-contractors.

**Cryostat:** The top lid segments which left the Indian shores last year and marked the end of cryostat manufacturing activities in India have since been delivered to the ITER site. The segments have been assembled in the on-site ITER India cryostat workshop and checked for proper alignment and fitment. Welding of the segments using robotic arms is currently



*Clockwise from top; top lid segments at ITER India work shop undergoing pre assembly and alignment checks prior to welding with robotic arms*

underway. In parallel, the welding of the base section of the cryostat with the lower cylinder has been completed.

**Completion of cryoline manufacturing activities in India:** Approximately 4 km of Cryolines, operating at temperatures ranging from minus 269 to minus 193 deg-C, and about 6 km of return lines for warm gases, have been manufactured by M/s INOXCVA in India and dispatched to the ITER Worksite in France. These 'first of kind' Cryolines have diameters as large as 1 m, include multiple process pipes, have complex layouts and are vacuum jacketed to ensure very low heat losses. They adhere to stringent Nuclear standards. The last consignment of these lines was flagged-off on 29th July 2021 at M/s INOXCVA's factory in Kalol Village near Vadodara in Gujarat. Successful delivery also demonstrates India's vision of developing Indian industry, M/S INOXCVA, in fusion related technologies by direct hand holding ITER-India, DAE and the industry. The deliveries of a hi-tech, first-of-a-kind product in Cryogenics, at par with the best in the world, are also a good illustration of Atmanirbhar Bharat.

The ceremony was remotely attended by Sh. K.N. Vyas, Secretary, DAE, Dr. Bernard Bigot, Director General of ITER Organization, Dr. Shashank Chaturvedi, Director, Institute for Plasma Research, Sh. Ujjwal



*Shri K N Vyas, Chairman DAE and Dr Bernard Bigot Director General ITER France addressing the audience remotely*

Baruah, Project Director ITER India and many others. Dr. Bigot applauded the engineering & manufacturing capabilities of INOXCVA and the quality and promptness of project related deliveries. Addressing the audience Sh. Vyas said, “I am happy to see M/S INOXCVA as one such industry which has made its presence felt globally in a short span of 5 years in cryogenic lines at 4K temperature level, and I congratulate them for this”.

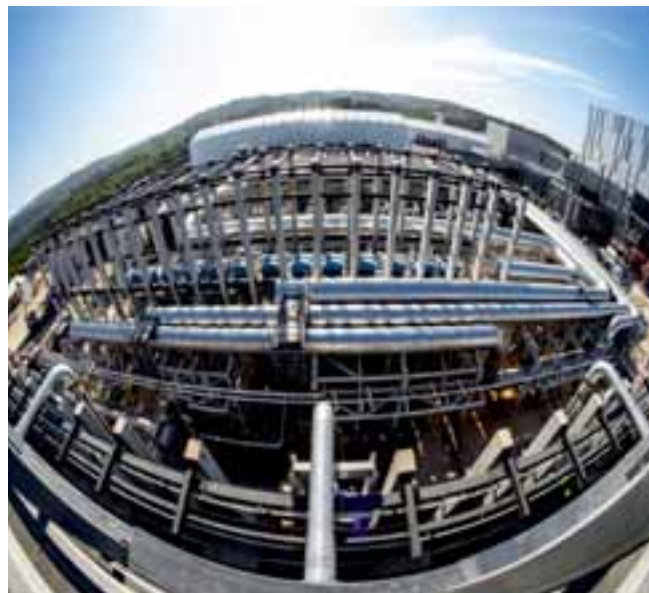
Various sections of the lines have since been installed at ITER site.

Installation of cooling water systems at ITER site: ITER India has successfully completed the supply of various components of the cooling water system capable of dissipating 510 MW of heat on average and 1.5 GW at peak load generated during machine operations. The installation of these systems is currently underway and is nearing completion post which the commissioning activities shall commence as per schedule.



*Cryolines and Warmlines manufactured by M/S INOXCVA under installation at ITER site*

In addition, several activities continue on the various experimental test beds at ITER India laboratory which are dedicated to establishing the performance of systems prior to the delivery to ITER in the coming years. The acceptance tests of the 1 MW, 170 GHz Gyrotron have been completed and efforts are underway to establish its performance in the laboratory. Various tests on the indigenously developed combiner circuits to be used for combining the outputs of 2, 1.5 MW amplifier chains and achieve 3 MW per RF source for the ion cyclotron tests have been performed. On the negative ion beam development front, H<sup>-</sup> ion beams with current densities upto 30 mA/cm<sup>2</sup> have been established in cesiated ROBIN source test bed and 40 kW of RF power from an indigenously developed 1 MHz solid state RF generator has been coupled to drivers of the TWIN



*Fish eye view of the cooling water system under installation at ITER site*

source in the configuration identical to multi driver RF ion source to be used in INTF, a negative ion based neutral beam test facility with a 21 m beam transport path length. Testing, operation and modifications on the multi mega-watt power supply systems continue to support the operations of the SPIDER beam source facility at RFX Padova. As a part of diagnostic system development, a special material, boron carbide (B<sub>4</sub>C) has been developed and qualified for its use as per ITER norms. This material shall be used for neutron shielding of the various diagnostic systems and the ITER port plugs.



*MEGH-3 Cloud Computing system*

## **CHAPTER 6**

# **RESEARCH EDUCATION LINKAGES**



*Faculty Development Programme of ATI*

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 development and knowledge management is taken up through Homi Bhabha National Institute (HBNI), BARC Training Schools 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 16 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 18th position in the Universities category, in the 2021 NIRF exercise. Based on high-quality publications during the calendar year 2020 in 82 Journals of high impact, the Nature Index 2020 has

placed HBNI in the second 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 2021, HBNI awarded 79 MD degrees, 24 DM and 25 MCh degrees, contributing significantly to the number of specialists in medical oncology in the country. Till December 2021, HBNI has awarded 1972 PhD degrees in a variety of disciplines. HBNI has launched “HBNI Research scholar Forum” on January 14, 2021 in order to advance/promote academic links between the research scholars of HBNI and to provide them a platform to grow their skills in communication, management and organizational domains.

During the year, HBNI organised two important value addition courses. As part of a MoU entered into with INSTN, France, a joint course was organized on Corrosion Degradation in Light Water Reactors from December 6 to December 10, 2021 at HBNI, Mumbai. HBNI also organized a course on Nuclear Law and policies for professionals of AERB and for professionals of various units of DAE such as BARC, IGCAR, HWB NFC, BRIT and TISS. In addition, HBNI also organized several value-added courses on online platform such as Nuclear Science and Technology; Design of multiphase Reactors/Contactors; Advanced Materials Chemistry and Emerging Trends in Biophysics.

During COVID-19 pandemic year also, HBNI continued dissemination of knowledge to its research scholars and students across all CIs/OCC through several webinars by eminent scientists conducted over WebEx platform. HBNI webinars were streamed live on its YouTube channel (HBNI Webinar) and recordings of webinars were made available on the channel for the benefit of students/faculty across all educational institutions in India and abroad.

The Foundation Day of Homi Bhabha National Institute was celebrated on June 3, 2021 in hybrid mode.

Prof. Jean-Marie Lehn, Noble Laureate and Chair of Chemistry of Complex Systems, Professor, University of Strasbourg Institute for Advanced Study, was the Chief Guest for the function. Shri K.N. Vyas, Chairman, Council of Management, HBNI and Secretary, DAE presided over the function. Apart from participation of functionaries of HBNI at various CIs/OCC and Central Office, faculty, alumni, students of HBNI, vice-chancellors, directors and students of prestigious institutions across India also participated in the function online. Prof. Jean-Marie Lehn delivered the J.B. Joshi Research Foundation Endowment Lecture on the topic "Steps towards Life: Chemistry." Outstanding students of the institute in various academic programs and winners of Prof. J.B. Joshi Research Foundation innovation awards for the year 2019 and 2020 were also honoured on the occasion.

HBNI organized a Half Day Special Webinar on March 1, 2021 jointly with the Indian Association of Nuclear Chemists and Allied Scientists (IANCAS) over WebEx platform to Commemorate 125 Years of Discovery of Radioactivity. Shri K.N. Vyas, Chairman, CoM, HBNI and Secretary, DAE presided over the event. Scientific talks on topics related to radioactivity were delivered by eminent nuclear chemists and physicists from India and abroad on the occasion.

NAAC peer team consisting of six members from different educational institutions in India visited HBNI during March 3, 2021 to March 5, 2021 for second cycle of accreditation. During the course of their visit, the peer team members had interactions with students, faculty, alumni and management. The team members also visited CIs of HBNI located in Mumbai, viz., BARC, TMC and ACTREC to get an overview of research and infrastructure facilities available in these institutes to conduct research in the various disciplines of sciences. HBNI has been accredited by NAAC with a score of 3.4, as a category 'A+' University in 2021.

HBNI organized a Memorial Program in honour of Dr. Sekhar basu, Former Secretary, Department of Atomic Energy and Former Chairman, Council of Management, HBNI on October 1, 2021. Dr. V. K. Saraswat, Member, NITI Ayog (Science & Technology) & Chancellor, Jawaharlal Nehru University, Delhi was the

chief guest on the occasion. Dr. V. K. Saraswat delivered Dr. Sekhar Basu Memorial lecture giving an overview of nuclear power in India including the path so far, nuclear and renewable penetration, SMR technology and long term energy strategy. During the program, Dr. Sekhar Basu Memorial awards were also presented to the outstanding young engineers who have shown excellent performance in the Training School and in M.Tech program and also made exemplary contributions to the DAE projects.

## Training School

Human Resources Development Division (HRDD) of BARC provides highly skilled human resources to DAE through two flagship programs, OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). The linkage of BARC Training School programs with HBNI ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various DAE units.

A total of 91 graduating TSOs of 64th batch of OCES/DGFS-2020 (57 engineering+ 14 physics + 7 chemistry + 7 biosciences + 6 RSE), after successful completion of training, were placed in various units of DAE. There were 8 Trainee Defence Officers, as compared to 6 last year, who passed out with this batch and were assigned to different Divisions/Units for undertaking project for MTech.

While the academic programme of the 64th batch was underway, screening examination for 9 engineering and 4 science disciplines for the 65th batch was organized successfully at 63 venues in 47 cities. The number of applicants for OCES/DGFS-2021 were 98,259 as compared to 1,21,332 in the previous year. Out of these, 51,877 candidates appeared in the online examination as compared to 71,341 in the previous year. A total of 198 candidates were selected for OCES/DGFS-2021 as compared to 199 last year.

HRDD conducted the QUEST programme under DAE's Continuing Education Programme (CEP). During the year, it offered courses on Process

Modelling, Simulation and Optimization and Reliability Engineering for PhD students and DAE employees. Certificates were issued to candidates who scored more than 50 per cent.

HRDD coordinated 1 to 2 months practical training and offered 3 to 12 months academic projects in BARC for students of BE / Btech / Mtech / ME / Msc / MCA / JRF / SRF from all over the country. Due to prevailing Covid-19 scenario this programme was completely stopped during January –December, 2021 and it could not be resumed.

Interviews were held in HRDD during July 2021 for induction of candidates under JRF scheme for Physics, Chemistry and Life Science streams.

During the year, RP&AD of BARC conducted 35 training courses on radiation safety in industrial and medical domains and 800 candidates received certificates after successful completion.

The Homi Bhabha National Institute in Mumbai assisted BARC, IGCAR and AERB in their joint efforts to publish a 767-page comprehensive book titled as “PHYSICS OF NUCLEAR REACTORS” on topics related to reactor physics based on 60 years of experience of various experts and peers in DAE. The book was edited by P. Mohanakrishnan, Om Pal Singh and K. Umasankari and published by Elsevier/Academic Press. Released by Shri K.N. Vyas, Chairman AEC on June 3rd, 2021, it is intended for entry level scientists and engineers in nuclear energy arena.

Human Resources Development activities at RRCAT revolve around imparting training to Ph.D. Scholars and M.Tech. Students from various Indian institutes. At present 14 Ph.D. Scholars are registered. The stipendiary programme for CAT-I and CAT-II is conducted for the Scientific Assistants and Technicians. The 13 TSO's were graduated in the OCES programme on Oct 30, 2021.

BARC Training School AMD Campus, Hyderabad continued its activity wherein 16 (Geology) Trainee Scientific Officers (TSO) of the 11th batch (OCES-2020) completed induction training on 31st October 2021.

At IGCAR, 30 young trained scientists and engineers (OCES-2020, 15th Batch) have successfully completed their orientation programme at BARC Training School at IGCAR and have been placed in various units of DAE. Online classes using Vi-meet, google meet, WebEx were also conducted to complete their training. Also, around 135 Category I & II trainees have completed their classroom training and are presently pursuing their on-the-job training.

NPCIL has strong and dedicated workforce of 10823 employees as on December 31, 2021 consisting of Engineers, Technicians and Supervisors,

## Administrative Training Institute

The Administrative Training Institute (ATI) formally came into being on 02.07.2007 which was earlier known as O&M and Training Division of the Department of Atomic Energy.

The mandate of ATI is to conduct department specific induction training programme to the new recruits in the Administrative and Auxiliary cadre of Constituent Units of DAE and orientation courses to the middle level and senior employees of Constituent Units, Public Sector Undertakings and Aided Institutions on service-related matters, legal issues, financial matters, vigilance topics and computer development skill. The ATI impart a special thrust in demystifying the ongoing activities of the DAE and in creating awareness about the benefits of Radiation, Health and Society to the Administrative and Auxiliary cadre employees through its various training programmes. The ATI also conducts special programmes to the Scientific, Technical, Medical



**A mandatory induction training programme for Work Assistants conducted by ATI**

and Para-medical officers and staff members of DAE on various job-related issues and soft skills. Over the decade, ATI has developed a robust training system to meet the unique requirements of the DAE and has been successfully imparting series of training programmes on Behavioural and Soft Skills, Cadre Plan, Capacity Building, Faculty Development, Induction, Management Development, Refresher / Orientation Courses, Yoga, etc. The ATI has also successfully developed in-house faculties for imparting training to the DAE employees.

In 2020-2021, ATI had shifted to its own campus at DAE Convention Centre, Anushakti Nagar, Mumbai with DCSEM handing over the ATI Project. The ATI is now equipped with advanced training aids for conducting both offline and online programmes. Conducting online programme had become a challenge during and post Covid-19 pandemic. But online training facilitated ATI to “reach the unreachable”. Thus, ATI has converted this challenge into opportunity and enhanced the number of participations in its training programs during the 2020-2021 and 2021-2022 and maintained the momentum of training and development activities across DAE Units. During 2021-2022 till date, the ATI has already imparted training to about 2000

officers and staff members in 50 different courses / workshops. The ATI has also conducted workshops in short notice on the special demand of DAE and its Units.

The ATI also continues to carry out Training Need Analysis for the Department, Evaluation of Training of selected programmes, Transparency Audit under RTI Act on behalf of the Department. The endeavour of the ATI to innovate and re-invent continues to inspire the ATI team with the constant support of the DAE Units. The ATI is progressing ahead to explore newer area of human resource development in the Department.

## 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](http://www.brns.res.in)) of BRNS.

### Research Projects Funding

During this financial year 2021-22, 58 new research projects of 3 years duration each, were sanctioned. As a first year grant for these projects, ₹ 8.9 Crore was released to various Indian Universities and Institutes. A sum of ₹ 26.36 Crore has been disbursed for ongoing and new research projects, symposium, International Science Olympiad funding



*A Yoga Programme conducted by ATI*



*Faculty Development Programme of ATI*

and other schemes. A total number of 532 project files were processed for sanctioning the grants of new and on-going research projects. In this duration, 84 research projects were technically and financially closed and, in the process, total unspent balance amounting to ₹ 4.27 Crore was received from the PIs institutes.

### **Technical Programme Discussion Meetings (TPDMs)**

All the projects entering in the final (usually 3rd) year or requiring extensions were reviewed by BRNS CDPs. To accomplish these tasks, 37 Meetings (known as Technical Programme Discussion Meetings, TPDMs) of the CDPs were organized. Apart from reviewing, evaluating and recommending new projects, CDPs were also engaged in monitoring activities of ongoing projects and suggesting mid-course corrections. They also evaluated the projects when their tenures were completed. Suitable grading was also awarded to each completed project and same is communicated to Project Investigator (PI) and Project Collaborator (PC). The deployment of Video Conferencing Mode in BRNS meetings since January 2019, has not only expedited 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.

### **Support to International Science Olympiad Programme in India**

Participation of Indian Students in International Science Olympiad programme started in 1997-98 in Physics, other subjects followed soon after. HBCSE, TIFR, Mumbai, a DAE unit, is the nodal centre to manage this programme. Significant involvement of large number of teachers and national teacher associations helps the students to achieve success. Funding to HBCSE is provided by various central government agencies including DAE, DST, DOS and MHRD. Under the able mentorship, performance of Indian students at the International Science Olympiads remained

excellent. From the data available at BRNS, 64% of Olympiad medallists choose academic careers.

### **Funding to Current Science Journal**

BRNS has been supporting the Current Science Association with an annual grant of ₹ 10 lakhs towards publishing of Current Science Journal which have both direct and indirect relevance to the programmes of the Department of Atomic Energy. The Board has approved a request of Current Science Association to continue supporting for next 3 years for publication of Current Science Journal.

### **Fast Track COVID-19 Research Projects**

During June 2020, Board of Research in Nuclear Sciences (BRNS) made a special call of fast-track research project proposals (18-months duration) to deal with COVID-19 issues under the Health Care Committee (HLC) of BRNS. Research proposals were invited from researchers across India. In response to this, 75 research project proposals were received in a span of two months' time. After rigorous review by HLC committee, 9 best projects were funded by BRNS. Particular considerations were given to the specificity/ sensitivity/ effectiveness while reviewing projects related to diagnostics/therapeutics. Researchers from Bio-Science group, BARC, Trombay, were interfaced with Nine PIs and were marked as PC/DCs based on their expertise. According to nature of their deliverables, nine recommended projects, Therapeutics (small molecule/ aptamer/ antibody) - 5 Nos.; Diagnostic assay/kit-based projects - 3 Nos. and Protective Materials (PPE) - 1 No. were categorized. First year progress review of all the Nine on-going COVID-19 fast-track research projects has been conducted and applicable 2nd year grants have been released. The outcome of these 9 projects was found to be very encouraging and one project investigator along with a BARC researcher has filed for Indian patent.

### **Launch of New Coordinated Research Projects (CRPs) Scheme**

During this year, new Coordinated Research Projects (CRPs) scheme was initiated on areas in which participation of multiple institutions will be fruitful to DAE.

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. On BRNS website, an invitation was placed indicating DAEs requirement in form of 14 CRP projects proposals. In a short span of three months, 57 new research proposals were submitted by PIs from various non-DAE academic institutes across India. The proposals were scrutinised and further assigned to appropriate committees (CDPs) for the scientific and technical evaluations & recommendations as per BRNS guidelines.

### Subject Distribution of BRNS Research Projects

The subject-wise distribution of new R&D projects in FY 2020-21 is shown in following figure. The subject “energy” includes solar devices and hydrogen energy. The subject “sensors” includes both basic research as well as device fabrication.

### BRNS Research Projects in Basic Sciences

BRNS deals with large number of basic science research projects under BRE Committee of BRNS. One of the important outcomes of these projects is in the form of good number of journal publications having high impact factor. In view of this an effort was made to categorize the journal publications arising out of research projects in BRE committee of BRNS. Therefore, 136 publications originating from the BRE (committee) projects completed in last Financial Year (FY 2020-21), were analysed in terms of “impact factor” are shown in Fig. 3. In all these projects, BRNS grant has been acknowledged. It is evident from the histogram that the most of the publications originating from the BRNS projects were in the peer-reviewed journals having 2 to 4 impact factors. However, many publications were in very high impact journals (>5) which is considered to be a reasonably good outcome for the basic science research. Most of these projects resulted in more than two journal publications.

### Patents Filed in Basic Science Projects

This year six patents were filed from the works

originating from the BRNS - BRE research projects. These patents were filed by PIs with PCs as major collaborators from DAE institutes.

### State-wise Distribution of BRNS funded Research Projects

The state-wise distribution of the BRNS funded projects in FY 2020-21 is shown in the figure.



*State-wise distribution of the BRNS funded projects in FY 2020-21*

### BRNS funding to Scientific Events – Symposia & Workshops

In Financial Year (FY) 2020-21, number of symposia/conferences were far less as compared to previous financial years due to COVID-19 pandemic situation in the country. These symposia were organized using VC mode and following all pandemic protocols. Apart from this, BRNS also provides partial financial support to various symposia / conferences / workshops organised by non-DAE Institutes & Indian universities. However, no partially funded events could be organized in FY 2020-21.

### Yearly Progress Review of BRNS - MOU Projects

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. 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. The physical and financial progress of such MOUs is monitored by an apex committee and user committee appointed Project Implementation Committee (PIC). No new MoU was sanctioned in FY 2021-22. 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. 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. To help in establishment and development of mathematical centres. 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. To support undergraduate and postgraduate teaching along with research activities in India by offering scholarships, travel support, support to libraries among other things.

NBHM Budget Estimation for FY 2021-22 was envisaged to ₹ 42 crore, but due to severe funds restriction, scheme allocations were revised to fit the funds allotted to NBHM for FY 2021-22 (₹ 20 crore). In the light of the expenditure incurred under various schemes of NBHM till mid-December, the Board reviewed the allocation of funds for FY 2021-22 and considered all the schemes one by one, and readjusted the allocation. For the remaining period of the FY 2021-22, the Board further granted its approval for reusing the funds wherever they have remained underutilized / unutilized to other schemes where they are required.

### Undergraduate Scholarship for BA/BSc and 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 mathematics or statistics. The selection for awarding these scholarships is done on the basis of written test / interview. The pandemic has prevented us from holding the written test for Master's scholarship 2021-22. There seems very little chance now of being able to complete the selection process and so in all likelihood no fresh scholarships being offered during the academic year 2021-22.

### PhD Scholarship

Students possessing Master's degree in mathematics, physics or statistics and wishing to take up research work in any branch of mathematics (including mathematical statistics and mathematical physics) leading to a PhD degree are eligible to apply for the PhD scholarships awarded by NBHM. The selection of the scholars is based on academic records and the result of a Selection Test / Interview by a selection committee constituted by the NBHM. The budget for PhD fellowships for the FY 2021-24 was ₹ 4 crore.

The written test was conducted on 18th August 2021. To ensure smooth conduct of the Test, NBHM wrote letters to all administration and police authorities concerned. Of the 2895 applicants, 1575 appeared in the Written Test. Based on the performance in the Written Test, 88 candidates were shortlisted for interview

which were held online during September 13-15, 2021. A total of 81 candidates (of 88 called) attended the online interview, and 47 (Zone1=8, Zone2=3, Zone3=7, Zone4=24, Zone5=5) of them have been recommended for the Doctoral Scholarship. It may be noted that 14 women (out of 88 total) were shortlisted for the interview, and 9 women made it to the final list of 47 candidates selected for the award. The examination Committee had created five interview panels and each panel was allotted almost equal number of candidates with similar spectrum. Results were announced on 21st September 2021.

The Written Test for Doctoral Scholarship (2022-23) is tentatively scheduled on 4th June 2022. Examinations Committee included Patna (IIT Patna) and Imphal in the list of Written Test Centres.

### Post-Doctoral Fellowship

NBHM has been supporting the postdoctoral candidates of the country which gives them an essential lifeline for 3 years after they complete PhD and before they are ready to apply for regular faculty positions. NBHM selects postdoc candidates twice a year - in the month of January and July. Funds of about ₹ 4.51 crore have been disbursed under this scheme during the FY 2021-22. NBHM PDF committee selected 33 candidates out of a total of 93 applications (February 2021) and 28 candidates out of a total of 109 applications (November 2021) in the year 2021-22.

### 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 ₹ 68,65,079/- was disbursed to such mathematicians under this scheme during the year 2021-22.

### 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. The

funds are meant for purchase of books and journals. The Board was happy to note that some of the grant-receiving institutes were having devoted corners for NBHM books.

NBHM could not support any Library Grant in the FY 2021-22 due to limitation in the funds allocated to NBHM.

### 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. Total approved budgetary estimates for this scheme was ₹ 60 Lakh for the FY 2021-22, but due to shortage of funds allocated to NBHM this year, no grant was released for this scheme in the FY 2021-22

### Research Project Grant-in-aid

NBHM provides assistance for Research Projects Proposals (along with JRF/SRG/RA) on the recommendations of its Committee. Based on the recommendations of the committee, NBHM extended a financial support of about ₹ 2.1 crore to selected 8 fresh and 50 on-going projects in FY 2021-22.

### Travel Grant

Total approved budgetary estimate for Travel Grants was ₹ 5 Lakh for the FY 2021-22. Due to Pandemic imposed travel restrictions, no travel grants were recommended /approved by NBHM in the year 2021-22.

### Conference Support

NBHM provides financial assistance for holding national and international conferences / workshops / seminars. Total approved budgetary Conference Support scheme for was ₹ 20 Lakh for the FY 2021-22.

Due to Pandemic imposed restrictions, no fresh grant under this scheme was recommended/approved by NBHM in the year 2021-22.

### **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 has sanctioned a sum of ₹ 55 lakhs to HBCSE for organising Mathematical Olympiad and Madhava Mathematics Competition for FY 2021-22. The EGMO is being held in Hungary during April 6-12, 2022 which comes under this scheme and NBHM issued the letters appointing team representatives.

### **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 fulfil the objective, IWM organizes various workshops and conferences that focus on presentation of original research work and discussion about career opportunities in mathematics. Due to the pandemic, the activities of Indian Women and Mathematics (IWM) continue to be in online mode. Five events have been planned in the financial year 2021-2022. They are (a) virtual seminars (replacing the Visitor's programme) (b) a Mini-course (c) Regional workshop on research and opportunities (d) Young Women in Mathematics workshop and (e) Annual conference.

The total approved budget of IWM for 3-year period (2019-22) was ₹ 87,27,160/-. But due to limited funds allocated to NBHM this year, ₹ 7 Lakhs (out of the budget of ₹ 30,49,200/-) was allocated to IWM for FY 2021-22. A grant of ₹ 5,13,989/- was released to IWM in November 2021.

### **Mathematics Training and Talent Search (MTTS), Hyderabad**

MTTS Trust established in 1993, holds a large number of cost-effective and immensely useful programmes for promotion of higher mathematics every year. NBHM approved a budget of ₹ 55 lakhs for holding MTTS programme in FY 2021-22. A grant of ₹ 30 lakhs was released to MTTS as 1st instalment in July 2021. The remaining grant as per MTTS requirement has also been released. NBHM has provisioned ₹ 1.5 crore for BE 2022-23.

### **Support to various Centres of Mathematics during the FY 2021-22**

#### **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. The Board has approved a grant-in-aid of ₹ 6.5 Crore to support Chennai Mathematical Institute (CMI), Chennai during the FY 2021-22. Towards this, 1st Instalment of ₹ 3 crore was released by DAE in November 2021, following which CMI has submitted a provisional UC. On NBHM's recommendation, DAE has released the remaining payment of 2nd (and final) instalment of ₹ 3.5 crore in the current FY 2021-22.

#### **Kerala School of Mathematics (KSoM), Kozhikode**

KSoM organised an International Conference on Class Groups of Number Fields and Related Topics from October 21-24, 2021. The conference brought together the top Number Theorists and young scholars to present their work. In keeping with the tradition,

ICCGNFRT-2021 hosted a handful of Ph.D. scholars and Post-Doctoral Fellows and provided them with opportunities to present their research in front of experts. A grant of ₹ 19,43,645/- was released to KSoM for the FY 2020-21 after adjusting the previous unspent balance of ₹ 61,56,355/- with them.

### **National Centre for Mathematics (NCM), IIT-Bombay Campus, Mumbai.**

Board permitted NCM to utilize the previous year's grant of ₹ 1 crore during the FY 2021-22. JS(R&D)'s suggestion to first seek UC of ₹ 1 crore grant before considering any further grant to NCM was well taken by the Board. Chairman informed that NCM receives some financial support from TIFR as well.

### **Bhaskaracharya Pratishthan (BP), Pune**

NBHM approved a grant-in-aid of ₹ 25 lakhs to BP during the FY 2021-22 of which ₹ 21 lakhs were released in November 2021 and ₹ 4 lakhs will be released in due course upon receipt of UC.

### **Institute of Mathematics & Applications (IM&A), Bhubaneswar**

NBHM had recommended the release of the grant of ₹ 50 lakhs to IMA for the FY 2020-21. The Board has appointed a liaison committee to consider NBHM funding under this head. A grant of ₹ 41 lakh was released to IMA.

### **National Centre for Mathematics (NCM), IIT-Bombay Campus, Mumbai**

Due to the pandemic, NCM could not utilize the grant of ₹ 1 crore in time DAE released during FY 2020-21. NCM has planned several activities, offline workshops and schools and has promised to utilize all the funds during this year itself.

## **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 frequent interaction taken place 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 and they are Tata Institute of Fundamental Research (TIFR), Mumbai; Tata Memorial Centre (TMC), Mumbai; National Institute of Science, Education & Research (NISER), Bhubaneswar; Institute of Physics (IoP), Bhubaneswar; Saha Institute of Nuclear Physics (SINP), Kolkata; Harish-Chandra Research Institute (HRI), Allahabad; Institute of Mathematical Sciences (IMSc), Chennai; Institute of Plasma Research (IPR), Gandhinagar; Atomic Energy Education Society (AEES), Mumbai; Homi Bhabha National Institute (HBNI), Mumbai and University of Mumbai – Department of Atomic Energy–Centre for Excellence in Basic Sciences (UM-DAE-CBS), Mumbai.

Out of total Budget Provision of ₹ 3115 Crore in the year 2021-22 an amount of ₹ 2645.58 Crore has been released as on January 2022 for Aided Institutes towards salaries, creation of assets etc.

### **Olympiad Programme**

India secured 1 Silver Medal and 1 Honourable Mention at the 10th European Girls' Mathematical Olympiad (EGMO) 2021, organized by Georgia, held online during April 9-15, 2021. India secured 1 Gold, 1 Silver and 3 Bronze Medals at the 62nd International Mathematical Olympiad (IMO) 2021 hosted by Saint Petersburg, Russia, held online during 14-24 July, 2021. India secured 3 Silver and 1 Bronze medals at the 32nd International Biology Olympiad (IBO), (named as IBO Challenge II) held online and hosted by Portugal from July 18 to 23, 2021. The Indian team of five students secured four Gold and one Silver medal in the 14th International Olympiad on Astronomy & Astrophysics (IOAA), organized by Colombia, which was held online from 14 to 21 November 2021. The Indian team also bagged the second prize in the Team Competition. In the country-wise medals tally, India was placed in the top position, jointly with Thailand and Russia.

## INFORMATION TECHNOLOGY APPLICATION DEVELOPMENT

The IPR-developed Deep Learning software DeepCXR is now at the heart of a national programme coordinated by ICMR, and involving 20 institutions all over the country, aimed at the automated high-speed detection of pulmonary TB and other lung ailments from chest X-rays. Earlier training of the AI tool had been done on a limited data set, so the entire range of variables could not be covered. Under an MOU signed with ICMR in 2020, training of the tool has been initiated on data from culture-confirmed X-rays from earlier surveys. Annotated X-rays images are being shared with IPR -- 1000 normal and 3700 abnormal & annotated images have already been received from ICMR and more are being progressively delivered. Once training is completed, DeepCXR will be placed in survey vans. To facilitate the conversion of X-ray films to digital images, IPR has also developed a low-cost X-ray digitizer and pre-processing software.

Various scientific computing softwares have been designed, developed and deployed which includes: parallel scientific computing applications software for Accelerator Physics Section, for BARC Beamlines Section, for Synchrotrons Utilization Section and for Human Resources Development Section, software to mark any unusual activity of non-employee population inside the RRCAT Technical Area.

Various network, electronic security and collaboration tools / systems has been designed, developed and deployed this includes: To enable RRCAT employees to participate securely in web based online meetings using various applications like Jitsi/ Google Meet/ Webex/ Skype/ GoTo Meeting etc., a secure Internet DMZ has been commissioned, Setup is commissioned to provide secure Personal Computer (PC) based Video Conferencing (VC) facility at few locations inside RRCAT technical area, Flap Barrier based access control system has been installed and commissioned at Guard House for regulating entry of pedestrians entering RRCAT technical area.

Various information management tools /

systems have been designed, developed and deployed this includes: software for e-Integrity pledge for the employees as per the Circular from Central Vigilance Commission, Vigilance Awareness Week was observed in RRCAT from October 26, 2021 to November 01, 2021 with the theme "Independent India @75 : Self Reliance with Integrity", PRIS-G target monitoring software has been enhanced, Open Source Blockchain platform Multichain has been configured and integrated with existing Material Gate Pass software deployed on RRCAT Infonet.

### **Commissioning of Private Cloud for providing on-demand computing and storage services at IGCAR**

A private cloud solution is deployed for IGCAR to provide a reliable, flexible and secure hosting platform for providing service delivery models of Infrastructure as Service (IaaS) and Platform as Service (PaaS) using Openstack over Intranet. The cloud is configured using 7 storage servers, 6 compute servers, 2 controller servers and 2 management servers.

### **Installation & Commissioning of Optical Fibre Cable (OFC) & passive components of 10G Fault-tolerant Campus Network**

IGCAR had laid ITU G.657A1 standard 24-core single mode Optical Fiber Cable for the Fault-tolerant campus network for connecting all the buildings in the campus for about 26 km. The campus network was divided into 6 physical rings with a maximum of five buildings in a ring considering permissible link loss and power budget. The OFC testing was carried out in all the rings for a wavelength of 1310nm using Optical Time Domain Reflectometer (OTDR) between core switch location 1 to core switch location 2 (i.e., end to end). The network connectivity was tested for the speed of 1Gbps and 10Gbps for all the rings.

### **Development USB Access Control and Monitoring Software for Desktops**

USB Access control and monitoring software is developed in-house to secure the user desktops (personal computers & thin-clients) from unauthorized

access of USB devices and monitor/control their usage. This software has three sub-modules: USB client module; Desktop Monitoring client module and Central Monitoring & Control server (CMCS).

### **Development and Deployment of Indigenous Wireless Sensor Network for the assessment of slope stability at Avalanche Site with Meteorological sensors**

A collaborative project, sponsored by Office of the Principal Scientific Advisor to Govt. of India, has been initiated by IGCAR with DGRE (Defense Geoinformatics Research Establishment), DRDO, Chandigarh with the prime objective to design indigenous Wireless Sensor Network (WSN) nodes and to deploy WSN for measurement and dissemination of snow and meteorological parameters from a mountain slope in the avalanche prone areas. This project is executed in two phases at Dhundi, Himachal Pradesh. As part of this project, WSN nodes, which can withstand harsh environmental conditions of the winter at Himalayas (up to  $-40^{\circ}\text{C}$ ), were designed and qualified at IGCAR. They have been interfaced with 24 different types of sensors such as wind speed & direction, snow depth (ultrasonic type), snow surface temperature (Infra-Red type), shortwave radiation, longwave radiation, temperature & humidity, atmospheric pressure, precipitation, snowpack temperature profiler and soil water content sensor.

To keep up with the growing demand for cloud computing services in BARC, a new Cloud Computing system known as MEGH-3 has been developed. Internet based document sharing system, AnuDocs, was developed as an alternative to third party cloud-based storage systems for ensuring better information security in BARC.

At VECC, an enhanced version of Handheld RFID (Radio Frequency Identifier) reader, designed and developed in-house has been deployed at VECC main gate for attendance recording. The system is specially designed to recognise only DAE issued ID card. Since accurate time-stamping of attendance record is essential, automatic clock synchronization with the database server has also been implemented in the



**MEGH-3 Cloud Computing system**



**Handheld RFID Reader**

system which keeps the time up to date. It is powered by a 3.7v Li-ion (18650) battery with in-built battery-protection module. The estimated run time of the system from full power is approximately 24 hours. The security personnel are using this new Handheld RFID reader for last three months without any problem.

A deep learning-based Windows Application software has been designed and developed in-house for digitising the reimbursement form of medical expenses under VECC CHSS facility. The Accuracy of the deep learning models is better than other publicly available OCR (Optical Character Recognition) software libraries. This will help in faster processing of medical bills.

Border Gateway Protocol (BGP), one of the key protocols for achieving Internet connection redundancy, has been implemented at VECC. VECC network is presently connected to two different Internet service providers (ISP), e.g., NKN and BSNL as multi homing facility. Multi homing provides redundancy and network optimization. It selects the uplink path out of available redundant paths of ISPs which offers the best suitable AS (Autonomous System) path to a resource. Once BGP is using more than one service providers, the autonomous system (AS) will become a transit AS. The system has been tested and being integrated with VECC LAN.

A Network Intrusion Detection System (NIDS) has been implemented using open-source software SNORT. The system has been deployed outside VECC perimeter to inspect entire incoming and outgoing network traffic of VECC and generate alert against any malicious event based on the defined rule sets. The alert logs from the IDS are analysed with ELK (Elasticsearch-Logstash-Kibana) based log analysis tool.

Network traffic monitoring and analysis are two key aspects of cyber threat management in any organisation. In view of these, a monitoring and analysis system for network traffic of VECC has been implemented using open-source software tools Ntopng and ELK. Ntopng is a high-performance web-based network traffic analyser and flow collector tool which is deployed to capture all the inbound and outbound packets of VECC network and analyse them from packet header and payload information using deep packet inspection technique (nDPI). This system provides a deeper visibility of entire landscape of external network traffic of VECC.

With the upsurge in the number of web meetings, webinars and video conferences, particularly in the aftermath of the COVID-19 pandemic, there is a substantial increase in the demand from users for accessing the facilities for holding such meetings and conferences. To streamline the arrangement of concurrent meetings at different rooms by different users, a meeting room booking portal has been implemented based on open-source software. By using the portal, users can make advance reservation of a meeting room of their choice for a given time slot. Once, the user makes a reservation, the room administrator is informed of it by an automated email. Users can easily find out the booking status of the meeting rooms on a particular day by looking at the room-reservation matrix for the particular day.





**BARC-CRISPR-CUBE unit for  
COVID-19 testing**

## **CHAPTER 7**

# **TECHNOLOGY TRANSFER AND COLLABORATIVE PROGRAMMES**



***80 kV, 12 kW Electron Beam Welding  
Machine developed in BARC***

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 AND COLLABORATIVE PROGRAMMES

At BARC, a total of 52 technologies were transferred to 78 parties pertaining to agriculture, radiation processing, medical, environment, engineering, chemical, and water domains during the year.

BARC is offering a one-time 75 per cent concession in license fee charged by it in return for transfer of technologies to interested parties. This initiative was launched under the 'Azadi Ka Amrit Mahotsav' drive to celebrate 75th year of Indian Independence, and is valid up to August 2022.

BARC released 31 new technologies into the public domain during the year.

Radiation based technologies introduced by BARC into the public domain included 10 MeV Linac for Radiation Processing Applications; ANUSUCHAK, a dongle for detecting elevated levels of Gamma Radiation; Industrial Fluoroscope Technology; Radiation Monitoring Watch; Ultra Flexible Lead-Free X-Ray Shields and a Quick Scan Whole Body Monitor.

In the medical domain, the newly introduced technologies included HDR Brachytherapy System "Karknidon-I"; Taap Darshak- remote monitoring of human body temperature; Engineered Valveless Transparent Face Mask (EVTFM); A CRISPR-based integrated system for detection of Covid-19; ABS IMRT/VMAT Phantom - for pre-treatment dose verification in Intensity Modulated Radiation Therapy (IMRT)/Volumetric Modulated Arc Therapy (VMAT).

Engineering industry related technologies included Serial Coordinate Measuring Mechanism (SCMM); Process for production of copper selective polymeric resins; Production of high purity Copper Oxide nanoparticles from de-populated Printed Circuit Boards (e-waste) using novel Cu-selective ligand grafted polymeric resins & Synthesis of novel copper selective polymeric resins; Atmospheric Pressure Plasma Jet" technology; 100kW, 35kV Electron Beam Melting (EBM) Gun Column for Metallurgical Application; Liquid Nitrogen Based Transportable Refrigeration System for Vaccine - Sheetal Vahak Yantra (SHIVAY-V); Liquid Helium (LHe) Dewar; 10 kW, 15 kV Electron Beam Melting Machine and 2 kW Electron Beam Welding Machine.

Environment related technologies were Dissolved Oxygen (DO) Monitor (Model-1); Upgraded NISARGRUNA - Biogas plant based on Biodegradable waste and Compact Helical Biodegradable Waste Converter-SHESHA.

For chemical industry, it has made available Visual Detection Kit (VDK) for monitoring ethanol in petrol; Preparation of Pb-Li alloy by fused salt electrolysis; Accurate estimation of alcohol content in alcoholic products through easy Synthesis of BODIPY dye; Nano-Ni Coating on Difficult-to-Plate Upon Metals/Alloys.

### Portable device for CRISPR-based detection of COVID-19

A battery powered portable system – BARC-CRISPR-CUBE – was developed in BARC for detecting



**BARC-CRISPR-CUBE unit for COVID-19 testing**

COVID-19 infection. CRISPR-Cas technology is employed to examine the RNA of patients for potential COVID-19 infection. The technique showed efficiency comparable to RT-PCR. The technology was transferred to 02 parties.

### **Technology for imparting flame retarding capability to cotton fabric**

A special method has been developed in BARC to impart fire retarding capability to cotton fabric, with proven applications in medical and hospitality sectors. Cotton fabric coated with a specially synthesized Graphene Quantum Dot (GQD) solution when exposed to flame forms a protective polymer layer that effectively limits the ingress of oxygen making the fabric highly flame retardant.

### **10 MeV electron accelerator for Radiation Processing Applications**

BARC has taken up an elaborate program for designing and building a 10MeV electron accelerator. 10MeV, 5kW electron beams are highly suitable for cross linking of cables and has proven applications in semiconductor, agriculture and diamond processing industries. The machine works without inducing any radioactivity in the environment. The technology was transferred to two parties.

BARC also transferred technology for a 80 kV, 12 kW Electron Beam Welding Machine with a 0 - 150 mA current range and weld capability in SS304 at 24 mm, and a Fast Current Transformer (FCT) for beam current measurement in electron accelerators with a

maximum peak beam current of 500mA and maximum pulse width of up to 10ms.

The licenses granted to private parties for commercial scale implementation of the following technologies were renewed for additional 5 years. These included Inductively Coupled Plasma Mass Spectrometer (ICPMS), Fluoride Detection Kit for ground water (FDK) and Nitrogen oxides releasing wound dressing.

The Technology Transfer and Collaboration Division of BARC participated in India International Science Festival Goa 2021 (IISF-Goa) during December 10-13, 2021.

The output power rating of power converters for electromagnets in particle accelerators may vary in a wide range from few watts to few 100's of kilowatts and further to megawatts. However, unipolar and bipolar power converters with relatively lower output power (few 100's of watt) are required in large numbers for applications such as corrector magnets as well as for various magnets in beam transport line of low-energy accelerators used for various research, industrial, medical and societal applications. For such applications, the power converters based on single printed circuit board (PCB) and using switch-mode power conversion schemes were developed. Technologies of unipolar (15 A, 50 V max.) and bipolar power converters ( $\pm 15$  A,  $\pm 50$  V max.), both having output current stability of  $\pm 100$  ppm, were made available to transfer to the industry through TT&CD, BARC and transferred to M/s Electronics Corporation of India Limited, Hyderabad.



**80 kV, 12 kW Electron Beam Welding Machine developed in BARC**



**Unipolar power converter on 6U printed circuit board**



**Technology license transfer to M/s. Persapien Innovations Private Limited**

A technology knowhow and license agreement was signed between IPR and M/s Persapien Innovations Pvt. Ltd. for a prototype system to generate Plasma Activated Water, which is found to have anti-microbial properties. Following the signing of the agreement, the team from the licensee industry underwent training for the knowhow transferred.

## COLLABORATIVE PROGRAMMES

BARC has launched a dedicated technology incubation program to boost entrepreneurship activities using technologies it has developed in-house. An MoU was inked for incubation of “Development of Carbon Nanotube-Boron Carbide (CNT-B<sub>4</sub>C) composite tiles by hot pressing and “Strong Motion Seismic Instrumentation system for Nuclear Power Plants” technologies. Further, it has advertised for potential partners in the incubation of “Handheld Gamma Spectrometer based on Cesium Iodide (CsI) Single Crystal” technology.

## SOCIETAL INITIATIVES

Under DAE's mandate on food security, RRCAT has developed an indigenous technology for refrigerated transportation of Fruits and Vegetables of Farmers. SHIVAY (Sheetal Vahak Yantra) uses Liquid Nitrogen (LN<sub>2</sub>) as a source of refrigeration. After successful road trials of more than 3000 kms, the technology has been shared with M/s Tata Motors Ltd., so that refrigerated trucks (reefers) based on this technology can be built by them. At present the diesel-powered and chloro fluoro carbon based refrigerated



**20 feet refrigerated container SHIVAY**



**Seven days Road Trials of SHIVAY**

trucks (reefers) are extensively used in country. These reefers are operationally expensive, maintenance prone and not eco-friendly. They consume diesel for powering refrigeration cycle. These issues have been addressed with SHIVAY technology and a system which is more suited to Indian conditions has been built. The source of refrigeration used in SHIVAY is LN<sub>2</sub> which is a by-product of oxygen generation plants. Large excess capacity exists in the country for generation of LN<sub>2</sub>. The system developed at RRCAT is a standalone container with multimodal features i.e. it can be mounted on a truck or a railway wagon.

The incubation agreement signed with M/s Tata Motors Limited for jointly developing reefers, to transport F&V, pharmaceuticals and other similar products is a significant step towards dissemination of DAE technologies in the country under the “Atma Nirbhar Bharat” mission of Government of India.

A variant of SHIVAY system named as Sheetal Vahak Yantra (SHIVAY-V) for transportation of pharmaceutical products (including vaccines) at any temperature, up-to minus 70°C has been developed. This standalone container has a cargo handling volume

of 266 cubic feet, and can hold 2 standard pallets. SHIVAY-V can be used for vaccine storage under stationary conditions and also for refrigerated transport. This container can be mounted on any truck or it can be built on the chassis of any vehicle. This technology has been tailor made for Indian conditions. SHIVAY-V mitigates multiple trans-shipments which many a time result into temperature excursions and spoilage of vaccines as it plays dual role of being a standalone, storage and transportable device. No such system is presently available in Indian cold chain.

57 licenses were granted to various parties interested in 17 BARC technologies under Advanced Knowledge & RUral Technology Implementation (AKRUTI) program. The licensee partners are spread across Odisha, West Bengal, Bihar, Uttarakhand, Rajasthan, Tripura, Andhra Pradesh, Tamilnadu, Uttar Pradesh and Maharashtra.

A total of 12 AKRUTI Agreements were signed with various parties for deployment of BARC technologies in rural areas. Technologies that were of interest to them include delicious & preservative-free shelf stable natural jamun product; a post-harvest technology for the development of intermediate moisture shrimp; development of instant fish soup powder; Banana health drink and gluten free- multigrain pre-mix.

## 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 this period, six DAE-IPR cell meetings were held, where fourteen new patent proposals were reviewed. A total of eleven patent applications have been filed in the current reporting period. This includes six in India, two each in USA & Europe and one application was filed under the Patent Cooperation Treaty (PCT).

During this period, thirteen of the previously

filed patents were granted to the Department. These includes nine in India, three in USA and one in Japan. Following is the list of patents granted:

### 1. Synthesis of Fibrous Nano-Silica Spheres with controlled Particle Size, Fibre Density, and Various Textural Properties - from TIFR (in India & USA).

The invention relates to a method for synthesizing fibrous silica nano spheres, wherein desirable product characteristics such as particle size, fibre density, surface area, pore volume and pore size can be obtained by controlling the reaction parameters during the synthesis. The invention could find application in catalysts, photo catalysts, CO<sub>2</sub> sorbents, supercapacitors, drug delivery and other biomedical applications.

### 2. A Method for preparing Chlorine-dioxide releasing polymer – from BARC (in India).

The invention relates to development of a chlorine dioxide (ClO<sub>2</sub>) releasing bio-degradable polymer (due to the presence of an enzyme) with sodium chlorite (NaClO<sub>2</sub>) embedded in it. The novelty of the invention lies in the use of a polymer matrix formulation for in-situ release of ClO<sub>2</sub> when it comes in contact with water. The presence of the enzyme degrades the polymer, releasing acid (H<sup>+</sup>), which reacts with NaClO<sub>2</sub> to give the active ingredient ClO<sub>2</sub>, which has disinfecting properties.

### 3. Developing Protocol for Depositing Adhesive, Durable and Protective Layers of Homogenous Y<sub>2</sub>O<sub>3</sub> coating on the Interior Surface of Quartz Tube by Solution Technique – from IGCAR (in India).

The invention relates to a thin film deposition of homogeneous Ytria (Y<sub>2</sub>O<sub>3</sub>) layer as protective coating on the interior surface of quartz tubes by chemical solution deposition (CSD) technique. The novelty of the invention is in the use of a composition of chemicals used, air flow, and annealing temperature to obtain a durable, uniform and adhesive protective layer of Y<sub>2</sub>O<sub>3</sub> on the inner surface of quartz tube used as moulds. The invention finds application in coating the interior surface of steel (or metal) tubes of varied diameter as well to coat different oxide materials, such as alumina, magnesium oxides, zinc oxide, tin oxide, ceramics, etc.

#### **4. Process for the Creation and Tuning of Defects in Nano-silica to produce Defected Nano-silica – from TIFR (in India).**

The invention relates to design and synthesis of nanomaterials with tunable defects and their use for conversion of CO<sub>2</sub> to fuel and fine chemicals by reduction. The novelty of the invention is in the development of a method to control the type, concentration and distribution of various defects on the surface of nanomaterials like silica, ceria, alumina, zirconia, metal silicates, metal oxides etc. These defect sites are transformed to catalytic sites, which can then catalyze the hydrogenation of CO<sub>2</sub> to fuels like methane, alkane, alkene, alkanol, etc., and even other chemicals. Unlike the expensive metal catalyst, these metals free catalyst are comparatively stable at high temperatures and can be easily regenerated by heating in air. The invention finds application in chemical industries, applications catalysis, CO<sub>2</sub> capture-conversion, etc.

#### **5. A Method of Manufacturing Radio Frequency (RF) Coil Multi-Driven RF based Negative Ion Source – from IPR (in USA).**

The invention is a new design for RF coaxial switches used in VHF and UHF frequency range for switching RF power between transmission line section for high power (upto 3 MW). RF switches commercially available are for low power applications. Due to simplicity of the movement mechanism (switching arrangement), the cost and the overall dimension as well as weight reduces. Simulation and analysis data for the coaxial RF switch using high frequency simulator, CST Microwave Studio (MWS), were found to be as predicted.

#### **6. Flame Retardant Transparent liquid based on novel functionalized Graphene Quantum Dot – BRNS Project by BARC & ICT, Mumbai (in India).**

The invention relates to a novel Phosphorous Functionalized Graphene Quantum Dots (PF-GQDs) which is transparent and has low toxicity, good thermal and chemical stability, has high surface area, good biocompatibility and eco-friendly thereby making it ideal as a flame retardant for fabrics. PF-GQDs were synthesized by using Graphene Oxide (GO), poly-phosphoric acid, and monosodium orthophosphate

through a hydrothermal treatment. Characterization studies of the PF-GQDs were carried out on cotton fabric using Infra-red Spectroscopy, Particle Size Analysis, Scanning Electron Microscopy (SEM) Analysis and Limiting Oxygen Index (LOI) Analysis. The flame retarding duration for a cotton fabric treated with PF-GQDs was found to be about 560 seconds.

#### **7. A Method and Device for Tuning SCRF Cavity – from RRCAT (in India).**

The invention relates to a method and device for tuning single-cell or multi-cell SCRF cavity for precise slow and fast tuning. The tuning device is the essential element of any SCRF cavities, which keeps the cavities in the correct resonating frequency with that of the source frequency at cryogenic temperature. The tuner uses an X-link mechanism, which is rugged, reliable, ease of manufacture & assembly, low hysteresis and reduced fabrication cost. The device could have wide applications in projects such as in International Linear Collider (ILC) and Indian Institutions-Fermilab Collaboration (IIFC) where a large number of SCRF cavities will be used.

#### **8. A process for the removal of <sup>99</sup>Tc from liquid intermediate level waste of spent fuel reprocessing – from BARC (in Japan).**

The invention relates to a process for removal of <sup>99</sup>Tc from liquid intermediate level waste of spent fuel reprocessing by using mild steel wool as a source of ferrihydrite. <sup>99</sup>Tc gets captured in the crystal lattice of the corrosion products goethite (FeOOH / Magnetite) which is then removed by filtration / settling. The supernatant solution, free of <sup>99</sup>Tc, is discharged while the goethite bearing the <sup>99</sup>Tc waste is subjected to vitrification and storage

#### **9. Method for Bio-beads Development for Normal and Saline Wastewater Treatment – from BARC (in India).**

The invention relates to a method of treating wastewater by the development of aerobic granular biomass (AGB). Conventional method uses activated sludge process (ASP) for the treatment of sewage. The novelty of the invention is a new method for AGB development without using activated sludge or other

seed biomass to bioreactors. The microorganisms present in the wastewater are promoted to grow directly in the form of aggregates and then into granules which helps in the removal of ammonia, nitrates / nitrite, phosphates, metals and organic carbon (COD/BOD). The invention is expected to find wide applications in the treatment of sewage and industrial effluents.

#### **10. Asymmetric Rotating Impeller Extraction Column – from HWB (in India).**

The invention relates to mass transfer equipment / device used for liquid-liquid extraction or solvent extraction processes. Conventionally, Rotating Disc Column (RDC), Asymmetric Rotating Disc Column (ARDC) and Rotating Impeller Contactors (RIC) are employed for liquid-liquid extraction. However, they permit static hold up, axial bypass and channeling which is not desirable for mass transfer. The novelty of the invention is in the extension of stators, shifting of horizontal stators and modification of agitators which helps overcome the above-mentioned drawbacks. The invention could find application in extraction of metal ions from an aqueous stream and also in chemical, petroleum, hydrometallurgy, pharmaceutical and mineral processing industries.

#### **11. A Method for Synthesis of Resol Beads with Good Control over their Size – from BARC (in India).**

The invention is related to development of a method/process of synthesis of resorcinol formaldehyde beads of spherical shape. This is achieved by controlling the stirring rate, ratio of organic to aqueous phase, quantity of polymers, etc. The inventors are able to achieve a well-tailored mean particle diameter of the beads which can be manufactured at low cost and with minimal secondary waste. The resultant beads have good mechanical strength and can be reused (upto 10 cycles) by washing it with a solvent followed by water and then drying it.

#### **12. Use of 3,3'-Di-Seleno-Dipropionic Acid (DSePA) as an Anti-Cancer Agent – from BARC (in USA).**

The invention relates to application of synthetic water soluble organo-selenium compound, 3,3'-Di-Seleno-Dipropionic Acid (DSePA), as a safe and effective chemotherapeutic agent against human

cancers particularly; tumours of the lungs (Non-Small Cell Lung Cancer - NSCLC) and Chronic Myelogenous Leukemia (CML). These types of aggressive cancers are more difficult to treat because of their resistance to wide range of chemotherapeutic drugs. Studies on oral administration of DSePA exhibited anti-cancer activity by inhibiting the growth of xenografts derived from human lung cancer and leukemia without producing any significant side effects on the normal tissues.

During the same period, the following four patented technologies were licensed to companies in India.

1. Hybrid Granular Sequencing Batch Reactor (SBR) for Waste Water Treatment
2. Compact Helical Biodegradable Waste Converter - SHESHA
3. Banana Health Drink
4. Superabsorbent Cotton – for removal of oily substance from aqueous media

Among the patent applications that have been filed till date, the following fifteen patent applications were published during the year.

**1. Magnetic Flowmeter for Electrically Conducting Liquids** – from IPR (in India – App. No. 202121006697 dated 17-Feb-2021).

**2. Preparation of Fiber Fortified Idli - Using Legumes (other than Urad) and Hydrocolloids - with Improved Textural Properties** – from BARC (in India – App. No. 202121007181 dated 20-Feb-2021).

**3. Acidic Amorphous Aluminosilicates (AAS) Solid Acid for Catalysis, Plastic Degradation and CO<sub>2</sub> to Fuel Conversion** – from TIFR (in India – App. No. 202021040554 dated 18-Sep-2020).

**4. Production of dilute Pb (0.2 to 1.1 wt %) - Li Alloys** – from BARC (in Europe – App. No. 18773618.6 dated 18-Feb-2021).

**5. Vacuum Compatible Device for Measurement of Work Function and Alkali Metal Atom Flux** – from IPR (PCT App. No. PCT/IN2019/050962 dated 28-Dec-2019).

**6. Process to Determine parts per billion levels of Ammonia in Water with Emphasis on Boiler Coolant Water** – from BARC (in India – App. 202121004484 dated 02-Feb-2021).

**7. RNA Elution Active System Using Dextritic Fibrous Nano-silica (DFNS)** – from TIFR (in India – App. 202121011175 dated 16-Mar-2021).

**8. Process for Uranium removal from near neutral aqueous solution by freshly prepared fine ferrihydrite generated during ultrasonic assisted corrosion of mild steel wool** – from BARC (in USA – App. No. 16/733388 dated 03-Jan-2020).

**9. A Method of Preparation of Forward Osmosis Membrane using Synthesized Poly(sulfone-co-amide) Polymer** – from BARC (in India – App. No. 202121021115 dated 10-May-2021).

**10. Novel Magneto-Liposomes for Active Fibrosarcoma Tumour Targeting and Combinatorial Chemo-, Radio- and Magnetic Hyperthermia Therapy of Cancer** – from BARC (in India – App. No. 202121012799 dated 24-Mar-2021).

**11. Synbiotic Chutney** – from BARC (in India – App. No. 202121025621 dated 09-Jun-2021).

**12. An Apparatus to Generate Large Plasma Arc Plume for Waste Disposal and Thermal Processing Applications** – from IPR (in India – App. No. 202121039223 dated 30-Aug-2021).

**13. An improved laser welding method for enhanced weld quality and enhanced surface smoothness** – from RRCAT (in USA – App. No. 16/999814 dated 21-Aug-2020).

**14. Magnesium Nanoparticles to Capture and Convert CO<sub>2</sub> to Methane and Methanol** – from TIFR (PCT App. No. PCT/IN2020/050458 dated 21-May-2020).

**15. A Method for Diffusion Bonding of Piezoelectric Crystal to Metal Wear Plate** – from IGCAR (in India – App. No. 202127040609 dated 07-Sep-2021).

The above published documents can be accessed from the respective Patent Office websites: -

1. Indian Patent Office  
<http://ipindiaservices.gov.in/PublicSearch/>
2. US Patent Office  
<https://portal.uspto.gov/pair/PublicPair>
3. European Patent Office  
[https://worldwide.espacenet.com/advancedSearch?locale=en\\_EP](https://worldwide.espacenet.com/advancedSearch?locale=en_EP)

During the year 2021-22, about 600 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), under section 4 and section 39 of The Patents Act, 1970, 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.

During the year, 5 new applications were filed for grant of patent by BARC.

1. “A novel process for production of composite tritium breeder material for fusion reactor application” from Powder Metallurgy Division (PMD), Materials Group, BARC.
2. “Multi-tube membrane reactor with provision for molten salt heating for hydrogen production using nuclear/solar heat” from Desalination and Membrane Technology Division (DMTD), Chemical Engineering Group, BARC.
3. “Strong stress inducible promoter with minimal expression under control conditions for understanding different novel applications in plants” from Nuclear Agriculture and Biotechnology Division (NABTD), Bio Science Group.
4. “Compact hydraulic pinned jaw crusher with higher size reduction ratio” from Uranium Extraction Division (UED), Materials Group, BARC.





*Shri. K. N. Vyas, Secretary DAE & Chairman AEC inaugurated the “Sangam Jal Vayu Vihar” in the presence of Director, BARC, Director, DCSEM and other officials of DAE, BARC & DCSEM on 29.10.2021*

## CHAPTER 8

### INFRASTRUCTURE



*Formal Inauguration of HBGS Technology Based  
STP at DAE Township, Kalpakkam*

## CONSTRUCTION, SERVICES & ESTATE MANAGEMENT

Directorate of Construction, Services & Estate Management (DCSEM) is responsible to provide infrastructure support to various Units of Department of Atomic Energy (DAE) including its aided institutions. DCSEM is involved in planning, design & execution of various construction 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.

The gist of major projects undertaken by DCSEM during the year is given below:

Construction of hostel for Trainees of HBNI/BARC; Extension of V.S. Bhavan; Construction of 356 flats of various categories at Anushaktinagar;



**Trainees Hostel for BARC/HBNI - B1 & M1M2 buildings from central avenue road**



**Construction of 312 flats of type V-E at Anushaktinagar**



**Construction of 100 bedded Hospital for TMC at Vizag**



**GCNEP Type D Front View - Block 1**

Construction of 100 bedded Hospital for TMC at Vizag; Construction of 312 flats of type V-E at Anushaktinagar; Upgradation of Elect, PH and Mechanical services; Rajarhat – Kolkata works; GCNEP works at Haryana Phase II; Restoration of old houses PH-II; Restoration, Renovation & upgradation of residential buildings PH-III; LIGO (India) Project; Project for RMP /BARC at Mysuru, Karnataka; SMF/BARC Township Project at Challakere, Karnataka; AERB works -Ph-2 NB-C building; Upgradation of water supply and sewerage system and Upgradation of Security related infrastructure works etc.

Various facilities completed and inaugurated by DCSEM during 2021 include “Sangam Jal Vayu Vihar” at Anushaktinagar; ‘vehicle parking facility’ at RMP Mysuru; Open Gym & Play Parks at Anushaktinagar; ‘Madhuban’ Urban Forest at Anushaktinagar; Expansion of RPL & LCL Facilities At BRIT, Vashi. Grid Connected RTS Photovoltaic System at Niyamak Bhavan A & B, AERB Complex, and Vikram Bhavan Anushaktinagar; Grid Connected Roof Top Solar Photovoltaic System at PTAAAF Complex, Anushaktinagar; Bio gas plant behind Tapti buildings and in-house testing laboratory for STP treated water at western sector etc.



**Shri. K. N. Vyas, Secretary DAE & Chairman AEC inaugurated the "Sangam Jal Vayu Vihar" in the presence of Director, BARC, Director, DCSEM and other officials of DAE, BARC & DCSEM on 29.10.2021**



**RIM GYM PARK with theme My Village at Mandala inaugurated by Director, BARC in presence of Director DCSEM on 27.2.2021**

During the year, construction activities of a state-of-art Sensor Evaluation Test Bed Facility (SETBF) at GCNEP campus is completed and handed over to the users. Central building, which is considered to be an iconic building of GCNEP campus, is in advanced stage of completion. During this year, a major mile stone of dome truss (weighing 120MT) erection is completed for the central building auditorium. Other works at GCNEP Campus such as construction of school 2, services buildings, UG tank and STP works are nearing

completion. At GCNEP Township, entire residential quarters of 32 flats of Type D, 32 flats of Type C, 4 units of Type E, substation, Gate house and UG tank construction activities are completed and handed over to the users. Other works such as guest house block B, recreation facility, dining hall, and multipurpose hall construction activities are nearing completion.

Civil maintenance of 9980 flats, VS Bhavan, AERB, AEES buildings common services at different areas of Mumbai like Anushaktinagar, Chembur, Bandra, Shivaji Park, Ghatkopar, Mulund, Worli, Peddar Road, Malabar Hills, Colaba, OYC, Guest House at New Delhi etc. were carried out by DCSEM during the year.

Allotment of departmental accommodation; monitoring of recovery of license fee & allied charges; management of departmental land and properties situated in the city of Mumbai, Navi Mumbai, Bhubaneswar, Delhi i.e., leasing of land and properties from and to outsiders, payment/receipt of lease compensation, payment of service tax, maintenance of land records etc. were also carried out by DCSEM.

## PURCHASE & STORES

Directorate of Purchase & Stores (DPS), a service organization of DAE since its inception in 1972 is responsible to carry out the Materials Management function of DAE. The mandate of DPS is 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 and scrap items and also to conclude clearance, Marine insurance, etc.

The e-tendering system used by DPS for procurement was upgraded and extended to more units for sale of tenders and DAE users located throughout the country were able to use the system. Tender documents were modified keeping in view the latest changes brought out in General Financial Rules by Ministry of Finance, Department of Expenditure.

During the year 2021-22, DPS processed 17644 indents, entered into 13114 purchase contracts for supply of equipment and consumables worth ₹ 2228.16 crores. This includes 6604 number of orders worth

₹ 405.93 crores which were released through GeM portal. In addition, DPS has floated 103 sales tenders, released 126 e-sale orders and disposed off 5112.607 MT of scrap involving 6259 unserviceable items and 28 old vehicles. The total number of CSRV issued during the year was 13239. Further, 76488 issue vouchers were released which includes 189121 numbers of item. DPS also provided other services such as logistical support, transportation, import, export, storage etc. to the respective units. Counsellor, AEW, Embassy of India, Paris conducted a total of 3 pre-dispatch inspections at the premise of the manufacturer in the European Union Countries for the purchase orders placed by DPS and for other DAE organizations viz; NPCIL, ECIL. During the current year, 11419 items were codified in different units.

It is very important that the suppliers are kept abreast of evolving purchase procedures and policies so that they can cater better to the indentors with their updated knowledge. To enable this DPS had organized five manufacturers meet. The meetings were held at different DAE Units for the suppliers from various regions of the country.

Two large consignments of strategic items were successfully cleared and transported to NFC, Hyderabad which resulted in savings to the tune of 33% due to change in mode of contract.

DPS had taken considerable efforts in finalizing the contracts for procurement of strategic material. Continuous interaction with the Suppliers and User were held to finalize the project. Proposals after changes at various levels of the department was put up to Government.

Earlier fuels bundle dispatches to various units from NFC, Hyderabad was undertaken through Container Corporation of India Ltd. (CONCOR), (PSU-under Railways) by 20 feet closed body container. The mode of transport has been changed to private 32 feet closed body container (trucks). This resulted in more than 50% savings.

331.395 MT of MDU in 18 containers and 115.712 MT of SDU in 15 containers were received at

NFC from UCIL, Jaduguda & Tummalapalli respectively and were safely unloaded in the plant.

34716 of Fuel Bundles in 1760 boxes were dispatched to NPCIL reactors through 75 containers in 25 occasions from NFC as per schedule. Four consignments of High Value Coolant Tubes and RM Assemblies were dispatched by NFC to RAPS, Kota, KAPP-3&4, Kakrapara and KGS, Kaiga.

PUC consignments have been collected by M/s IREL from NFC in trucks, loaded and dispatch was arranged in 12 trucks. Various types of consignments were dispatched to Zirconium Complex, Pazhayakayal in 55 truckloads.

29 SS Tubes were dispatched to other DAE Units.

MRPSU had arranged safe unloading and stacking of 33 carbon steel plates each weighing approximately 3 MT having a total of 100 MT weight. This job was carried out in two days working in extended hours.

Issued Stainless Steel Plates weighing 64 MT as FIM for Theni Project, Theni.

421 SS Pipes of various sizes measuring nearly 2500 Mtr were issued from MRPSU and loaded for Tarapur.

At FRFCF Stores Glass Slabs meant for RSW facility in FRFCF 88 Wooden Boxes, loaded in 4x40 Ocean Freight Containers and the same were safely unloaded and stores in the identified area.

IRPSU had arranged the export and import of high value and delicate research system with Fermilab National Accelerator Laboratory (FNAL), USA under Indian Institution Fermilab Collaboration (IIFC), under the Joint Project Document (MOU) between DAE and DOE, USA.

Import of 125.6 Kg weight dressed cavity assembly costing more than ₹ 4.5 Crores and single cell cavity weighing 130.750 Kg. costing around ₹ 41 Lakhs from Fermilab, Chicago to Mumbai have been arranged in most economical way by IRPU.

Export shipment of two HB650 Five cell SCRF cavity costing ₹ 4.3 Crore (\$567936) to Fermilab as part of R&D phase deliverables under IIFC was carried out.

Export shipment of 40 Kw 650 MHz RF amplifier costing USD 635395 (approx five crores) was exported which was voluminous as well delicate consignment.

## 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 4800 families reside at Kalpakkam Township and 2800 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 etc.

The Engineering Services Group and the Medical Group are the two Groups in GSO. The Engineering Services Group comprises of the Civil Engineering Division, Resources Management and Utilities Division and Electrical Services Division. The Civil Engineering Division designs and constructs residential and public buildings. It also takes care of civil maintenance, solid waste management and upkeep of gardens and greenery. The Electrical Services Division designs the total electrical system for new buildings, augments the sub-stations with all safety features and takes care of electrical construction, operation and maintenance of electrical system. The Resource Management and Utilities Division comprising of Planning, Resource Management, Computer, Mechanical Services, Industrial Safety, Telecommunication, and Autosshop Sections takes care of computer networking, e-surveillance, audio-visual system integration and computerization, drinking water

distribution, providing telecommunication services and air conditioning systems for the office buildings, hospital and other public buildings in the townships. The industrial safety requirements in the construction sites of both the townships are also managed by this Division. The Planning Section takes care of the budget planning and monitoring. The Autosshop takes care of maintenance of department transport.

In addition to providing the basic essential services to the residents, the Engineering Services Group supports the five schools in the Townships in terms of Augmentation of Infrastructure, maintenance and solid waste management.

The Medical Group, caters to the health care needs of about 30,000 beneficiaries. The 100 bedded hospital at Kalpakkam, offers specialist services to the Out Patients and In Patients and also has an ISO certified Laboratory and Radiology services. Since March 2020, subsequent to onset of 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 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 are supported by Accounts and Administration, who look after Personnel Management, Estate Management, and Recruitment.

Some of the significant works carried out by GSO includes the following:

- In-house Architectural & Structural Design of ATAL Incubation Centre, Scientist Apartment at PRP Township, Mechanical Workshop, 300KLD Tertiary Treatment Plant at Anupuram STP.
- During this period 58 Nos. of NIT were released and Work orders were issued for Rs. 37.78 Crore.
- Some Major Works' Orders include Operating Pharmacies for Supply of medicines to CHSS

Beneficiaries in DAE Townships at Kalpakkam and Anupuram at maximum price discount of 39.50% on the company Maximum Retail Price (MRP) on all the pharmaceutical items.

- Refurbishment of various types of quarters (5 Works).
- Construction of Balance works for 55 Nos. of type IVD quarters and 45 Nos. of type VE quarters (Tower 3 - G+ 12 storeys) in DAE Township at Anupuram.
- Construction of 1.5 MLD Hybrid Bio-film Granular Sludge(HBGS) Sewage Treatment Plant.
- Development of Fitness Park (ANU –FIT).
- Due to COVID 19 pandemic, new medical facilities were created for screening of patients with COVID symptoms through FEVER Clinics at Kalpakkam and Anupuram Hospitals and a separate Ward for fever cases is also functioning. RT-PCR testing facility is also made available at Kalpakkam and Anupuram Hospitals through a CHSS Panel Centre. A COVID Care Centre (CCC) has been established for providing treatment for mild COVID cases and it is now functioning at Anupuram Township.
- DAE Hospital, Kalpakkam has started a Haemodialysis Unit in its premises on 22.09.2021. It is the extension of services from Apollo Hospitals, Chennai (a CHSS recognized Hospital) at the panel hospital rate completely operated and manned by them for a period of two years and the premises has been allotted on chargeable basis.

Five latest generation units have been installed and dialysis services are operational since 22.09.2021. A Nephrologist from Apollo Hospitals makes fortnightly visits to oversee the functioning. The patients are immensely benefited by this as they can avoid travelling to Chennai.



**ANU-FIT – The Fitness Park at DAE Township, Anupuram**



**Inauguration of Dialysis Unit at DAE Hospital, Kalpakkam**



**Formal Inauguration of HBGS Technology Based STP at DAE Township, Kalpakkam**





*Chairman, AEC & Secretary, DAE inaugurating the Special Components Manufacturing Facility*

## CHAPTER 9

### PUBLIC SECTOR UNDERTAKINGS (FINANCIAL PERFORMANCE)



*Passive Catalytic Recombiner Devices*

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. A 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 end December 2021 in current FY 2021-22 is ₹ 4390 crore and the estimated profit for FY 2021-22 is around ₹ 5200 crore. The net profit after tax (Total Comprehensive Income) for previous FY 2020-21 was ₹ 4374 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 2020-21 were ₹ 2,352.90 Cr and ₹ 623.20 Cr as against ₹ 2,419.60 Cr and ₹ 596.83 Cr respectively during the previous year.

## INDIAN RARE EARTHS LTD.

During the financial year 2020-21, Despite Pandemic COVID-19, the company achieved sales turnover of ₹ 974.13 as against ₹ 1040.63 crore during previous year. The company achieved highest ever Profit Before Tax (PBT) of ₹ 415.11 crore registering growth of 3% as compared to corresponding previous year.

During the period from April to December 2021, the company has achieved Sales Turnover of ₹ 1019.06 crore as against ₹ 689.82 crore achieved during the corresponding period of previous year, registering growth of 48%. The Company achieved Profit Before Tax

(PBT) of ₹ 451.12 crore during the period April to Dec, 2021 as against ₹ 253.30 crore during the corresponding period in previous year.

IREL paid dividend amounting of ₹ 94.71 crore for the year 2020-21. The total amount of dividend paid by IREL surpassed the equity infused into the Company, multifold. IREL issued 100% equity bonus shares amounting to ₹ 86.36 Crore to the Government of India.

## ELECTRONICS CORPORATION OF INDIA LIMITED

Electronics Corporation of India Limited (ECIL) was established primarily to meet the Control and Instrumentation requirements of India's nuclear power program, ECIL has played a pioneering role in spurring the growth of indigenous electronics industry in the country, ranging from miniature components to complex systems and encompassing Instrumentation, Communication and Computer technologies. ECIL is a multi-product, multi-disciplinary and multi-technology organisation providing cutting-edge technology solutions to the strategic users in Defence, Atomic Energy, Aerospace, Electronic Security, IT & e-Governance. ECIL has been pursuing state-of-the-art technologies to establish itself as a Centre of Excellence in strategic and allied sectors, continuing to take up projects involving integration of complex and one-of-a-kind systems.

### Performance

During the financial year 2020-21, Revenue from Operations was recorded at ₹ 1504 Crores as compared to ₹ 1664 Crores in the previous year. Profit Before Tax (PBT) was recorded at ₹ 152 Crores compared to ₹ 81 Crores in the previous year. Profit After Tax (PAT) recorded at ₹ 109 Crores compared to ₹ 50 Crores in the previous year. Although the Revenue from Operations during the financial year 2020-21 has decreased by 9.62% when compared to financial year 2019-20, the profitability of the Company has increased. The PBT has increased by 87.65% as compared to the previous financial year and the PAT has increased by 118%. The revenue from operations has decreased during the financial year under review, mainly due to the impact of COVID-19 on supply chain disruptions and

restricted work duration. The profitability of the Company during this period has increased due to enhanced efficiency in monitoring the project delivery schedules, reduction in expenditure related to travel and other fixed expenditure.

DPE has set a target of ₹ 2700 crores for the year 2021-22. Against the set target, ECIL has achieved an Income of ₹ 934.84 crores till end December 2021.

The sector-wise significant contributions during the year are as follows:

### Nuclear

The major contribution came from supply of NUCON PLC to ISRO; Ultra Stable Power Converters to BOSE Institute; TSI Spares, Sensors, LCPs, PCRDs to RAPS, NAPS-1&2, KAPS, TAPS & MAPS-1&2 SITES; TPLC-32 based computer based Alarm Annunciation System (CAAS) to IGCAR; Hydrogen Steam Concentration Monitoring System to KAPP-3&4; C&I, SCADA, BF3, PMS for Dhruva, BARC; Nuclear Instrumentation Package for NPCIL, KAPP-3&4, & RAPP-7&8; Passive Catalytic Recombiner Devices to RAPP-7&8, E-Lock Type-I & Type-II, RMP Components,



**Ultra Stable High Power Converters**



**Passive Catalytic Recombiner Devices**

Electric Position Transmitter to BHEL and other services to various DAE units.

### Aerospace

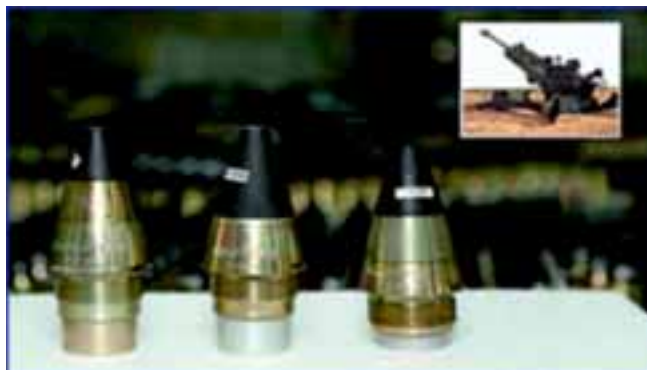
In Aerospace the Major contribution is through supply of Potentiometers for Akash, 11 M Antenna for IRNSS, BISAG Swayamprabha APL to Hindustan Aeronautics Limited (HAL).



**11 M Antenna**

### Defence

The major contribution to Defence sector came from Samyukta Upgradation, PUSHPAK project, supply of Electronic Fuzes to MoD, Mobile Missile Checkout Facility (MMCF) to BDL, and Mobile Squadron Control Center (MSCC) systems to BEL, TR2400 and M7 Radios to MO Karwar, SPIC DRDO, BEL, RF Seeker C4I for Brahmos Missile.



**Electronic Fuzes for Artillery Guns**

### Security

For security, the major contribution is by supply of CCTV and Switches to Delhi Police, AMCs for Delhi Police, Jammers / Room Jammers to various Prisons, Security gadgets to UP Vidhan Sabha.

## IT, e-Governance & OTHERS

First Level Checking (FLC) and Sealing, Distribution, Packing and Counting (SDPC) for EVMs (Electronic Voting Machines) to Election Commission of India and State Election Commissions of different states; supply of EVMs to Election Commission, Bhutan and Invalidation of EVMs and supply of internal Battery for CU/DMM to State Election Commission, Maharashtra.

## R&D Program and New Products

ECIL has maintained its thrust on technology and developed many new products and systems. The journey of innovations through collaborative R&D efforts jointly with DAE, DRDO, ISRO and other industries has resulted in successful realisation of new products/systems. Some of the products introduced include:

1. Hydrogen Steam Concentration Monitoring System (HSCMS)
2. Monitoring system for Alpha & Beta radiation using Scintillator Fiber and Silicon Photo Multiplier (SiPM) detector technology
3. Online Boron Meter (OLBM) based on Neutron detector technology
4. EC-Vikram IoT based solution for Remote Monitoring and Tracking of COVID 19 patients and quarantined people
5. Pocket Dosimeter with Wi-Fi connectivity
6. Automatic Dependent System – Broadcast (ADS – B) Receiver system
7. AXI-Symmetric Autonomous Underwater Vehicle (AUV)
8. RF seeker for Air Defence Programme

The major systems and technologies delivered during the year include:

1. Subsystems including in-house designed and manufactured HF and VHF amplifiers for EW system Upgradation project to Indian Army

2. Power Convertors and RF amplifiers to International Discovery Science Programmes
3. Rugged Indigenous computers for C4I applications for BrahMos systems
4. 18m Antenna system for Aditya Mission of ISRO.
5. Upgraded Ship Installed Radiac System (SIRS), XBT System and XBT Probes
6. Improvised Explosive Detectors

## Automatic Dependent Surveillance - Broadcast ADS-B

This technology enables the aircraft to determine its position via satellite navigation and periodically broadcasts the same for tracking purpose. ECIL has indigenously developed the ADS-B dual redundant receiver system for Indian Navy and has successfully completed User Evaluation Trials.

## EC-VIKRAM

ECIL successfully deployed Health Monitoring Device (EC-VIKRAM) during the peak of COVID Pandemic. This device is designed for measuring vital parameters viz. Body Temperature, Blood Oxygen (SpO<sub>2</sub>), Heartbeat Rate, Respiration Rate and NIBP (Blood Pressure). This device helps Doctors and Health Workers to monitor the vital health parameters of the COVID affected patients remotely.



**EC-VIKRAM**

## Software Defined Radios

ECIL in collaboration with CDAC has designed and developed Man Pack Software Defined Radio to

**Software Defined Radios**

meet the strategic and military communication requirements. The equipment is intended for Ground-to-Ground and Ground-to-Air Line of Sight communications in VHF/ UHF frequency band for both voice and data.

### **C<sup>4</sup>I Computer Consoles**

ECIL has designed, developed and standardised the Rugged Indigenous computers for C<sup>4</sup>I applications for both BrahMos and Akash C<sup>4</sup>I systems. These indigenous computers have resulted in saving significant amount of foreign exchange.

### **Ultra Fast PLC**

ECIL jointly with BARC has designed, developed, High Speed, Hot Standby PLC based Control System with 10ms cycle time to meet complex process requirements. The High Speed, Hot Standby Redundant PLC system is very useful for fast real-time control, monitor, abort and Interlock parameters with highest quality and reliability.

### **AXI – Symmetric Autonomous Underwater Vehicle (AUV)**

ECIL indigenously developed Mission

**Autonomous Underwater Vehicle**

Computer systems (MCS), Integrated Electronic Systems (IES) for Axi-Symmetric AUV in close association with Naval Science and Technology Laboratory (NSTL).

### **Antenna System**

ECIL has supplied 18m Antenna in association with BARC for Aditya Mission. An 11m Ku Band Monopulse Tracking Antenna, which is completely in-house designed & developed, has been supplied to MCF, Hassan.

**Flash X-Ray system**

### **Indigenous Manufacture of Switches and Routers**

ECIL has undertaken production of Indigenous Manageable Network Switches of Industrial Grade in technical collaboration with a Start-Up firm. These indigenous switches are being used as part of IT Infrastructure in various projects implemented by the corporation.

**Terabit Router (TBR)**



**8-Port PoE+ Industrial Switch (PoE0804)**

### Wearable Health Monitoring Device

ECIL in association with ESIC, Hyderabad has developed an IoT based innovative solution for Remote Health Monitoring and tracking of COVID-19 Patients and quarantined people. Vital parameters of Corona patient like body Temperature, amount of Blood oxygen (SpO2), Heart Beat Rate, Respiration Rate, NIBP (Blood Pressure) and ECG (Electrocardiogram) along with patient location can be reported to health care personnel by means of mobile app or web browser through Bluetooth or GSM/GPRS network.



**Inauguration of Remote Health Monitoring System by Dr Jitendra Singh, Minister of State in the Prime Minister's Office, Shri G Kishan Reddy, Minister of Tourism & Culture & Shri K N Vyas, Chairman, AEC & Secretary, DAE through video conference**

### New Facilities

#### Advanced Rear End Development facilities (AREDF) for Electronics and Instrumentation

As part of XII FYP, "Advanced Rear End Development facilities (AREDF) for Electronics and



**Chairman, AEC & Secretary, DAE inaugurating the Special Components Manufacturing Facility**

Instrumentation" for ECIL, several projects are under execution, most of the facilities have been established and are currently in use. Shri K. N. Vyas, Secretary DAE & Chairman, AEC inaugurated the Special Components Manufacturing Facility (SCMF).

#### Nal/CsI Crystal Growth and Characterisation Facility

For making Alkali Halides like Cesium Iodide (CsI) and Sodium Iodide (NaI) has been established at ECIL. The Facility is equipped with Bridgman Crystal Growth Systems and Crystal Processing Facility. The facility is being utilised for development of indigenous detectors using SiPMs technology.

#### Upgradation of ESS Test Facilities

The existing environmental test facilities have been augmented with Rain Test Chamber, Ingress Protection Water Test Setup and Environmental Stress Screening Thermal chamber.

#### Radar Test Facility

An integrated test facility has been created to test the subsystems of RF systems being developed and manufactured by ECIL. The facility consists of Automated Radar Test Facility, DRFM (Digital Radio Frequency Memory) Based Radar Scenario Generator, Compact Radar Test Facility and High-power RF test dome.





*Hon'ble Minister of State Dr. Jitendra Singh during his visit at DAE pavilion at the India International Science Festival, 2021 held at Panaji, Goa*

# CHAPTER 10

## OTHER ACTIVITIES



*Hon'ble Minister of State for communications, Government of India  
Shri Devusinh J. Chauhan along with Hon'ble Member of Parliament  
Shri Ranjit Singh Naik Nimbalkar at the DAE pavilion during the exhibition  
"Shining Maharashtra, 2022" at Phaltan, Maharashtra. DAE held during  
March 25-27, 2022*

## BARC-SAFETY COUNCIL

BARC Safety Council (BSC) is responsible for safety review of all nuclear, radiological, industrial facilities of BARC. These include operating and upcoming facilities, such as research reactors, fuel fabrication, fuel reprocessing, waste management and post irradiation examination facilities, industrial irradiators, 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 2021, more than 200 meetings of BSC were held. It has published a new safety guide titled "Regulatory Consenting Process for Industrial Radiography Facilities". Training Courses on Safety and Regulatory Measures for BARC Facilities were conducted regularly by the Council during the year.

## CRISIS MANAGEMENT

The Crisis Management Group (CMG) is the standing Committee of senior officials of the Department of Atomic Energy (DAE) which 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.

The Crisis Management Group (CMG) continued to carry out its functions. 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 24x7 functioning of the control rooms was ensured even during the lockdown period due to Covid19 pandemic.

During the year 2021-22, up to December 2021, India participated in four numbers (projected figure for FY 2021-22 is five 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 carried out variety of emergency exercises. The numbers of such exercises monitored / participated by CMG during the year 2021-22 are Communication Exercises – 484; Fire Emergency Exercises – 89; Plant Emergency Exercises – 49; Site Emergency Exercises – 19 ; Off-Site Emergency Exercises – 06; and Rad. Emergency Exercise at Airports – 04 numbers.

CMG participated in off-site emergency exercises conducted in 'Integrated Command Control and Response' mode at Narora, Tarapur, Kudankulam as well as Kaiga NPP sites. The exercises were found to be effective and satisfactory.

Review of the document for 'Transport of spent fuel by road' was done and the revised document was issued by NPCIL.

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 65th Annual session of the IAEA General Conference, Vienna during 20-24 September 2021**

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 comprising of Director, BARC, Chairman, AERB and Joint Secretary (ER) to the IAEA 65th General Conference which was held at Vienna, Austria from 20-24 September, 2021. In addition to this, the Ambassador and officials from Indian Permanent Mission in Vienna, participated in the event.

### **Bilateral meetings with our international partners**

On the sidelines of the 65th General Conference, Chairman, AEC had bilateral meetings with DG, IAEA and delegations from USA, USA, Westinghouse, U.K., OECD-NEA, Russia, AFCONE, EU, CEA, France, INVAP Argentina, Ghana, Kazakhstan, CNEA Argentina and Bangladesh.

### **The following Agreements and MoUs were signed:**

#### **A) Inter-Governmental Agreement (IGA) between India and Ghana**

On the sidelines of the 65th General Conference held during September 20-24, 2021, an IGA was signed between India and Ghana regarding cooperation for peaceful uses of Nuclear Energy on 22.09.2021. From the Indian side the MoU has been signed by Dr. K.N. Vyas, Secretary, DAE and Chairman AEC; and from the

Ghanian side by Minister, Ministry of Environment, Science, Technology and Innovation of Ghana.

The IGA envisages cooperation in transfer and exchange of knowledge, expertise and technology, sharing of resources and experiences, training of personnel and capacity building in various aspects of peaceful uses of nuclear energy, including assistance in nuclear projects.

### **B) Signing of New GCNEP MoUs**

#### **1. Global Centre for Nuclear Energy Partnership (GCNEP), India and Ghana Atomic Energy Commission (GAEC), Ghana.**

Memorandum of Understanding (MoU) between Global Centre for Nuclear Energy Partnership (GCNEP), India and Ghana Atomic Energy Commission (GAEC), Ghana was signed on 02.07.2021. From the Indian side the MoU was signed by Shri Rahul Chhabra, Secretary (Economic Relations), MEA and Prof. B.J. B. Nyarko, Director-General, Ghana Atomic Energy Commission (GAEC), Ghana.

The MoU 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.

#### **2. Global Centre for Nuclear Energy Partnership (GCNEP), India and National Nuclear Centre (NNC), Kazakhstan**

On the sidelines of the 65th General Conference held during September 20-24, 2021, Memorandum of Understanding (MoU) between Global Centre for Nuclear Energy Partnership (GCNEP), India and National Nuclear Centre (NNC), Kazakhstan was signed on 20.09.2021. From the Indian side the Arrangement has been signed by Dr. K.N. Vyas, Secretary, DAE and Chairman AEC; and from the Kazakhstan side by Dr. Erlan Batyrbekov, Director General, NNC, Kazakhstan.

The MoU 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.

### 3. Arrangement between Atomic Energy Regulatory Board (AERB), India and Nuclear Safety Authority (ASN), France.

On the sidelines of the 65th General Conference held during September 20-24, 2021, an Arrangement between Atomic Energy Regulatory Board (AERB), India and Nuclear Safety Authority (ASN), France was signed on 21.09.2021. From the Indian side the Arrangement has been signed by Shri G. Nageshwara Rao, Chairman, AERB, India and from the French side by Mr. Bernard Doroszczuk, Chairman, ASN, France.

This Arrangement is for exchange of technical information and cooperation in the regulation of nuclear safety and radiation protection.

### Participation in International Mega Science Projects

Mega Science Projects (MSPs) are international collaborative projects and because of their sheer scale, pose several scientific, technological and engineering challenges. Such projects need substantial financial and human resource commitments. Hence, these projects tend to be multi-agency, multi-institutional and international in character.

DAE and the Department of Science & Technology (DST) are jointly spearheading India's participation in several International Mega Science Projects (MSPs) and they have signed a long-standing Memorandum of Understanding to jointly facilitate funding, implementation and monitoring of such projects. Both DAE and DST have a prominent Scientific, Technological, Intellectual and Financial stake holding in several such global experiments involving thousands of scientists, engineers and industry personnel to foster breakthroughs in science and technology.

DAE, through its R&D centers and grant-in-aid institutions, is pursuing 8 MSPs independently or in collaboration with DST with a total outlay of about ₹ 25400 Crores. The Indian participation in such

collaborative international programmes is not only aimed at augmenting our own research facilities and capabilities but also helps us to compete and come at par with the international scientific community by getting improved access to international state-of-art facilities. The various projects being coordinated by DAE and/or DST are: ITER, CERN, FAIR, LIGO, INO, SDKA, TMT and Fermilab.

DAE, DST and its constituent units have made significant in-kind contributions to these projects by fabricating, supplying and installing key mechanical hardware, detectors, and electronics and electrical components besides software development. The Indian industry has been able to successfully participate in the project activities for all these projects not only within the country but also on a global basis.

Global Centre for Nuclear Energy Partnership (GCNEP) is being established at Kheri-Jasaur, Bahadurgarh, Haryana. GCNEP is the sixth R&D unit under the aegis of Department of Atomic Energy (DAE). Phase I of the Centre is operational since April 2017. Works related to Phase II are in advanced stage.

Despite the 2nd wave of Covid-19 pandemic, construction & facility augmentation process at GCNEP continued uninterrupted. All essential services and construction progressed in accordance with Government guidelines. During April to December 2021, GCNEP conducted online "Indo-US-UK technical exchange on security by design (SBD) for devices and facilities that use radioactive materials" and "Indo US Workshop on Modelling & Simulation of PPS". Follow up & review meetings for on-going activities with other countries were carried out using virtual platform. The Centre also expanded its activities for experiments on mutated seed for wheat & mustard with the help of NA&BTD, BARC. Also, GCNEP participated in exhibitions conducted in Uttarakhand & Rajasthan for utilizing and promoting applications of radio-isotopes and radiation technologies for societal benefits.

The construction works of four major packages including Central Building, School Building-2, Guest House Block-B, Gate House (campus) and Dining & Recreation facilities are in advanced stage. Electrical



**Online Indo-US Workshop**



**Central Building**



**Sensor Evaluation Test Bed Facility**

and mechanical works are in progress. Preparatory work to populate the buildings with essential infrastructure like furnishing, IT/AV facilities, e - Surveillance etc. has started. Accommodation facility has been developed in township. At campus, civil & electrical works for Service Building, Gate House (township), and Sensor Evaluation Test Bed Facility (SETBF) have been completed.

In the last quarter of FY 2021-22, it is planned to complete setting up of Sensor Evaluation Test Bed Facility (SETBF) and Gate House construction at

campus. Indo US online workshop on Modelling & Simulation for NUMAC is scheduled in the month of Jan 2022.

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 (TC) 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 TC and WANO Moscow Centre. Due to restrictions of COVID-19 pandemic since last year, WANO has been conducting virtual meetings and training programmes using Microsoft Teams or equivalent facility. Since August 2021, WANO has started a six month training programme on Leadership Effectiveness which is being conducted for four hours every month. In various virtual programmes many persons from NPCIL stations and HQ participated including senior Plant Managers and young generation from NPCIL plant sites.

During this year COG conducted a Candu Chemistry Workshop (virtual) to present and discuss experiences and issues with regard to plant chemistry. NPCIL participated in this information exchange programme of COG.

NPCIL continued to provide information for IAEA-PRIS (Power Reactor Information System) database. IAEA conducted a Technical Meeting on Power Reactor Information System Developments (Virtual Event) for PRIS data providers of member countries. IAEA also conducted an "International Conference on A Decade of Progress After Fukushima-

Daiichi: Building on the Lessons Learned to Further Strengthen Nuclear Safety” (virtual via Cisco WebEx). NPCIL has participated in this conference.

## COMPUTER AND INFORMATION SYSTEMS DIVISION (CISD)

Computer and Information Systems Division (CISD) has implemented Centralised Monitoring System using Grafana, a multi-platform open-source analytics and interactive visualization web-application. This system helps to study, analyse and monitor server related data over a period of time. It also enables monitoring of network, services and health of systems. The data is collected using Prometheus, another open-source for event monitoring and alerting, and is then sent to Grafana for visual representation.

CISD has implemented a new email server using postfix service along with Maildir format which helps faster fetching of mails. To enhance the user experience, a simple, secure and extensible fast email client has also been implemented using RainLoop, an open-Source web application based on PHP which provides a fast interface to access mails.

DAE is sponsoring Raja Ramanna Fellowship (RRF) to utilize the services of active retired scientists, engineers and technologists involved in high-quality research in specialized disciplines and wish to contribute further post-retirement. RRF portal was earlier developed to facilitate online nominations. A reporting module has been added in RRF portal to monitor and manage 4 different types of progress reports - Final Technical Report, Optional Interim report, Annual Progress Report, Draft Final Technical Report.

CISD has implemented an online system named Anusankalak for collecting periodic reports from all the constituent Units of DAE including PSU and Grant-in-aid Institutions. Anusankalak is a role-based application which provides access to specific data and applications based on the designated role. The system is being used by SCS and Vigilance sections of DAE for collecting the data online from various Units and Institutions of DAE. Two new modules - Filling up of Vacant Post in Central Government Ministries/



**Online system named Anusankalak for collecting periodic reports from all the constituent Units of DAE**

Departments and Periodical Information About Vacancies have been added to Anusankalak.

## 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 during the year included submission of 21 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); Disciplinary cases in respect of Group 'A' officers and retired Government servants; Processing of complaints: 39 complaints were downloaded from CVC portal and 2 complaints received through PG Portal which was forwarded to respective Units for investigation after thorough examination and reporting. Besides, 2 complaints from CBI have also been processed. 79 cases were closed with the approval of Competent Authority after necessary investigation; Fifty nine complaints have been received directly in the Department. After confirming the authenticity of the complaint, necessary investigations were carried out and complaints were closed with the

approval of Competent Authority, where necessary; Vigilance clearances for various purposes were issued to 3657 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 a few establishment cases / work orders from 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 2021" was observed in DAE during October 26th to November 1st, 2021 on the theme of "Independent India @ 75: Self Reliance with Integrity"; "स्वतंत्र भारत @75: सत्यनिष्ठा से आत्मनिर्भरता". The week commenced with administering integrity pledge by Joint Secretary (A&A) and Director (Vigilance) to the all employees of DAE Secretariat on 26.10.2021. Various competitions such as Slogan writing, Quiz competition and Role play were held during the Vigilance Awareness Week in which officers and staff of DAE actively participated. Smt. Ity Pandey, Chief Commercial Manager, IRTS delivered a talk on 01.11.2021. Prizes for the winners of the respective competitions were also distributed during the valedictory function held on 01.11.2021. Vigilance Awareness Week was also observed in the Constituent Units, Public Sector Undertakings and Aided Institutions of DAE.

The menace of corruption is one of the major obstacles to the economic, political and social progress of a country. All the stakeholders need to be vigilant and commit to uphold high standards and integrity at all times. Vigilance strives to promote integrity and eradicate corruption with the active support of all the stakeholders and believes that public participation plays an important role in fighting corruption and nation building.

Vigilance in any organization is an integral function like any other function of management such as

finance, personnel, operation etc. Vigilance Directorate of NPCIL is working effectively to promote integrity, spread awareness and to sensitize employees against malpractices and corruption to achieve organizational goals. NPCIL carried out many activities and events to achieve this during the period April - December 2021.

## 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.

During the period from January to December 2021, total 662 RTI applications and 62 appeals were disposed/transferred by DAE Secretariat. During the period from January to March 2022, total 185 applications and 31 appeals were disposed / transferred.

RTI related issues have been dealt with efficiently. A total of 196 RTI applications were received at AMD HQ, out of which 169 applications were replied and 2 applications were transferred to other PIOs of AMD. 15 first appeals were received out of which 14 were replied. Three (03) second appeals were received and complied with CIC.

An elaborate RTI Application management mechanism exists with functional arrangement of 8 CPIOs and 7 APIOs, one at each NPCIL Station/Site 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/Trainings were organized in NPCIL for creating awareness about the importance and ways to implement the Act.

During the FY 2021-22 as on December 31, 2021, about 880 RTI applications and 130 Appeals were

received under the RTI Act, 2005 and disposed off. In the case of NPCIL, there were 25 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 online portal.

At IREL, during the period from 01.04.2021 to 31.12.2021, 134 RTI applications were received, out of which 127 applications have been replied as per RTI Act, 2005.

At UCIL, the RTI queries received and replied during the year 2021-22 (up to November, 2021) were 90.

At SINP, nineteen (19) RTI applications have been received during the Financial Year 2021 – 2022 and eighteen (18) have been replied (as on 15.12.2021). Three (3) RTI appeals were received during the Financial Year 2021-2022 and two (2) have been replied (as on 15.12.21).

The total number of RTI applications received at RRCAT were 112 and out of these 101 were disposed.

IGCAR complied with the provisions of RTI Act, 2005. In this regard, the Unit had suo moto declared information under the provision of Section 4 of RTI Act 2005. This suo moto declaration was updated regularly. During the year 2020, 167 applications were received and they were processed.

DPS received 205 RTI queries and out of which 198 were answered.

Out of the total of 448 numbers of RTI requests received during the period at HWB, 433 queries were disposed, equivalent to 97% disposal of RTI queries received. 15 queries are pending with CPIO.

The no. of RTI queries received at AEES were 158 out of which 148 have been processed and 10 were under process.

## 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 15 OL inspections in the Offices of its Units/PSUs/Aided Institutions. During this period, Hon'ble Parliamentary Committee on Official Language inspected 09 Units/PSUs/ Aided Institutions namely, AMD, Jaipur; Tarapur Atomic Power Station, Tarapur; IPR, Gandhinagar; Heavy Water Plant, Baroda; IOP, Bhubaneswar; AMD, Bangalore; ECIL, Bangalore; ECIL, Kolkata and VECC, Kolkata.

A total of 49 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 357 sections out of 1033 sections under department have been notified for carrying out work in Hindi. An aggregate 25643 computers are having bilingual processing facility out of 27035 and 1392 are attached with scientific work. 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 43 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. An over-all 167 Hindi workshops were conducted to impart training of "Noting and Drafting" in Hindi in which around 4000 officers and 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. ₹ 5,34,390/- were spent on purchase of Hindi Books.

Quarterly meetings of Official Language Implementation Committee (OLIC) in DAE Secretariat were organised under the Chairmanship of Jt. Secretary (AA) 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 in the form of soft and printed of various establishments of DAE were published in Hindi/ Bilingual. Hindi competitions were organised during “Hindi Fortnight” and “World Hindi Day”.

Nuclear Power Corporation of India Limited (NPCIL) complied by the Official Language Policy, instructions and Annual Programme issued by Department of Atomic Energy (DAE) and Department of OL, Ministry of Home Affairs, Government of India. Official Language Implementation Committee (OLIC) headed by Chairman and Managing Director NPCIL, reviewed the progress of implementation HQ as well as at its sites/stations/projects/offices. The Parliamentary Committee on Official Language inspected the sites during the year and action taken reports on assurances were submitted to the Secretariat of committee through Department of Atomic Energy. Hindi e-workshops, e-Hindi competitions and Hindi Day were organised at NPCIL HQ as well as at its sites in this financial year following the COVID-19 protocols. In order to propagate Hindi E-house magazines were published from headquarters as well as its all sites for propagation of Hindi.

NPCIL HQ bagged 2nd prize for Official Language implementation for the year 2020-21 from



**NPCIL also honoured by “Aashirwad” an NGO working in Mumbai since 1969 in the field of propagation of Hindi**

Mumbai PSU Town Official Language Implementation Committee (TOLIC) among 65 PSUs. NPCIL also honoured by 2nd prize of “Aashirwad” an NGO working in Mumbai since 1969 in the field of propagation of Hindi. This award function was chaired by His Excellency Governor of Maharashtra on 29th September, 2021 at Governor House. Director (HR) received the award on behalf of NPCIL.

## SCIENTIFIC INFORMATION RESOURCE MANAGEMENT

BARC has published a book titled “Non-Power Applications of Nuclear Technologies” in 2021. The book comprises of 19 articles, which highlight R&D activities in BARC in development of nuclear technologies having widespread industrial applications. The 285-page book jointly edited by Dr. A.K. Mohanty, Director BARC and Dr. A.K. Tyagi, Chemistry Group Director, BARC, was granted ISBN recognition.



**Shri K.N. Vyas, Chairman AEC, Dr. A.K. Bhargava, Former Chairman AERB and Dr. A.K. Mohanty, Director BARC releasing the book on Founder's Day event in BARC Trombay**

The mobile-friendly version of BARC official website with latest Content Management System based technology features was launched for providing better site navigation and rich experience for internet users. The website has clocked over 51,000 users consistently on a month-on-month basis with 95% of them accessing the website through Android based devices.

Fresh apex project, “Digital Resources for R&D Support” was approved with an outlay of ₹ 42.10 crore

for implementation of advanced digital information resource platforms through acquisition of new servers and network devices in BARC.

Access to knowledge resources of BARC Library digitally was made easy with the launch of Saraswati portal 3.0 Version in November this year. BARC has employed Open Source Stack software based tools in overhauling the portal, which now hosts extensive archives of published scientific and technical literature.



**Formal launch of improved version of BARC library resources service portal, Saraswati**

BARC Newsletter on various themes, including Nuclear Reactor Technology, Research in Physics, Atomistic Modelling and Simulations, and Applications of Computational Fluid Dynamics in Chemical Engineering, Material Science & Safety were published online. Key R&D outcomes of BARC have been presented in the form of articles catering to both technical and general audience.

During the year, 31 Internal, 23 External and 05 Restricted reports based on scientific outcomes of R&D activities were published to meet specific requirements of BARC. Three issues of in-house magazine - Pulse - of BARC Hospital were also published.

Old scientific reports totalling 4300, vintage photographs, published copies of proceedings of BRNS-funded seminars and conferences were digitised and archived on the DACP portal.

BARC carried out translation of scientific documents from French, German and Russian into

English as well as interpretation regularly to cater to the specific requirements of various groups of BARC and the constituent units of DAE.

The International Nuclear Information Service (INIS) of IAEA in India has been augmented with journal articles, conferences and reports totalling 4000 in nuclear energy domain published by multiple scientific agencies within the country. Nuclear News Web Digest is a latest initiative of SIRD to keep BARC scientific community abreast of day-to-day happenings in nuclear energy arena. Articles published in various dailies are collated and featured in an easy-to-read format in the weekly Web Digest.

To ensure scholarly work of BARC scientists reflects originality, similarity check was performed and reports were generated for 700 articles and 100 PhD theses during the year.

To ensure uninterrupted running of academic program for 2020-21 batch of Trainee Scientific Officers of BARC Training School, Mumbai and to ensure compliance to guidelines in view of COVID-19 pandemic situation, lectures by BARC Training School faculty were recorded and streamed to the TSOs through a suitable online channel.

## PUBLIC AWARENESS

The Department of Atomic Energy (DAE) carried out a gamut of Public Awareness programmes in order to alleviate unwarranted fears, misconceptions and apprehensions harboured against nuclear energy. To keep the public abreast of the latest developments and contributions of atomic energy towards societal welfare, DAE 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 the exhibition, "Alluring Rajasthan 2021" at Udaipur, Rajasthan organised during August 4-6, 2021. The main focus of this exhibition was to bring awareness to the school students, rural masses, research scholars and youths.



**Students and local people visited the DAE stall during the exhibition “Alluring Rajasthan 2021” held at Udaipur, during August 4-6, 2021**

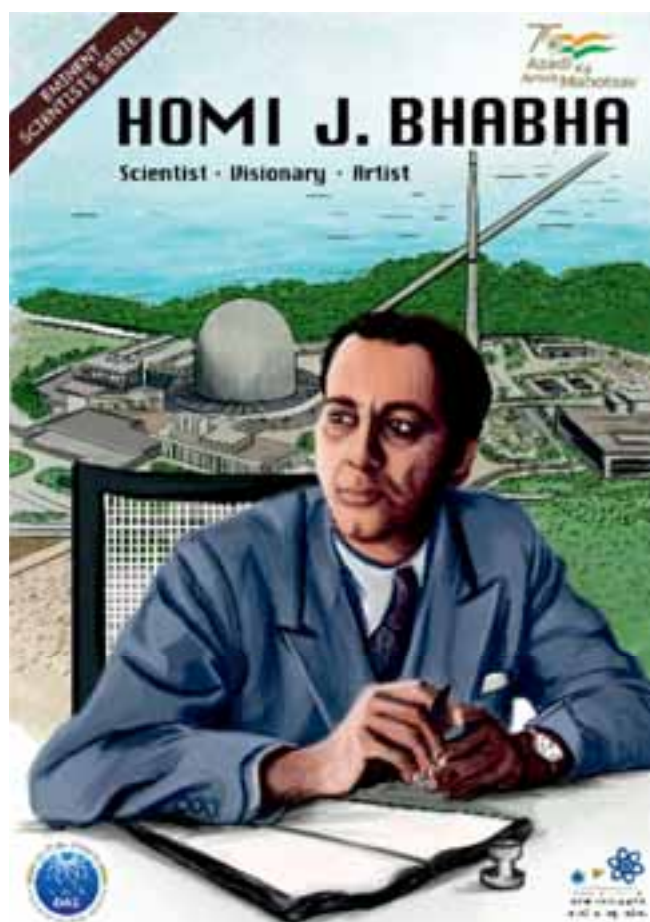
DAE put up a pavilion in “Make in Uttarakhand – 2021” held at Ramnagar, Uttarakhand during Sept. 16-17, 2021. DAE along with a team from Global Centre for Nuclear Energy Partnership (GCNEP) participated in this two-day event. The focus of the event was to encourage the young students to overcome real world challenges by applying science and technology.



**The DAE exhibition stall at “Make in Uttarakhand – 2021” held at Ramnagar, Uttarakhand during Sept. 16-17, 2021**

DAE participated in the 8th Rajasthan Science Congress IIS University, Rajasthan exhibition held at Jaipur, Rajasthan during October 20-22, 2021. DAE and a team from GCNEP participated in this 3-day programme. The exhibition was witnessed by large number of students, teachers and the general public.

DAE celebrated the 112th birth anniversary of Dr. Homi J. Bhabha. On this occasion the Public Awareness Division of DAE released an illustrated picture book on the life and scientific contributions of



**Release of illustrated picture book on “Homi J. Bhabha” by Dr. R. Chidambaram, former Chairman, AEC and former Secretary, DAE**

Dr. Bhabha, the Chief Architect-cum-Founding Father of Indian Atomic Energy Programme and an Institution Builder under the series called Eminent Scientists Series. The book was released by former Chairman, AEC and former Secretary, DAE Dr. R. Chidambaram at BARC auditorium, Mumbai.

As a part of the Public Awareness Programme, DAE has been organizing every year 'The DAE All India Essay Contest' for undergraduate students on topics relating to Nuclear Science & Technology. In 2021, DAE organized the 33rd DAE All India Online Essay Contest. Three topics were given to the students for participation. The notification was put on DAE website for giving wide publicity. Around 400 essays were received and out of which 30 students (10 students from each topic) were selected as winners and the winners were awarded with winners' certificates and cash awards of ₹ 10,000/- each. All other participants were given participation certificates.

The 24th National Science Exhibition was held at Kolkata on the occasion of 75 years of India's Independence during October 28-31, 2021. DAE participated in the exhibition along with VECC and exhibited DAE technologies. The event was well received by the students, teachers and general public.

India International Science Festival - 2021 (IISF-2021) was organised by Ministry of Science and Technology, Ministry of Earth Sciences and Vijnana Bharti at Panaji, Goa during 10-13 December 2021. DAE



**Hon'ble Minister of State Dr. Jitendra Singh during their visit at DAE pavilion at the India International Science Festival, 2021 held at Panaji, Goa**



**Students from various schools during their visit at DAE pavilion at the India International Science Festival, 2021 held at Panaji, Goa**

participated in the science festival by putting up an exhibition along with BARC, BRIT, HWB etc. The event was well received by the students and the general public. Large no. of students visited the DAE pavilion.

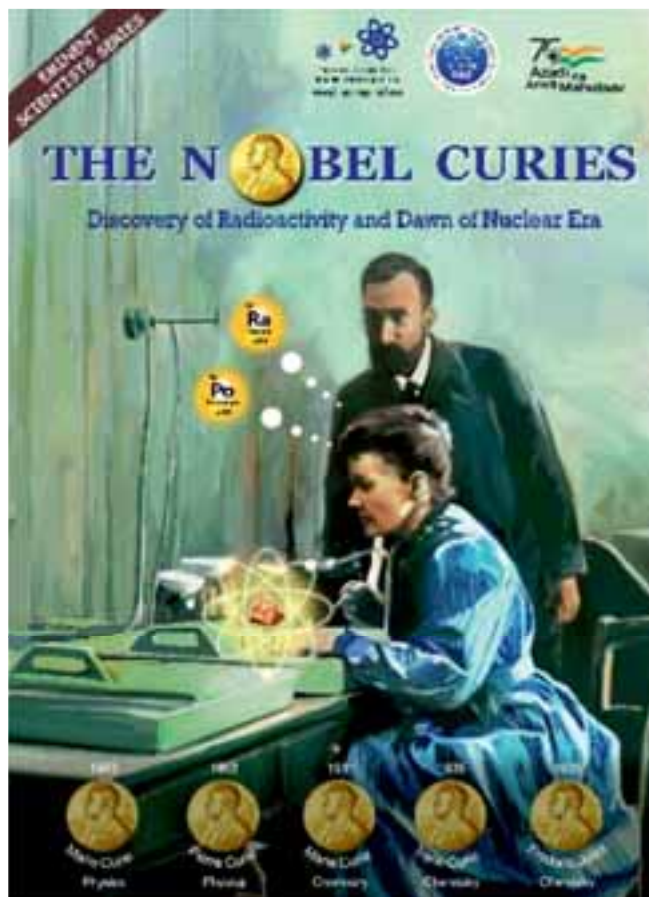
DAE published an article titled as "Department of Atomic Energy: A Technology Powerhouse" in the anniversary issue of the Outlook magazine on January 2022. The article highlighted high end technologies at a glance for betterment of society. These included the Clean & Green Nuclear Power; Compact and portable health-care instruments for real-time screening / diagnosis of oral cavity cancer called as OncoDiagnoScope; The indigenous Ruthenium (Ru-106) Plaque (Ruby Plaque) for eye cancer therapy; Portable, lightweight, pocket friendly Tele-ECG machine developed by BARC; ECIL based innovative solution called EC-VIKRAM for Remote Health Monitoring and tracking of different patients and quarantine people; Medical Cyclotron Facility operated by Variable Energy Cyclotron Centre (VECC) at Kolkata along with Labelled Sodium Fluoride ( $^{18}\text{F}$ -NaF) produced by the Board of Radiation and Isotope Technology (BRIT), an industrial unit of DAE. The application of Heavy Water and Deuterium in the field of life sciences was also covered. Further, Radiation Hygiensiation Technology for converting sewage sludge into organic manure which is a simple, effective, economical, reproducible, scalable and sea management process to deal with the sewage sludges and hgSBR (hybrid granular Sequencing Batch Reactor) for wastewater treatment technology developed and patented by BARC was also covered in the article.

A Mega Expo as festival of Science & Technology under Azadi ka Amrit Mahotsav was organised by Vigyan Prasar at JLN, New Delhi during 28th February, 2022. DAE participated in the expo and a picture book brought out by the Indian Plasma Research Centre, Gandhinagar was released during the above event.

DAE contributed an article titled as “Novel Pathways in Healthcare” in The Week magazine during celebration of Science Week (February 22-28, 2022). DAE has been in the healthcare sector by means of Nuclear Medicine techniques, which utilises radiopharmaceuticals (drugs tagged with radioisotopes) for diagnosis and therapy of various ailments, including cancers and tumors. Cancer therapy using radioisotopes has also been one of the major contributions of DAE in the healthcare sector. The article highlighted some of the recent healthcare contributions of DAE like Thermography for Early Diagnosis of Breast Cancer, Early Diagnosis of Coronary Artery Disease. Information on Compact and Portable Kit for Quick Detection of Covid-19 developed by DAE was also covered.

DAE participated in the 8th Indian National Exhibition-cum-fair 2022 on the focal theme of “Science & Technology for sustainable development of India” at Kolkata Metropolitan Development Authority (KMDA) ground, Patuli, Kolkata during February 24-28, 2022. DAE participated in the event along with VECC by putting up an exhibition stall, displaying DAE technologies. Members of academia, scientists and general public visited the exhibition.

The Public Awareness Division of DAE brought out another picture book “The Noble Curies”, the second in the Eminent Scientists Series, depicting the life and contributions of the Curie family (Marie Curie, Pierre Curie, Irene Curie and Frederick Joliot Curie). The book was released at BARC on International Women's Day (8th March, 2022) as Marie Curie was the first woman and one of the most illustrious achievers in the field of science and the only person to win two Nobel Prize in Physics & Chemistry and the only women to achieve this feat. The book was released by Dr. A. K. Mohanty (Director), BARC along with the guest of



**Release of book on “The Noble Curies” at BARC auditorium on International Women's Day (8th March 2022) by Dr. A.K Mohanty, Director, BARC along with Ms. Divya Seth, famous actress and TV personality**

honour Ms. Divya Seth, famous actress and TV personality at BARC.

DAE participated in the exhibition "Shining Maharashtra, 2022" at Phaltan, Maharashtra. DAE had put up a mega exhibition in Phaltan held during March 25-27, 2022. The exhibition was designed to popularise Science & Technology. Large no. of visitors such as students, parents, farmers, general public etc. visited the DAE pavilion.



**Hon'ble Minister of State for communications, Government of India Shri Devusinh J. Chauhan along with Hon'ble Member of Parliament Shri Ranjit Singh Naik Nimbalkar (left) and Smt. Jijamala Ranjit Singh Naik Nimbalkar (right) visited DAE pavilion**

Various public outreach activities were organized by RRCAT as part of 'Azadi Ka Amrit Mahotsav' including a two-day camp for screening of oral cavity using OncoDignoscope developed at RRCAT. The camp was specially arranged for CISF and RRCAT Security Staff and their family members of RRCAT. More than 290 persons were screened including 60 workers from various construction sites in RRCAT campus.

The Public Awareness activities are being carried out by NPCIL to address the myths and the apprehensions in the minds of the people regarding various aspects of nuclear power. The young minds are educated with factual information and the compelling

benefits of nuclear power for obtaining electricity on a sustainable basis. The people are also conveyed about the high safety standards maintained in the nuclear power industry. The strength of the organization to act as many companies in one and its proven mettle and maturity right from siting, design, construction, commissioning, operation and maintenance, life extension, safety upgradation, renovation and modernization & waste management are also shared with the public. This awareness campaign also includes aspects caring for the environment and the biodiversity around the sites. The awareness activities do emphasize on the neighbourhood welfare programs being undertaken by the organization on a continual basis. The awareness activities also include sharing about various programs instituted under the Corporate Social Responsibility (CSR) around the sites for the upliftment of the people living in the nearby areas to achieve an inclusive growth in the region.

In the year 2021-22 (upto December-2021), due to the COVID-19 Pandemic, various restrictive measures were in place and the activities carried out were mostly limited to the digital platforms. Taking advantage of this, we could address to different sections of the society pan India and interact with them from a single platform. The cumulative outreach from April to December, 2021 has reached around six lakhs and forty-six thousand people.

NPCIL has fabricated Halls of Nuclear Power as permanent nuclear galleries at Science Centres located in Mumbai, New Delhi and Chennai and miniature nuclear galleries at Kavar, Mangalore, Hyderabad and Vijayawada. In the year 2021, four more miniature nuclear galleries have been set up at Coimbatore, Jalandhar, Kota and Bhopal. More such galleries are planned to be set up at other places in a phased manner.

Also, as India is celebrating the Azadi ka Amrit Mahotsava, NPCIL has taken up many special public awareness drives under its aegis to make the people aware of the saga of DAE in general and NPCIL in specific and the development of the nuclear power program in India. The audience is being made aware of the efforts taken by the department towards the development and mastering of the indigenous PHWR Technology and way forward. Also, efforts are being

made to make the audience aware of the contribution of the department towards the realization of the dream of Aatmanirbhar Bharat.

With the gradual easing of Covid19 countermeasures, the public outreach activities are expected to pick up gradually.

During the year 2021-22 (upto December-2021), NPCIL has reached out to the public mostly on the digital platform. In all, a total of about 235 activities were carried out in the aforementioned period which includes around 170 site visits and around 60 lectures, 2 exhibitions and few other special programs such as interviews of CMD which are detailed below.

### **Online Competitions Organized**

NPCIL has organized various online competitions including “**Catch a Phrase**” and “**Master Stroke**” on aspects of nuclear power and there was about 300 participation of students in these events.

### **NPCIL Participation in the national and international level exhibitions**

Even amidst the pandemic, NPCIL participated in the Mega Udyami Santhe event held at Karwar, exhibition organized by the Regional Bureau of Information Ministry, Government of India and the India International Science Festival (IISF) Goa 2021. It is noteworthy that the DAE Stall at IISF was recognized and awarded with the “Best Technology Pavilion Award”.

### **Special Interviews of CMD, NPCIL on Doordarshan**

A special Panel Discussion with CMD, NPCIL as the key participant was telecast on DD Sahayadri (Mumbai Doordarshan) on world ozone day which recorded a viewership of around 87,000 people. In addition, a special interview of CMD, NPCIL was televised under Azadi Ka Amrit Mahotsava on DD Sahayadri (Mumbai Doordarshan) with a viewership of about 79,000 and on Sansad TV (Mumbai Doordarshan) with a viewership of about 50,000.

### **Making of Films on CSR Activities with Doordarshan**

Shooting of the films on the CSR Activities of NPCIL has been completed at all the sites and the films are in the post production stage and are expected to be released shortly.

### **Handing over of the 7020 MWe Model to Bhopal Science Centre**

The 700 MWe model was handed over to the Bhopal Science Center and installed in the nuclear miniature gallery made by NPCIL at the Science Center.

### **Sessions and visits organized for the media persons**

An awareness initiative, as a part of the off-site emergency preparedness, was organized at MAPS, Kalpakkam for 8 media persons. Also, a nuclear miniature gallery visit at Bhopal Science Center was organized for the young media students of the LNCT University, Bhopal.

### **Online Technical Workshops Organized**

A two-day workshop on the “Peaceful Uses of Atomic Energy and Job Opportunities” was organized by NPCIL for Human Resource Development Centre, Delhi Technical University (DTU), Delhi and Harcourt Butler Technical University (HBTU), Kanpur with talks by experts from BARC, DAE, BRIT, NPCIL and NFC. This benefitted more than 800 students. This was organized as a special drive to reach out to maximum students under the aegis of Azadi ka Amrit Mahotsava.

### **Pan India Online Doctors Meet**

An Online Doctors Meet was organized for all the doctors of NPCIL pan India on “Sources of Radiation in Nuclear Facilities” with a participation of more than 100 doctors.

### **Special Drive to reach out to AECS Students to celebrate Azadi ka Amrit Mahotsava**

In order to celebrate the Azadi Ka Amrit Mahotsava, NPCIL has taken up a Public Awareness

Drive for all the outgoing students of Class 10 and Class 12 of the AECS Schools pan India telling them about the saga of DAE and its contribution in the development of the nation along with the basics on nuclear energy. During the year, 15 out of 31 schools have been covered and the remaining are planned to be addressed.

As part of the year-long Azadi Ka Amrit Mahotsav celebration in DAE to mark 75 years of Indian Independence, BARC decided to publish new scientific documents and books in bi-lingual form, organise farmer-scientist interactions, student seminars and lectures both online and offline, new short films to highlight significant achievements of the Centre to general public. BARC took part in the inauguration of Annual Tech Festival of Mumbai-based Somaiya College of Engineering. Technical presentations of one-hour duration were made by scientists of Reactor Engineering Division and Remote Handling and Robotics Division of BARC, Trombay.

## 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 under developed areas. The area within 16 Km radius from these sites is designated as Local Area for implementation of CSR programme. During the FY 2021-22, the Company allocated an amount of ₹ 101.90 Crore for implementation of CSR programme. It is a matter of satisfaction that for the last five 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 i.e. [www.npcil.nic.in](http://www.npcil.nic.in). 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 levels 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, class rooms, science laboratories, establishment of smart classes, smart boards, furniture for schools, deployment of teachers in schools, coaching classes for the students aspiring for competitive examinations, organizing quiz; assistance to schools like drinking water, prayer stage with shed, multipurpose hall, library, hostel building, boundary wall, toilets, development of anganwadis, playgrounds and footpath, kitchen shed with store, stainless steel containers for mid-day meal, assistance to students like school bags, notebooks, school kits, umbrella, sports kit, scholarship and sponsorship, etc. were taken up during this year.



**Additional class rooms were constructed at GHSS, Chettikulam, Tirunelveli District, Tamil Nadu**

### Healthcare

Under healthcare, the CSR projects included running of primary health centre and OPD services at



**OPD dispensary at Community Centre, NAPS Township, Bulandshahr District, Uttar Pradesh**

Tarapur Maharashtra Site, Rawatbhata Rajasthan Site, Narora Uttar Pradesh Site, Kakrapar Gujarat Site and Kaiga Karnataka Site; providing mobile medical van services at Tarapur Maharashtra Site, Rawatbhata Rajasthan Site, Kakrapar Gujarat Site, Kaiga Karnataka Site, Gorakhpur Haryana Site, Chutka Madhya Pradesh Site; organizing medical, eye and special health care camps; upgradation of infrastructural facilities for Primary Health Centres (PHCs), equipment to Government Hospitals, providing assistive devices to differently abled persons, nutrition garden for anganwadis, carry bags for medicinal plants, development of drinking water facility, and laying of pipelines, installation of water coolers and purifiers etc.

Under Covid-19 related relief, contribution was made to PM CARES Fund; procurement of various equipment and kits was done for Community Health Centre (CHC), Rawatbhata, Primary Health Centres (PHCs) of Sadras, Koovathur, Nerumbur, Government Hospitals of Tirukalukundram and Mammallapuram, General Hospital Vyara, Government Hospital Mandvi, Government Hospital Palghar, Government Hospital Tirunelveli, Civil Hospital Fatehabad and Maharaja Agrasen Medical College Agroha, infrastructural facilities for Uttar Kannada District Government Hospital, M. G. Hospital Banswara, Government Hospital Chittorgarh; oxygen generation plant for 100 bed Hospital at Dibai, Bulandshahr and Community Health Centre (CHC), Rawatbhata etc.

### Infrastructure Development

Under infrastructure development, the projects like laying of approach roads with drains, installation of paver blocks in streets, development of multipurpose ground, construction of community hall, installation of



**Construction of multipurpose hall at Kadra, Uttar Kannada District**

cement benches, construction of water tanks, installation of street lights, construction of drain in the premises of Gaushala, procurement of boats and fire pumps for the rescue of flood affected persons etc. were taken up.

### Skill Development

Skill development initiatives were undertaken to ensure income generation for unemployed adults. Skills in handicraft including plastic basket, flowers making,



**Lift for irrigation at Vankla, Surat District, Gujarat**



**Development of pond at Chettikulam,  
Tirunelveli District, Tamil Nadu**

embroidery and chicken work on fabrics, stone carving skills, tailoring and distribution of sewing machines, training and education for children with special need, computers, life skills, soft skills, communicative English, backyard poultry, cattle and dairy farming, food processing from agriculture and forest products, etc. were focused upon.

### Projects carried out in Aspirational Districts

As regards CSR projects in Aspirational Districts, purchase of ambulance for Community Health Centre (CHC), Kelwara, PHC, Badora and blood donation van at aspirational district Baran in Rajasthan was done. Funding of medical equipment at aspirational district Karauli in Rajasthan was done. Medical equipment for the Government hospitals and aid for improving health and nutrition of children at aspirational district Ramanathapuram in Tamil Nadu as well as nutrition supplementation for underweight children through anganwadis at aspirational district Raichur in Karnataka was done. Construction of class room building and girls' toilet facilities in school at aspirational district Virudhunagar and infrastructure upgradation of anganwadis and implementation of the National



**Supply of ambulance for CHC, Kelwara, at  
Baran District, Rajasthan**

Program for Healthcare of the Elderly (NPHCE) at aspirational district Yadgir in Karnataka was done. Training, monitoring and assessment for anganwadis at aspirational district Gadchiroli in Maharashtra is under progress. Renovation and construction of new block at CHC, Bhagwanpura at aspirational district Haridwar, Uttarakhand has been taken up. Strengthening facility based management of Severe Acute Malnutrition [SAM] at four Nutrition Rehabilitation Centres (NRC) and establishment of oxygen plant at aspirational district Dahod in Gujarat were taken up. Construction of class rooms in ZPH School, Pedaboddepalli and in Urban Deprived Residential School, Bheemunipatnam at aspirational district Visakhapatnam in Andhra Pradesh have been started. In all 16 projects are being carried out in 10 aspirational districts.

### 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.



**Blood donation van for Baran District, Rajasthan**



**Rapid bio-composting with dry leaves and garden  
waste at Kakrapar Site, Tapi District, Gujarat**



**Akruti Centre at Tarapur Site,  
Palghar District, Maharashtra**

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

Swachhta Pakhwada was introduced in all the Central Government Ministries & Departments on the directives of the Hon'ble Prime Minister as a part of the Swachh Bharat Mission. Swachhta Pakhwada was observed in DAE headquarters from 16th February – 28th February, 2022 on the occasion of the World Science Day on 28th February, 2022. The programme



**Inauguration of Swachhta Pakhawada  
at DAE headquarters**

was inaugurated on 16th February, 2022 by Dr. Sunil Ganju, Head, ICPD. The programme comprised of Swachh Section Competition, Quiz Contest, Essay Contest, Poster Contest and Slogan contest. All the events were held as per the schedule which was circulated in advance. In all these contests, the staff members of DAE participated wholeheartedly. The results of these contests were announced on 28th February, 2022. Prizes were distributed to the winners of the various contests held and employees were felicitated for their contribution to maintain cleanliness.

Indore Municipal Corporation (IMC) has chosen RRCAT colony for the “Swachhta Champion Award” for the record fourth time in the category of “Cleanest Colony of Indore” as part of the Swachh Survekshan - 2021. As part of the Swachh Survekshan - 2021, a survey was conducted in the Indore city by the Quality Council of India under the aegis of IMC. RRCAT was adjudged as “श्रेष्ठ रहवासी संघ” in the Swachhta Rankings in this



**Swachhta Champion Award**

Survekshan, for which a "Certificate of Appreciation" and a trophy of "Swachhta Champion – 2021" was awarded to RRCAT in an award ceremony (स्वच्छता चैंपियन सम्मान समारोह) organized by IMC on 2nd October 2021.

Swatch Bharat Abhiyan was implemented in the Directorate of Purchase and Stores (DPS). Every effort was taken to keep the premises clean.

## 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 empanelled by respective Units.

### 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.

## Results

### All India Secondary School Examination (AISSE)-2021

#### CBSE

About 1911 students from 28 schools which are affiliated to the CBSE studied class X for the year 2021. Since no examination could be held due to pandemic situations, the assessment and evaluation of students was done by the CBSE on the basis of internal assessment and best overall performance of the school in the previous 3 years' Board Examination. The Pass percentage was 100% (98.3% last year) and the quality Index was 7.94 (7.48 last year). The overall excellence Index stood at 90.01 (80.71 last year).

### All India Senior Secondary Certificate Examination (AISSCE)/HSE Exam, 2021

#### CBSE

About 1191 students from 13 Atomic Energy Central Schools (AECS) which are affiliated to the CBSE studied class XII for the year 2021. Since no examination could be held due to pandemic situations, the assessment and evaluation of students was done by the CBSE on the basis of internal assessment and best overall performance of the school in the previous 3 years' Board Examination. The overall Pass Percentage was 100% (95.88% last year) and the Overall Excellence Index stood at 97.15 (80.73 last year). The quality Index was 7.89 (7.01 last year).

## State Boards

### Maharashtra Board

There were around 296 students from AEC School-1, Tarapur and Junior College, Mumbai which are affiliated to the Maharashtra State Board, studied class XII for the year 2020-21.

Since no examination could be held due to pandemic situations, the assessment and evaluation of

students was done with Class 12 internal marks carrying a weightage of 40%; whereas, 30% weightage was given to Class 11 final exams and 30% weightage was given to Class 10 Board exam marks, in which the average of the best three subjects with high marks are considered for the evaluation.

The Pass Percentage of Atomic Energy Junior College (AEJC) and AECS-1, Tarapur was 100% (93.42% last year) and average quality Index was 8.01 (6.63 last year) and Excellence Index was 99.46 (70.46 last year)

### Tamilnadu Board

There were around 60 students from AECS-2, Kalpakkam which is affiliated to the Tamilnadu State Board studied class XII for the year 2020-21. Since no examination could be held due to pandemic situations, the assessment and evaluation of students was done giving 50% weightage to class 10 board exam marks of the students; 20% weightage to their class 11 scores and 30% weightage to their scores in the class 12 practical exams and internals.

The pass percentage was 100% (98.40%) and the overall excellence Index stood at 100 (72.58 last year). The Quality Index was 7.68 (6.73 last year).

### Kishore Vaigyanik Protsahan Yojana (KVPY) - Scholarships by Indian Institute of Science, Bangalore

Ms. Oviya G. of AECS, Mysore bagged 84th All India rank in KVPY and Master Tanmay Ganguli of class XII got selected in KVPY.

### Karnataka State Topper in Art Competition

Ms. Tanushree, of Class VI of AECS, Kaiga participated in the Art competition held at Bengaluru by the CPRI (Central Power Research Institute under Ministry of Power) on 8/12/2021 and bagged the State topper in Category 'A' and has been selected for Nationals. She was awarded ₹ 50,000/- as cash prize apart from reimbursement of TA for self and escort.



*Ms. Tanushree, of Class VI of AECS, Kaiga bagged the State topper in Category 'A' in the Art competition*

### National Talent Search Examination (NTSE)

Total 11 students were selected for scholarship in 2020 at National level (Level-2, who appeared for State Level in 2019).

### National Essay Writing Competition

Ms. Prachi Thombe, AECS-1, Tarapur of class XII bagged the first position with a cash award of ₹ 20,000/-.

### Azadi ka Amrit Mahostav

#### Audio/Video Competition

To commemorate the 75th Independence Day celebration of Free India, AEES has conducted an Audio/Video Competition for the students of AEC Schools on topics Freedom struggle for – “Renaissance of New India towards Agriculture, Science & Technology, Education and Economy.” The winners were AECS, Kakrapar and the runners up were AECS-3, Tarapur.

#### Book Release

AEES organized 'Azadi Ka Amrit Mahotsav' with the release of the illustrated book on Dr. Homi J. Bhabha: Scientist Visionary Artist on 29th October, 2021 at 3.00 PM at Central Complex Auditorium, Bhabha Atomic Research Centre. Dr. Chidambaram, DAE, Homi Bhabha Chair Professor and former Chairman, AEC, was the Chief Guest. Shri. K. N. Vyas, Chairman, AEC &

Secretary, DAE presided over the function in the gracious presence of Dr. A. K. Mohanty, Director, Bhabha Atomic Research Centre. Copies of the books were distributed to the meritorious students of all the AEC Schools, Mumbai.

### INSPC-21

The Indian Nuclear Society and Atomic Energy Education Society jointly organized the “INSPC-21-Poster Exhibition” under the auspices of AEES. An awareness Programme on the theme - “Nuclear Energy for the mankind” was initiated by INS to dispel the misconceptions on usage of Nuclear Energy in the minds of Public. As a part of this awareness programme, Poster Competition was conducted for all the students of AEC Schools and DAE family members. Around 400 posters were received. These posters were exhibited together with the working models of BARC Cyclotron, Blood Irradiator etc. in the premises of Atomic Energy Junior College for the Public for 3 days. The Director, BARC inaugurated the exhibition and appreciated the posters of creative, young and budding artists of AEC Schools and DAE and advised to conduct similar programmes in future. The students of Classe VIII and above were shown this exhibition. The Chairman, AEES emphasized the need for visit of the students to BARC to ignite their zeal and scientific temper for Science and Technology. The Secretary, AEES in his speech, also, appreciated the programme and proposed to conduct similar Poster Exhibitions in other AEC Schools for the benefit of the students.



*Glimpses of INSPC-21 Poster Exhibition*

### SEEP (Societal Educational Enrichment Programme)

The AEES started the Talent Nurturing Programme, the programme of nurturing the bright Children (between 7-9 years of age) from the rural/tribal communities residing in the vicinity of DAE Project sites from the year 1999-2000 by providing education in AEC Schools.

The students selected under this programme are given free education and scholarship of Rs 300/- per month (per child) to meet the transport and refreshment expenses. In addition to that, they are provided with four sets of school uniforms annually and a set of text books and note books. The Principals, Headmasters and the Teachers are taking the earnest efforts to help these children fit into the academic environment of our schools.

From 2018 onwards, this facility is extended to some students who have been admitted under the RTE Programme. These students are provided with free education, a monthly scholarship, school uniforms, text books and note books throughout their schooling years in AEES.

The total number of students admitted under SEEP in all AEC Schools of AEES were 1167.

### NISHTHA (National Initiative for School Head's and Teachers Holistic Advancement)

As a sequel to the implementation of second phase of NISHTHA (National Initiative for School Head's and Teachers Holistic Advancement) by NCERT, AEES also has accepted in principle to implement the same in all AEC Schools for PRTs, TGTs, Co-scholastic Teachers, HMs, Vice-Principals and Heads of the Institution.

Some of the outcomes of the NISHTHA were Transformation of the Heads of the Schools into providing Academic and Administrative Leadership for the schools for fostering new initiatives; Improvements in learning outcome of the students and integration of ICT in teaching, learning and assessment.

The courses for the above were launched sequentially and conducted in batches in DIKSHA Portal. Each Course requires a minimum of 3-4 hours of engagement by the learners where there was flexibility for teachers to complete the course in a self-paced manner.

The teachers did self-enrolment and self-learning and were certified on course completion. After all the 12 Generic courses and 1 pedagogy course in 6 months duration, were completed, the NCERT conducted three Courses every fortnight starting from 1st August, 2021 for Autonomous Bodies in English and Hindi.

## DAE SPORTS & CULTURAL ACTIVITIES

DAE Sports and Cultural Council (DAE S&CC) looks after the promotion of sports and cultural activities among DAE employees and their families located at various units all over India. Its office located at the New Community Centre, Anushaktinagar is a demonstration hub of sports and cultural activities established by the Council in 1998. Ever since its inception, for more than thirty-five years, the DAE S&CC has been facilitating promotion of sports, physical fitness, yoga and cultural. 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 XXXVIth Annual DAE Sports and Cultural Meet was conducted in twelve different sports and cultural events (Ball Badminton, Cricket, Cultural, Carrom, Basketball, Volleyball, Football, Lawn Tennis, Bridge, Badminton, Table tennis and Kabaddi) at various units of DAE at different locations of the country. DAE S&CC nominated observer for each event in order to make sure that the events were conducted as per the guidelines issued by DAE S&CC. DAE units participated

through eight leader groups (Ajanta, Dwaraka, Ellora, Golkonda, Konark, Nagarjuna, Pushkar and Rameswaram). Selection trials were conducted by each leader group at various DAE units to represent the leader group. The Sports Council allotted events to units and provided trophies and flags. DAE S&CC also supported the participation of these players in National



*A glimpse of various sports activities conducted during the year by DAE S&CC*

Championships by payment of affiliation fees, provision of kit allowance and arrangement of training camp.

Every Year Special Summer Coaching camps are organized jointly by DAE S& CC and Atomic Energy Education Society (AEES) as a regular annual event with more than 1500 children of DAE employees in the age group of 10-14 years receiving entry level coaching in various games and sports like Athletics, Swimming, Cricket, Football, Basketball, Table Tennis, Badminton, Lawn Tennis etc. Due to Covid-19 pandemic the summer coaching could not be conducted. However, this year, DAE S&CC has proposed to organize summer coaching camps for DAE school children for four weeks jointly with AEES at various DAE Schools located at different units of DAE. Council will share one third of the cost of summer camp and will frame the camp guidelines. Selection for advanced coaching will be done based on performance of the players in summer coaching camps.

Health & Fitness section of BARC staff club has been celebrating the international yoga day on 21st June at various Govt organizations and school and colleges in and around Anushaktinagar as per the protocol AYUSH, Govt. of India. Due to pandemic, BARC staff club & DAE Sports and cultural council had organised the e-celebration of international yoga day with the theme “Be with Yoga and Be at Home!” on 21st June (Monday) via Google meet platform. The live demonstration and instruction of yogic posture as per AYUSH protocol were done by senior yoga teachers. More than 200 participants took part in the celebration.

Under Nature & Adventure related activities, Team Girisanchar of DAE S&CC usually arranges various Nature & Adventure related activities throughout the year. However, this year on account of the ongoing Covid-19 pandemic situation, activities were resumed in graded manner. Day treks were organized by team Girisanchar with limited participation during 2021-22 and these included Matheran (One Tree Hill Point) trek, Malshej Ghat (Ancient route) trek, Tamhini-Dongarwadi trek, Peb trek and Nakhindi. Girisanchar Cycling group has initiated cycling activity in a gradual manner.

Country-wide celebrations are being undertaken under the 'Azadi ka Amrit Mahotsav'



**Day Treks and cycling activity organised by Girisanchar**

campaign to commemorate the completion of 75 years of India's independence. In view of this, team Girisanchar & Nature and Adventure Circle of BARC Staff Club had organised a 75 km Cycling ride in Anushaktinagar. Total 102 participants took part in this event.

In order to promote Art, Culture & Cultural activities, DAE Cultural Centre (DCC) has initiated various activities like Dance, Drama, Music, Literature, Traditional Art, Films etc. For the first time in Anushaktinagar, DCC had organized a unique Craft Exhibition titled “Anushilp” showcasing talents of DAE fraternity in handicraft art forms. This exhibition got an overwhelming response, both from participants as well as from the visitors. Exhibits comprised of Pottery,



**ANUSHILP Exhibition Glimpses**

Sculpture, Metal Work, Needle work, Papier-mâché, Ceramics, Glass & Woodwork etc. were exhibited during the event.

The International Women's Day was celebrated on 8th March at Nilgiri Tennis Court, Anushaktinagar during XXXVI Annual DAE Lawn Tennis Meet. Around 25 women players participated in the friendly Lawn tennis tournament. Director BARC was Chief Guest and Guest



**Celebration of the International Women's Day on 8th March at Nilgiri Tennis Court, Anushaktinagar during XXXVI Annual DAE Lawn Tennis Meet**

of Honour were Dr. (Smt). Archana Sharma, Smt. Anita Behere & Smt. Smita Manohar.

## 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:

National Safety Council (Maharashtra Chapter) awarded plaques (2 Nos.) to Tarapur Atomic Power Stations (TAPS) -1&2 for "Factories Working over One Million Man-Hours under Scheme-I - Lowest Accident Frequency Rate for the year 2020 and Scheme-II - Longest Accident-Free Period for the year 2020.

Madras Atomic Power Stations (MAPS) -1&2 received "PRASHANSA PATRA" from National Safety Council of India under the Manufacturing Sector in Group-C category of Power Generation for the assessment period of 2017 to 2019 for the award year of 2020.

The Narora Atomic Power Stations (NAPS)-1&2 NAPS won AERB's Industrial Safety Award 2020.

The Kakrapar Atomic Power Stations (KAPS)-1&2 won AERB Fire Safety Award for the year 2020 in category-I. One of the KAPS-1&2 employee has been selected for grant of "Vishwakarma Rashtriya Puraskar" for the performance year 2018 by ministry of Labour and Employment, Government of India. KAPS-3&4 bagged Industrial Safety Award 2020 (Construction Units) and Fire Safety Award 2020 from AERB (Category-II).

The Kaiga Generating Stations (KGS) -1&2 has been awarded the Certificate of Appreciation from National Safety Council, India for the year-2020. KGS-1&2 has bagged "Unnatha Suraksha Puraskara-2021" award from National Safety Council, Karnataka Chapter. KGS-3&4 received "Sarva Shreshtha Suraksha Puraskar" (Golden Trophy) from National Safety Council, India for the year 2020. KGS-3&4 bagged the prestigious Safety Award "Unnatha Suraksha Puraskara" from National Safety Council, Karnataka Chapter for the year 2021.

NPCIL was conferred prestigious 'National Award – 2020' by Technology Development Board, Department of Science and Technology, for 'Development of Technology for Production of Low Alloy Steel Heavy Forgings for 700 MWe Nuclear Power Plant Steam Generators and Bleed Condensers (BCD), commercialized by M/s L&T Special Steel and Heavy Forgings Pvt. Ltd.'



**CMD, NPCIL with TDB National Award – 2020**

Tarapur Maharashtra Site (TMS) received Second Prize and shield for best implementation of Hindi work in PSU group for the year 2020-21 from NARAKAS, Thane on August 31, 2021. TMS received this award consecutively for third year.



**Tarapur Maharashtra Site (TMS) received Second Prize and shield for best implementation of Hindi work in PSU group for the year 2020-21**

Hindi House magazine of Madras Atomic Power Station "Anuprerna" was conferred with Excellent Prize On 15.12.2021 by Town Official Language Implementation Committee, Chennai.

During the year, IREL won many awards these includes best CMD Corporate Management Innovative

Leadership Excellence Award during the 21st Annual Geomintech International Symposium; CEO of the year; Implementation of official language by Mumbai PSUs TOLIC for the year 2020-21 (3rd Prize); Leading Director Award 2021 in the Leading Directors' Conclave conducted by Greentech Foundation and Carpet Swachh Bharat Mission & Covid-19 Management Excellence Award. During the 21st Annual Geomintech International Symposium, IREL was conferred with Violet Diamond HR Excellence, Indigo Brow Chakra CSR Excellence, Blue Agate Machinery Equipment Maintenance, Green Emerald Environment Excellence, Yellow Sapphire Overall Production Glitter, Orange Crystal Occupational Health & Safety and Red IREL's Plant in Tamil Nadu was declared as winner of National Safety Award (Mines) for the year 2019 and Runner Up for the years 2018 & 2020.

DPS received many awards as part of their cleanliness efforts these include receipt of an appreciation letter from Secretary, DAE in recognition and appreciation of the Swachhata activities undertaken by DPS as part of Swachhata Prakhwada; Stores Units of MRPSU bagged Best Office Premises award of Kalpakkam during Swachhata Prakhwada; Stores Unit of DPS at Heavy Water Plant, Tuticorin Won the "PLANT-HOUSE KEEPING AWARD" and HRPSU bagged Good House Keeping Award.

AERB's Industrial Safety Award-2019 was presented to HWP, Tuticorin in the category of "R&D and Other Low Risk Units" during this period. HWP, Talcher was conferred with AERB's Industrial Safety Award-2020



**AERB Industrial Safety Award - 2019 was presented to HWP, Tuticorin in the category of "R&D and other Low Risk Units"**

in the category of "R&D and Other Low Risk Units" during this period.

Scientists from TIFR won prestigious awards during this period. Prof. Anish Ghosh, School of Mathematics, was awarded the Shanti Swarup Bhatnagar (SSB) Prize for the year 2021 in Mathematical Sciences, by the Council of Scientific and Industrial Research (CSIR). ICTS faculty member, Subhro Bhattacharjee, received the prestigious Swarnajayanti Fellowship of the Department of Science and Technology, Govt. of India, in the physical sciences category. The Homi Bhabha Award in Science Education 2020 was conferred upon Dr. B. Satyanarayana (TIFR, Mumbai) and Dr. Uma Ramakrishnan (National Centre for Biological Sciences, Bengaluru). Prof. Shravan M. Hanasoge, Department of Astronomy and Astrophysics, TIFR, Mumbai was awarded the Prof. Peraiah Foundation Award for the year 2021 by the Indian Institute of Astrophysics, Bengaluru. Prof. K. K. Mishra (HBCSE, Mumbai) was conferred with the prestigious 'Atmaram Award' for the year 2018, by the Central Institute of Hindi (Agra), Ministry of Education, Government of India. ICTS faculty member Anirban Basak was awarded the INSA Medal for Young Scientists, 2021 by the Indian National Science Academy, New Delhi. ICTS faculty member, Riddhipratim Basu, was awarded the 2021 NASI Platinum Jubilee Young Scientist Award for his contributions to probability theory.

# **CHAPTER 11**

**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 01.01.2022 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2021 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	Total	VH	HH	OH	
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)		
Group A	8968	2	4	52	0	0	0	4	0	136	0	0	0	0	0	0	0	0	0
Group B	7742	5	10	84	0	2	3	5	0	86	0	0	0	0	0	0	0	1	3
Group C	8680	11	40	88	0	5	17	20	4	309	0	1	0	0	0	0	0	0	0
TOTAL	25390	18	54	224	0	7	20	29	4	531	0	1	0	0	0	0	0	1	3

**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 disability 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 01.01.2022 AND NUMBER OF APPOINTMENTS MADE  
DURING THE PRECEDING CALENDAR YEAR 2021 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	1708	3	0	13	0	3	4	4	3	12	0	0	1	0	0	0	0	0	0	0	0
Group B	2724	4	4	27	1	2	2	11	2	9	0	0	1	0	0	0	0	0	0	0	0
Group C	2391	5	17	28	0	3	2	4	2	8	0	0	0	0	0	0	0	0	0	0	0
TOTAL	6823	12	21	68	1	8	8	19	7	29	0	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 disability 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 01.01.2022 AND NUMBER OF APPOINTMENTS MADE  
DURING THE PRECEDING CALENDAR YEAR 2021 IN RESPECT OF PUBLIC SECTOR UNDERTAKINGS

Group	Number of Employees					Direct Recruitment				By Promotion							
										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
(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)		(9)	(10)	(11)	(12)		(13)	(14)	(15)
Group A	7361	13	6	74	0	2	3	1	0	55	0	0	0	0	0	0	0
Group B	4556	12	11	68	0	0	1	5	0	20	0	0	0	0	0	0	0
Group C	4037	14	11	50	0	9	9	19	0	96	1	0	5	0	0	0	0
<b>TOTAL</b>	<b>15954</b>	<b>39</b>	<b>28</b>	<b>192</b>	<b>0</b>	<b>11</b>	<b>13</b>	<b>25</b>	<b>0</b>	<b>171</b>	<b>1</b>	<b>0</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>4</b>

**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 disability 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](http://www.rti.gov.in)

## VI) WHOM TO CONTACT

### I. Nodal Officer and Nodal Appeal Authority for CPGRAMS

**Shri E. Ravendiran,**  
Director(SCS) & Nodal Officer,  
Department of Atomic Energy,  
Anushakti Bhavan, C.S.M. Marg,  
Mumbai – 400 001.  
Tel. No.022-2286 2531  
Email I.D. – diradmn@dae.gov.in

**Shri Sanjay Kumar,** Joint Secretary (A&A) &  
Nodal Appeal Authority  
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

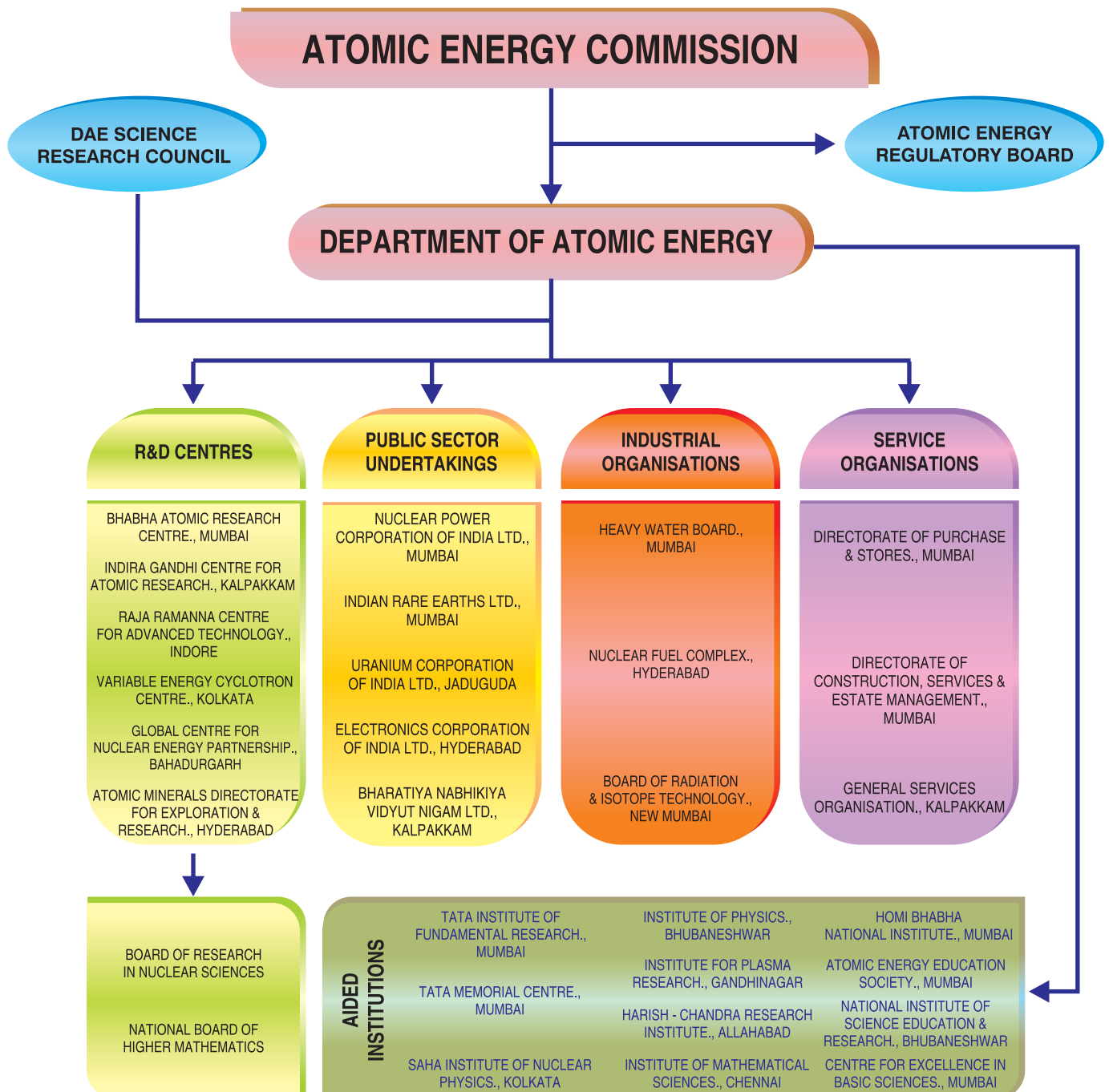
# ANNEX-I

## 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 ESTABLISHMENTS IN INDIA



Research & Development  
Organisations

Public Sector  
Undertakings

Industrial  
Facilities

Grant-in-aid  
Organisations

Service  
Organisations

# 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. 2 of 2021 :**

**Financial Audit, Union Government**

**Para No.3.1- Non-installation of Special Purpose Winding Machines**

Institute for Plasma Research Gandhinagar procured two Special Purpose Winding Machines without identifying site for their installation. The machines were not installed even after lapse of more than seven years, resulting in idling of funds of ₹ 4.29 crore.

**Action taken:**

Submission of Final ATN is Under Process

**Para No. 3.2 - Short realization of lease rent**

Non revision of license fee in accordance with extant Government Orders and non-Renewal of expired lease agreements by General Services Organization Kalpakkam resulted in short realization of lease rent of ₹ 3.75 crore.

**Action taken:**

Submission of Initial ATN is Under Process

**Para No. 3.3 - Payment of House Rent Allowance at higher**

National Institute of Science Education and Research, Bhubaneswar paid House Rent Allowance to its employees at higher rates, which resulted in excess payment of ₹ 2.80 crore during the period from July 2015 to February 2020.

**Action taken:**

Submission of Initial ATN is Under Process

**Para No. 4.5 - Payment of Inadmissible Family Planning Allowance to employees”.**

Nuclear Power Corporation of India Limited paid Family Planning Allowance of ₹ 5.42 crore to its employees in violation of extant Government of India orders.

**Action taken:**

As per observation of Audit, Action has been initiated to recover Inadmissible Family Planning Allowance paid to employees.

## REPRESENTATION OF SCs, STs AND OBCs

Groups	Representation of ST/ST/OBC (as on 01.01.2022)	Number of appointments made during the calendar year 2021													
		By Direct Recruitment				By Promotion			By Deputation						
		Total Emp	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		8970	608	209	1113	150	2	1	33	138	12	0	0	0	0
Group B		7741	1443	785	2557	104	10	25	42	447	81	25	3	0	0
Group C		8679	1698	831	3140	327	22	34	178	236	54	31	0	0	0
TOTAL		25390	3749	1825	6810	581	34	60	253	821	147	56	3	0	0

**ANNUAL STATEMENT SHOWING THE REPRESENTATION OF SCs, STs AND OBCs AS ON 01.01.2022 AND NUMBER OF APPOINTMENTS MADE DURING THE PRECEDING CALENDAR YEAR 2021 IN RESPECT OF AIDED INSTITUTIONS**

Groups	Representation of ST/ST/OBC (as on 01.01.2022)				Number of appointments made during the calendar year 2021											
					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	1708	87	16	127	96	2	0	5	6	2	0	0	0	0		
Group B	2724	489	200	781	204	34	11	57	14	5	0	0	0	0		
Group C	2391	648	161	567	50	4	3	15	0	0	0	0	0	0		
TOTAL	6823	1224	377	1475	350	40	14	77	20	7	0	0	0	0		



ACTREC	Advanced Centre for Treatment, Research and Education in Cancer	FRENA	Facilities for Research in Experimental Nuclear Astrophysics
AEC	Atomic Energy Commission	FRFCF	Fast Reactor Fuel Cycle Facility
AECS	Atomic Energy Central School	GCNEP	Global Centre for Nuclear Energy Partnership
AEES	Atomic Energy Educational Society	GFA	General Framework Agreement
AERB	Atomic Energy Regulatory Board	GHAVP	Gorakhpur Haryana Anu Vidyut Pariyojana
AEWTP	Advanced Effluent Water Treatment Plant	GSO	General Services Organisation
AHWR	Advanced Heavy Water Reactor	HBCSE	Homi Bhabha Centre for Science Education
AKRUTI	Advanced Knowledge & RUr al Technology Implementation	HBNI	Homi Bhabha National Institute
ALARA	As Low as Reasonably Achievable	HLLW	High-Level radioactive Liquid Waste
ALIP	Annular Linear Induction Pump	HSAR	Hydraulically Suspended Absorber Rod
AMD	Atomic Minerals Directorate for Exploration & Research	HSCMS	Hydrogen and Steam Concentration Monitoring System
AOTWM	Automatic Orbital TIG Welding Machine	HWB	Heavy Water Board
APO	Alkyl Phosphine Oxide	HWP	Heavy Water Plant
ATI	Administrative Training Institute	IAEA	International Atomic Energy Agency
BARC	Bhabha Atomic Research Centre	IDCT	Induced Draught Cooling Tower
BCD	Bleed Condenser	IGA	Inter-Governmental Agreement
BHAVINI	Bhartiya Nabhikiya Vidyut Nigam Limited	IGCAR	Indira Gandhi Centre for Atomic Research
BNHS	Bombay Natural History Society	IISF	India International Science Festival
BoG	Board of Governors	ILRT	Integrated Leak Rate Test
BRIT	Board of Radiation & Isotope Technology	IMO	International Mathematics Olympiad
BRNS	Board of Research in Nuclear Sciences	IMSc	Institute of Mathematical Science
BWR	Boiling Water Reactor	IMSBR	Indian Molten Salt Breeder Reactor
CCPS	Capacitor Charging Power Supply	IOP	Institute of Physics
CCE	Centre for Cancer Epidemiology	IPR	Intellectual Property Rights
CFD	Computational Fluid Dynamics	IPR	Institute for Plasma Research
CHSS	Contributory Health Service Scheme	IREL	Indian Rare Earths Limited
CISD	Computer and Information Systems Division	IRMA	Immunoradiometric Assay
CMG	Crisis Management Group	ISI	In-service Inspection
COG	CANDU Owner's Group	ITER	International Thermonuclear Experimental Reactor
CORAL	Compact Reprocessing facility for Advanced fuels of Lead cells	KAMINI	KAlpakkam MINI Reactor
CSR	Corporate Social Responsibility	KAPP	Kakrapar Atomic Power Project
CVC	Central Vigilance Commission	KAPS	Kakrapar Atomic Power Station
CVO	Chief Vigilance Officer	KARP	Kalpakkam Atomic Reprocessing Plant
DAE	Department of Atomic Energy	KGS	Kaiga Generating Station
DAE S&CC	DAE Sports and Cultural Council	KKNPP	Kudankulam Nuclear Power Plant
DCSEM	Directorate of Construction Services & Estate Management	LEBT	Low Energy Beam Transport
DFRP	Demonstration Fast reactor fuel Reprocessing Plant	LHC	Large Hadron Collider
DGFS	DAE Graduate Fellowship Scheme	LOCA	Loss of Coolant Accident
DPS	Directorate of Purchase & Stores	LRP	Large Rotatable Plug
ECCS	Emergency Core Cooling System	LWR	Light Water Reactor
ECFM	Eddy Current Flow Meter	MACE	Major Atmospheric Cerenkov Experiment Telescope
ECIL	Electronic Corporation of India Limited	MCF	Medical Cyclotron Facility
ECR	Emergency Control Room	MoEFCC	Ministry of Environment, Forest and Climate Change
EDF	Électricité de France	MoU	Memorandum of Understanding
EMS	Environmental Management System	MPMMCC	Mahamana Pandit Madan Mohan Malaviya Cancer Centre
ERM	Environmental Radiation Monitor	MRECL	Mixed Rare Earths Chloride
FBTR	Fast Breeder Test Reactor	MRTDDF	Magnesium Recycling Technology Development and Demonstration Facility
FBR	Fast Breeder Reactor	NAPS	Narora Atomic Power Station
FDG	Fluorodeoxyglucose	NABL	National Accreditation Board for Testing and Calibration Laboratories
FMTF	Fuelling Machine Test Facility	NBHM	National Board of Higher Mathematics
FPC	First Pour of Concrete	NDCT	Natural Draught Cooling Tower

NFC	Nuclear Fuel Complex	TBP	Tributyl Phosphate
NGADU	Nuclear Grade Ammonium Di-Uranate	THM	Total Heavy Mineral
NISER	National Institute of Science Education & Research	TIFR	Tata Institute of Fundamental Research
NPCIL	Nuclear Power Corporation of India Limited	TLD	Thermo Luminescence Dosimeters
NPP	Nuclear Power Plants	TMC	Tata Memorial Centre
NSDF	Near Surface Disposal Facility	TMH	Tata Memorial Hospital
NUFAP	Natural Uranium Fuel Assembly Plant	UCIL	Uranium Corporation of India Limited
NUJ	National Union of Journalists	UOP	Uranium Oxide Plant
NUOFP	Natural Uranium Oxide Fabrication Plant	VECC	Variable Energy Cyclotron Centre
NUP	National Uranium Project	WANO	World Association of Nuclear Operators
OCES	Orientation Course for Engineering graduates and Science postgraduates	WEC	Westinghouse Electric Company
OHSMS	Occupational Health and Safety Management System	WII	Wildlife Institute of India
OLIC	Official Language Implementation Committees	XRD	X-Ray Diffraction
PBT	Profit Before Tax	ZOP	Zirconium Oxide Plant
PCPTF	Primary Coolant Pump Test Facility	ZSP	Zirconium Sponge Plant
PET	Positron Emitting Tomography		
PFBR	Prototype Fast Breeder Reactor		
PHT	Primary Heat Transport		
PHWR	Pressurised Heavy Water Reactors		
PIE	Post Irradiation Examination		
PLC	Programmable Logic Controller		
PMD	Photon Multiplicity Detector		
RAPP	Rajasthan Atomic Power Project		
RAPS	Rajasthan Atomic Power Station		
REE	Rare Earths Elements		
RFID	Radio Frequency Identification		
RFQ	Radio Frequency Quadrupole		
RIA	Radioimmunoassay		
RMC	Radiation Medicine Centre		
RMRE	Rare Metal and Rare Earth		
Rph	Radiopharmaceuticals		
RPP	Radiation Processing Plant		
RPV	Reactor Pressure Vessel		
RRCAT	Raja Ramanna Centre for Advanced Technology		
RRF	Raja Ramanna Fellowship		
RTC	Room Temperature Cyclotron		
RTI	Right to Information		
SCRF	Superconducting Radio Frequency		
SDU	Sodium Di Uranate		
SEM	Scanning Electron Microscope		
SGDHR	Safety Grade Decay Heat Removal		
SGTF	Steam Generator Test Facility		
SINP	Saha Institute of Nuclear Physics		
SLM	Supported Liquid Membrane		
SNM	Special Nuclear Materials		
SPECT	Single-Photon Emission Computed Tomography		
SRC	Safety Review Committee		
SRP	Small Rotatable Plugs		
SSFDC	Secondary Sodium Fill and Drain Circuit		
TACTIC	TeV Atmospheric Cerenkov Telescope with Imaging Camera		
TAPS	Tarapur Atomic Power Station		
TBM	Test Blanket Module		

*Edited & Published By Head, Public Awareness Division, DAE and Printed by him at  
M/s. Sundaram Art Printing Press*

