Department of Atomic Energy: An overview of past decade

I. Achievement in Nuclear Power Program

a. During the last nine years, the Department of Atomic Energy has achieved many milestones in the country's Nuclear Power Program. These achievements encapsulate the entire spectrum of activities related to the nuclear power programme including design, construction, operation, renovation, modernization, and rapid expansion of nuclear power, especially in the field of PHWR technologies. The economy of scale was realized with the enhancement of the 220-Megawatt PHWR to 540-Megawatt PHWR with indigenous efforts. The latest achievement is the milestone of successful commissioning and operation of the 700-Megawatt PHWR at full power in 2023.

b. Safety is of paramount importance in nuclear power and the safety record of Indian nuclear power plants has been impeccable, with no accident or instance of release of radioactivity beyond stipulated limits in over 53 years of nuclear power plant operation. The environmental radiation doses due to nuclear power plants have been a negligible fraction of the natural background radiation, and also within the limit stipulated by the Atomic Energy Regulatory Board. DAE has been endeavouring to enhance the safety to even higher levels and increase the performance and efficiency of Nuclear Power plants.

c. In terms of capacity addition in the last nine years, NPCIL's installed capacity has increased by over 56%, from 4780 MW to 7480 MW by the addition of a third unit of Kakrapara Power Plant KAPP-3 (700 MW) and two units of Kudankukam Nuclear Power Plant- KKNPP 1&2 (2X1000 MW). The latest achievement has been the full power operation of KAPP-3, at Kakrapar in Gujarat on August 30, 2023. KAPP-3 is a first-of-a-kind indigenous 700 MW Pressurised Heavy Water Reactor (PHWR), which has advanced safety features comparable to the best in the world. With the design, construction, commissioning, and operation of the reactor by Indian Engineers and scientists and the supply of equipment and execution of works by Indian industry, it is a shining example of the proud spirit of "Atma Nirbhar Bharat".

Its smooth operation at full capacity bears testimony not only to the capabilities of Indian scientists and engineers in the industry but also to the extremely stringent standards set by the Atomic Energy Regulatory Board and rigorous reviews undertaken by it at various stages. The united and dedicated efforts put in by all stakeholders in the face of severe restrictions during the Covid pandemic and in addressing challenges associated with a first-of-a-kind reactor have enabled the achievement.

d. Although KKNPP 1&2 at Kudankulam in Tamilnadu were Light Water Reactors (LWR) of Russian design, the entire construction, equipment erection, commissioning of various systems, system integration and integrated commissioning of the plants followed by operation was carried out by Indian engineers. A significant part of the supplies (equipment etc.) were also sourced from Indian industries. Setting up and operation of KKNPP-1&2 led to NPCIL gaining expertise in LWRs also apart from the already held expertise in PHWRs.
e. The last decade has also been marked by largest capacity expansion programme being launched in the field of Indian Nuclear Power. The KAPP-3 unit is a front runner in a series of 15 more indigenous 700 MW PHWRs which are at various stages of pre-construction and construction. In addition, four more LWRs with Russian cooperation at Kudankulam- KKNPP 3&4(2X1000 MW) and KKNPP 5&6 (2X1000 MW) are under construction. Thus, presently a capacity of 14500 MW comprising of 19 reactors is under implementation by NPCIL.
f. On progressive completion of this capacity, the present installed capacity of 7480 MW is expected to increase to 22480 MW by 2031-32, which includes the 500 MW PFBR under commissioning at Kalpakkam. DAE and NPCIL are working incessantly to add more nuclear capacity based on both proven and innovative designs to ensure long term energy security in the country in a sustainable manner, making India Atma Nirbhar in Energy.
g. NPCIL also has expertise in Renovation and Modernisation (R&M) of reactors. In the last 9 years, the R&M of KAPS-1 &2 (2X220 MW) was completed ahead of schedule and the reactors brought on-line after Enmasse Coolant Channel Replacement and Enmasse Feeder Replacement, the core components of the reactors, to enable enhanced safety & performance and extended life.
h. The current fleet of Nuclear Power Plants has demonstrated some outstanding performance with continuous operation of 962 days by Kaiga-1 unit, setting a world record of continuous operation of nuclear power reactors. In addition, some of our PHWRs have operated continuously 43 times for over a period of one-year, which includes more than 700 days of

continuous operation on five occasions. The highest generation of 47112 million Units in a year was achieved in this period.

i. Apart from its nuclear business, NPCIL as a responsible corporate, ensures inclusive growth of neighbourhoods of its NPP sites by implementing projects for their welfare in areas of Healthcare, Infrastructure, Education & Skill Development, Sustainable development, sanitation, etc. The amount being spent by NPCIL on its CSR activities has been steadily increasing and in 2022-23 it was about ₹ 137 Cr. NPCIL is also implementing the Environment Stewardship Programme (ESP), focussed on habit conservation, conservation of flora and fauna, scientific studies like bird counts, publication of coffee-table books, etc. The ESP has further enriched the environment around the nuclear power plants, making them treasure troves of flora and fauna, both endemic and migratory.

j. As India is blessed with vast resources of Thorium, Thorium utilization for large-scale electricity generation and associated technology development are some of the important aspects of three stage Indian nuclear power programme. India adopts a closed fuel cycle policy. Spent nuclear fuel is not a waste but it is a resource for obtaining fuel by reprocessing for reactors in the next stage of the three-stage nuclear power programme. India's modest uranium resources can support a first-stage programme on PHWRs for present and near-term needs using natural uranium as fuel and heavy water as moderator and coolant. The energy potential of natural uranium can be increased in the second stage of the programme in the coming years through Fast Breeder Reactors (FBRs), utilizing depleted uranium and plutonium obtained from the recycled spent fuel of the first stage along with thorium as a blanket, to produce U-233. The 500 MW Prototype Fast Breeder Reactor (PFBR) is being constructed indigenously with the involvement of major Indian industries and sustained power operation of this reactor will be a feather in the cap in line with the nation's **'Aatma Nirbhar Bharat'** campaign. With the deployment of thorium in the third-stage Breeder Reactors (BRs), using U-233 as fuel, the energy potential for electricity generation is substantially large and sustainable for centuries.

k. Besides utilizing the full energy potential of fissile and fertile materials, DAE has been adopting the strategy for a closed fuel cycle which aids nuclear waste management. This strategy enables recovery of the long-lived minor actinides by partitioning of high-level waste for subsequent transmutation in specially designed reactors and recovery of valuable radionuclides for use in societal applications. As a result of the recovery of minor actinides and other radionuclides, the footprint of the geological repository and the time frame required for the geological isolation of waste are also significantly reduced.

l. Indigenous industrial infrastructure for nuclear power programme is also well developed. Special infrastructure for the production of fuel, heavy water, reactor control and instrumentation have been developed within the Department of Atomic Energy (DAE). Besides, in last decade Indian industry has gained momentum with valuable experience and reached a stage of maturity in manufacturing equipment, various components and handling of these reactors.

m. Safety is given paramount importance by NPCIL in design, construction and operation of nuclear power stations. To achieve the level of highest safety, a "Defense-In-Depth" philosophy is followed by NPCIL, involving multiple barriers, diversity, redundancy, independence and fail-safe design of the safety related systems. Safety of nuclear power stations is further ensured through sound design, using international standards and codes, stringent quality assurance, approved operating procedures, in-service inspection and maintenance of safety systems, etc. Nuclear Power Plants are operated strictly in accordance to approved technical specifications and procedures by trained and licensed persons. Robust regulatory mechanism comprising multitier reviews are in place. There are also periodic audits and reviews at station, corporate and regulatory level.

n. Nuclear power is clean, environmentally benign, economically viable and safe source of base load electricity, available 24x7. The life cycle Greenhouse Gas emissions of nuclear power are comparable to that of wind and solar power. It does not get affected by changing weather or climate conditions. Since inception, the electricity generation through nuclear power till March 2023 alone averted release of about 700 million tons of CO_2 equivalent emission to the environment. This is a measurable contribution against climate change.

Nuclear energy has a huge potential to play an important role for the medium- and long-term electricity needs of the country by setting up more reactors in future and thus, can lead to the overall economic development and contribute in improving the life of the citizens of the country. Nuclear power can help the country's energy transition towards net zero and carbon neutrality, supplementing other clean sources like renewables to meet its climate goals. Thus, DAE is poised to contribute to the growth of the nation by generating environmentally benign electricity in a clean, green and safe manner.

Major highlights in Nuclear Power Generation & Fuel Cycle Activities in last nine years

1) Start of Commercial Operation – KKNPP-1 (1000 MW PWR) in 2014-15; KKNPP-2 (1000 MW PWR) in 2016-17; KAPS-3 (700 MW IPHWR) in June 2023.
2) Approval and Financial Sanction of 10 PHWRs in fleet mode and KKNPP 5&6 (2X1000 MW) in 2017-18.
3) Creation of Indian Nuclear Insurance Pool (INIP) for civil nuclear liability.
4) Amendment of Atomic Energy Act to enable Joint Ventures of PSEs to set up nuclear power plants.
5) Safe Operation of about 582 reactor-years till date; continuous operation of nuclear power reactors 43 times for over a period of one-year, which includes more than 700 days of continuous operation on five occasions. Setting of World Record of 962 days continuous operation by KGS-1; Continuous Operation of RAPS-5 for 765 days; Continuous Operation of 777 days by RAPS-3; Continuous operation of 852 days of NAPS-2.
6) Highest generation of 47112 Million Units of electricity in 2021-22; high operational performance – Capacity factor 81 % (FY 20-21), 88 % (FY 21-22) & 87 % (FY 22-23).
7) Administrative Approval and Financial Sanction of 10 PHWRs in fleet mode and KKNPP 5&6 (2X1000 MW) in 2017-18.
8) First Pour of Concrete for KKNPP 5 in June'21 & in December'21 for KKNPP 6.
9) Start of excavation work (Ground Break) of first pair of fleet mode reactors, Kaiga 5&6, in April'22.
10) Commencement of commercial operation of 700 MW Pressurised Heavy Water Reactor, KAPP-3 at Kakrapara on 30 June'23.
11) NPCIL & BHEL signed MoU for collaboration in implementation of nuclear power plants based on PHWR technology.
12) NPCIL and NTPC signed a supplementary Joint Venture agreement to develop nuclear power facilities in the country.
13) ***IGCAR/*** Fast Breeder Test Reactor attained its design power level of 40 MWth with TG generating 10MWe and connected to grid.
14) ***AERB***/IAEA Integrated Regulatory Review Service (IRRS) team completed 12-day mission in June'22 and finds strong regulatory commitments, professionalism & arrangements to ensure nuclear and radiation safety in the country – at nuclear power plants as well as facilities using radiation sources in the field of research, industry, medicine & agriculture.
15) ***UCIL***/ Tummalapalle Uranium Project in Andhra Pradesh was capitalized with effect from January 2017.

16) ***UCIL***/ Jaduguda mine was brought back to operation after receiving final clearance w.r.t. renewal of forest land diversion of Jaduguda mine in 2018.
17) ***AMD***/Cumulative augmentation of uranium resource (U3O8) is 3, 89,042 tonnes (as on Mar 2023) vis-à-vis 2,14,158 tonnes (as on Mar 2014).
18) ***UCIL***/New Uranium mines are being started at Rohil Deposit in Rajasthan.
19) ***UCIL*** In principle approval of AEC for 13 new projects for opening up new mines.

II. Non-power Applications of Nuclear energy

Production and application of radioisotopes and radiation-based technologies is an important programme of the Department of Atomic Energy (DAE) since its inception. Radioisotopes are extensively used for human healthcare, industry, agriculture and many other societal applications. India is marching steadily towards self-reliance in production of radioisotopes for meeting the requirement in nuclear medicine, industry and agriculture. In India, radioisotopes are primarily produced in research reactors and cyclotrons, particularly medical cyclotrons. Although there is a steady growth in the production of radioisotopes in medical cyclotrons for use in nuclear medicine, major part of radioisotopes for use in societal applications is still produced in research reactors. The focus of DAE is on societal applications of radiation i.e., Food preservation, Agriculture, Healthcare, Municipality waste management and Industrial Applications.

(A) Radiation Processing for Food Security, Safety and Promotion of International Trade

In India, annual food grains production is around 281 million Metric Tonnes, whereas that of horticultural produce is 315 Million MT. Out of these, FAO (Food and Agricultural Organization) estimates nearly 30-40% of the food produced in India is wasted due to lack of appropriate farming practices, unavailability of storage and packaging facilities, cold storage, transportation, processing, and irregularities at retail and consumer levels. Adaptation of radiation processing can help in reducing these post-harvest losses.

DAE's Food Irradiation Program

1. Onion Preservation by Radiation Processing

Non-availability of onion during the lean period as well as limited shelf-life due to weight loss, microbial spoilage, rotting and sprouting quite often leads to huge post-

harvest storage losses leading to fluctuation in the market price of the onions. R&D and commercial trials by Bhabha Atomic Research Centre (BARC), DAE has resulted in the development of an integrated operating procedure through which radiation processed onions can be effectively stored for 7.5 months under specified cold storage conditions. This modality not only ensures availability of quality onions through controlling post-harvest losses but also price stabilization during lean period. A 250 MT onion specific cold storage facility has been commissioned at KRUSHAK, Lasalgaon by BARC, DAE for storing the radiation processed onions as per the optimized standard operating procedure (SOP) for awareness and technology demonstration and dissemination. In this facility, 30 MT of onion has been radiation processed and stored for extended preservation. Furthermore, Department of Consumer Affairs (DoCA) along with National Cooperative Consumers' Federation of India Limited (NCCF), Ministry of Consumer Affairs, Government of India have signed an MoU with BARC for "Large Scale Trial for Preservation of Onion using Radiation Technology with Integrated Cold Storages". Subsequently, radiation processing of 1000 MT of Onion has been done and extended preservation is currently under progress.

2. Preservation of potatoes by radiation processing

A commercial trial for shelf-life extension of potato (28 MT) was performed by BARC with three varieties using gamma irradiation and followed by cold storage. Radiation-treated samples were found to be in good condition till eight months of storage. Non-irradiated potato samples completely sprouted within 100 days whereas irradiated potatoes retained the quality attributes without any sprouting till 8 months. Potatoes were found to be suitable for table consumption as well as industrial processing.

3. Radiation treatment of mangoes to overcome quarantine barrier of trade

Radiation technology has been extensively used for mango export to overcome quarantine barriers since 2007. This year, India exported more than 2,500 MT which is a significant quantity in comparison with 1,048 MT of average annual exports in the last 5 years. Four food irradiation facilities were involved in this process as per the SOP developed by BARC. Radiation-processed mangoes were exported to majorly four major countries – the USA, Australia, South Africa and Malaysia.

In 2022, a large trial shipment containing around sixteen tons of Kesar mangoes was shipped to the USA. Mangoes were processed as per the BARC-developed protocol. The shipment reached New Jersey port, Newark, USA on 30th June, 2022. Mangoes were found in excellent physical condition with good cosmetic appeal. Regulatory

clearances also accorded to the shipment by U.S. Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS) and United States - Food and Drug Administration (US-FDA). The fruits were marketed successfully in USA. Sea-route shipment will reduce the freight charges to 1/8th to that of air shipment and thus will help in cost effective export of larger quantity of mangoes.

4. **Radiation processing to control insect infestation in grains**

Grains including cereals and pulses are often infested with insects/ pests leading to huge post-harvest losses during storage. Current existing practices of using fumigants such as ethylene dibromide (EDB), methyl bromide(MB), ethylene oxide (ETO), malathion, aluminium phosphide, etc. are deleterious to the health as well as the environment. Therefore, the use of such chemicals has been recommended to be phased out by the statutory bodies including WHO. BARC has been working for radiation treatment of such commodities, which provides a green and safe technology to control their losses. As the quantum of grains being produced is quite huge and therefore their storage requirement, radiation technology is also being customized to fulfil the need through design development to operate in continuous mode and integration with modern storage facilities like silos.

5. **Shelf-life extension of sea-foods, meat, and meat products**

India is one of the major producers and exporters of seafood. With a coastline of over 4500 km, fish production has steadily increased over the years. Fresh catch of fish is prone to rapid spoilage due to improper storage conditions, and contamination with pathogens under usual handling and processing practices. This poses serious health risks to consumers. Under the ice, fish like Bombay duck, pomfret, Indian Salmon, Mackerel, and shrimp can be stored for about 7-10 days. Studies in BARC have demonstrated that gamma irradiation (at 4-7 kGy) followed by storage at melting ice temperatures increases its shelf-life nearly three-fold. In India, meat and meat products are marketed either fresh or in frozen form. Meat and meat products including poultry have a shelf-life of about a week at 0-3ºC, which could be extended up to four weeks by applying a dose of 4-7 kGy, which inactivates spoilage bacteria. Radiation treatment has been employed in BARC to enhance the shelf-life of intermediate moisture fish and meat products.

6. **Hygienization of spices**

India is a major spice-producing and exporting country. However, due to inadequate handling and processing conditions, spices often get

contaminated with insect eggs and microbial pathogens. When incorporated into semi-processed or processed foods, particularly, after cooking, the microbes, both spoilers, and pathogens can outgrow causing spoilage and posing risk to consumers. Many of the spices develop insect infestation during storage. BARC has developed technology for the hygenization of spices through an average absorbed dose of 10 kGy which brings about commercial sterility while retaining the natural characteristics of spices.

7. Recent Regulatory Approval of Radiation Processing of Foods

Recently, the Food Safety and Standard Authority of India (FSSAI) has endorsed 'Generic class-based approval of radiation processing of food" which is as per the Radiation Processing of food and Allied Products Rules, 2012. This has been subsequently Gazette notified by the Government of India in 2016 (F.No.1-120(2)/Standards/Irradiation/FSSAI-2015) (Table 1& 2).

(a)*Food irradiation facilities*

In India, the first pilot radiation processing facility "The Food Package Irradiator" was commissioned in 1967 at the Food Irradiation Processing Laboratory (FIPLY), Bhabha Atomic Research Centre, Mumbai. Later four food irradiation facilities were commissioned in the Government sector in states of Maharashtra and Gujarat namely, Radiation Processing Plant (RPP), Vashi; Krishi Utpadan Sanrakshan Kendra (KRUSHAK) at Nashik; Irradiation Facility Centre (IFC), Maharashtra State Agriculture and Marketing Board (MSAMB), Vashi; and Gujarat Agro Industries Corporation Limited, Ahmedabad. An additional 22 plants have been established under private entrepreneurship. Thus, currently 26 gamma irradiation plants are operational in the country treating food and allied products.

(b) Radiation Treatment for Crop Improvement

Improving crop productivity requires the availability of quality seeds of improved varieties, nurturing the crop through irrigation and manuring/fertilization, and protecting crops against pests and diseases. Bhabha Atomic Research Centre, DAE has been working on these aspects with an aim to aid in the food security of the nation through sustainable and climate-smart agriculture. Mutation breeding, the use of radiation to create genetic variability, is one of the core programs of BARC. The major breeding objectives are higher yield and quality, tolerance/resistance to abiotic and biotic stresses, and modification of plant architecture. Radiation-induced

mutagenesis, along with cross-breeding has been successfully deployed to develop and release 60 varieties in crops like groundnut, mustard, pigeon pea, urad bean, mung bean, rice, sorghum, linseed, soybean, sunflower, and jute. In addition, biotechnological tools like plant tissue culture combined with radiation have been used to induce mutants in vegetatively propagated and flowering crops like banana, sugarcane, pineapple, chrysanthemum, gladiolus, and gerbera.

(B) Radiation Technology for Health Care

The use of radioisotopes in human healthcare, both in the diagnosis and staging of diseases as well as in treatment, has been continuously gaining momentum. This is partly attributed to the broader availability of a large variety of radioisotopes with desired decay characteristics at an affordable cost. In India, a significant quantity of radioisotopes is produced per year in research reactors in BARC and deployed for various applications. Some of the major radioisotopes used in health care are Iodine-131 (131I), Molybdenum-99/Technetium-99m (99Mo/99mTc), Fluorine-18 (18F), Gallium-68 (68Ga), Lutetium -177 (177Lu), Samarium-153 (153Sm), Iridium-192 (192Ir), Iodine-125 (125I) and Cobalt-60 (60Co). Bromine-82 (82Br) is used in industry whereas Iridium-192 (192Ir) finds use both in industry and medicine.

Radioisotope	Production route	Annual production	Utility
In routine use			
^{99}Mo	^{98}Mo(n,γ)	~ 800 Ci	^{99}Mo/^{99m}Tc generator – diagnostic nuclear medicine
^{131}I	^{131}Te(n,γ)^{131}Te(β^-)	~ 1500 Ci	Diagnosis and treatment of thyroid disorder
^{153}Sm	^{152}Sm(n,γ)	~ 150 Ci	Bone pain palliation in advances stage of cancer
^{177}Lu	^{177}Lu(n,γ)	~ 1200 Ci	Targeted cancer therapy
^{125}I	^{124}Xe(n,γ)^{125}Xe(EC)	~ 10 Ci	Brachytherapy
^{192}Ir	^{192}Ir(n,γ)	~ 50000 Ci	NDT, industrial radiography
^{82}Br	^{81}Br(n,γ)	As per requirement	Industrial radiotracer
Emerging			
^{90}Y	^{89}Y(n,γ)	~ 3 Ci	Treatment liver cancer, arthritis
^{64}Cu	^{64}Zn(n,p)	~ 1 Ci	PET imaging
^{165}Ho	^{166}Ho(n,γ)	~ 5 Ci	Treatment liver cancer, arthritis
^{177}Lu (no carrier added)	^{176}Yb(n,γ)^{177}Yb(β^-)	~ 2Ci	Targeted cancer therapy

Radiation therapy using Cobalt-60-based teletherapy units is used in cancer treatment wherein the gamma energy emitted is directed towards the tumour from outside. The indigenously built BhabhaTron machine by BARC is extensively used for this purpose. Low dose rate Blood Irradiator (BI), using Cobalt-60 or Cs-137 is unique equipment which ensures safety of blood transfusion to immuno-compromised patients by averting post-transfusion graft-versus-host disease (GVHD) and is used for irradiation of blood bags. Recently introduced Ruthenium 106 Plaque (RuBy plaque) by BARC has become very popular to treat patients with conjunctival lymphoma (a form of eye cancer).

Major Highlights

1) ***BRIT***/Production towards commercialization of Fission Molly (work horse for nuclear medicine) started in Dhruva reactor in 2023. Fission Moly plant started commercial operation.
2) ***HWB***/Agreement for supply of D2O for producing deuterium labelled compounds (used in healthcare sector) signed with private industry.
3) ***HWB***/Indigenous production of O^{18}-water for PET scanning etc. started.
4) ***BARC/***GoI approval for setting up of Isotope Production & Processing Facility at an estimated cost of ₹ 1200 Cr in PPP mode.
5) ***BARC***/5 lakh Ci of Cesium was recovered and about 33 kg of this has been converted to pencils for irradiation since its beginning in 2016.
6) ***BRIT***/29 different radiopharmaceuticals were made indigenously available in form of injection and freeze-dried kit.
7) ***BRIT***/New radiopharmaceutical product, 'Kit for the preparation of 99mTc-HSA Nanocolloid injection' useful for imaging of neuroendocrine tumours (technology transfer from BARC) has been launched in 2014.
8) ***BRIT***/New product, 131I-Lipiodol injection (Code: IOM-40) launched, used for treatment of liver cancer.
9) ***BRIT***/177Lu-EDTMP, a palliative care drug for reducing bone pain in cancer patients is introduced; regular production & Supply started since Sept 2019.
10) ***BRIT***/ New product, 177Lu-DOTA-TATE used for therapy of neuroendocrine tumours is launched (Code: LUM-3).
11) ***BRIT***/ Supply of Ruthenium-106 for the Treatment of Eye Cancer commenced since July 2019.
12) ***BRIT***/ Production of [18F]-DOPA for the Diagnosis of neurological disorders and Oncology and [18F]-Fluoro Choline for the Diagnosis of Tumour (PET Rphs) at Medical Cyclotron Facility (MCF), Parel, Mumbai started in 2019.

13) ***BRIT, VECC***/ Fluorine-18 isotope was successfully produced for the first-time using CYCLONE-30 in Medical Cyclotron Project (MCP).
14) ***BRIT, VECC***/ New Products: Na[18F]F (PET imaging agent), [68Ga]Gallium PSMA-11 (for Prostate Cancer Diagnosis) & [68Ga] Gallium DOTATATE (for Breast Cancer & Neuroendocrine Tumor Diagnosis) were produced. [201Tl] Thallous Chloride for Myocardial Perfusion (heart ailment evaluation) & Parathyroid Imaging has been produced First time in India.
15) ***BRIT***/ Two new ready-to-use radiopharmaceuticals 90Yttrium-hydroxyapatite (90YHA) and 177Lutetium-hydroxyapatite (177Lu-HA) were launched for treatment of joint related disorders. These radiopharmaceuticals are import substitutes for treatment of rheumatoid arthritis.
16) ***BRIT***/ Higher specific activity (200 – 225 RMM) Co-60 Teletherapy Sources (CTS) is fabricated successfully at RAPPCOF, Kota for the treatment of cancer which eliminated the import dependency.
17) ***BRIT***/ Export of numerous lots of Co-60 Irradiator source to Sri Lanka, Kenya, Vietnam, UK, Nigeria, South Africa, Malaysia, Canada; Tc-99m Cold Kits were exported to USA.

Medicine – Cancer Care (Tata Memorial Centre)

1) MD/ DM/ MCh degree awarded in oncology area – 965.
2) Registering close to 1,25,000 new patients and over 650,000 follow ups annually at Tata Memorial Centre (TMC) Mumbai, more than 60% of patients are treated almost free of cost.
3) TMC has now expanded to six other hospitals located in Varanasi (2), Guwahati, Sangrur, Visakhapatnam, Chandigarh and Muzaffarpur.
4) Honourable Prime Minister Shri Narendra Modi inaugurated the Homi Bhabha Cancer Hospital & Research Centre, Punjab on 24th August 2022.
5) Development and technology transfer of Oncodiagnoscope for early detection of oral cancer.
6) India's first National Hadron Beam Therapy Facility in the Government Sector became operational at ACTREC, Navi Mumbai.
7) The National Cancer Grid, created in 2012, has grown into the world's largest cancer network with 287 members, comprising cancer centres, research institutes, patient advocacy groups, charitable organizations and professional societies. Between the member organizations of the NCG, the network treats over 750,000 new patients with cancer annually, which is over 60% of all of India's cancer burden.
8) The NCG also partners with the Ayushman Bharat – Pradhan Mantri Jan Arogya Yojana (AB-PMJAY) in ensuring evidence-based cancer care and rationalizing tariff packages under the scheme. The NCG's work on Patient Health Records (PHR) was

extensively used in the National Health Authority's National Digital Health Mission (NDHM).

9) With the creation of NCG "Vishwam" the international component of the NCG, the network is rapidly being acknowledged as one of the most influential organizations in global cancer care.
10) Starting from 740 beds in 2017, TMC has grown to 2450 beds (in 2022) and will further increase its capacity to 2700 beds by mid-2023. TMC has now expanded to six other hospitals located in Varanasi (2), Guwahati, Sangrur, Visakhapatnam, Chandigarh and Muzaffarpur.
11) ACTREC has expanded to 500 beds in 2022 and will expand to 900 beds by mid-2023, and will offer cutting-edge treatment with dedicated facilities for solid tumor chemotherapy, hemato-lymphoid cancers management, treatment with radionuclide isotopes, and the first Proton Beam therapy unit with three gantries in India and the first in the government sector.
12) The hub and spoke model of cancer care has been successfully implemented in Punjab and in Uttar Pradesh.

(C) Radiation Technology for Sludge Hygienization

Management of large quantities of sewage sludge is a severe problem for urban development authorities. Sewage sludge is a rich source of organic carbon and micro and macronutrients but contains pathogenic microbes. Thus, the utilization of pathogen-free sludge in farmlands provides a healthy and economic way to increase production yield, improve soil health, and make full use of the potential of sewage sludge. Converting municipality waste into useful organic fertilizer is another very useful application of radiation technology. Pilot plants have been established by BARC in Ahmedabad and Indore for demonstration of this technology. This technology has potential for use in bigger cities, to address the waste disposal issue on a large scale. This will benefit the fundamental environmental issues significantly by grossly improving the fertility of land while replacing chemical fertilizers.

(D) Industrial applications of Radiation Technology

Radioisotope (RI) tracer studies utilize 82Br, 131I, 99mTc, and 137mBa for detection of leakage and blockage, assessment of wear and tear, mixing efficiency, residence time distribution in chemical processes, etc. Sealed RI source (192Ir, 60Co, 137Cs, 22Na) - based techniques have been developed by DAE units, which are used for gamma scanning of large columns in oil and petrochemical industries to identify

malfunctioning and trouble-shooting. In addition, Nucleonic Gauges (NG) developed by DAE units are extensively used in several industries for online processes and quality control. A radiography camera is an important tool for Non-Destructive Testing /Examination (NDT/NDE) for identifying defects in the weld, joints, casting machine parts (e.g., airplanes), etc. BRIT supplies both radiography sources (192Ir and 60Co) and Radiography Exposure Devices (ROLI-1, ROLI-2, and ROLI-3 radiography cameras) to NDT centers in the country. The recently launched 60Co-based COCAM 120 camera with hybrid shielding and an inspection range of 40 –200 mm has proved quite useful to the heavy engineering industry.

(E) Waste Management and Utilization

Nisargruna Biogas Plant has been developed at Bhabha Atomic Research Centre, Mumbai for comprehensive solid waste management. The name Nisargruna means "Loan or debt from nature." The plant aims to repay the nature with the manure obtained from the waste processing in an appropriate way. Nisargruna plant has aerobic and anaerobic phases. Solid waste originating in kitchens, vegetable markets, municipal solid waste, abattoir can be treated in this plant for conversion into methane (fuel) and slurry with microbial biomass. The digested slurry is passed through sand filters and good-quality manure is obtained which is an excellent soil conditioner. This is very important for replenishing fast-decreasing resources of productive soils.

(F) Desalination & Water Purification Technologies

Bhabha Atomic Research Centre (BARC) has developed several water purification and desalination technologies, as a part of its research and development efforts towards the betterment of society. These technologies or products are backed with robust design concepts and pilot plant studies, which can cover the needs of households, communities, industries, and metropolis. Know-how of products/components/technologies and services available in the field of water treatment can be broadly classified based on their applications:

- Water purification systems for the removal of microorganisms, turbidity & and toxic contaminants such as, As, Fe, F, etc for producing safe drinking water.
- Desalination Units for the removal of salinity using a membrane process or thermal desalination for producing pure water for drinking or industrial uses.

- Effluent treatment plants based on UF & RO for recovery of water for reuse or for safe disposal.
- Units that can operate without electricity (domestic UF) or operating on solar power (UF & RO), which are most suited for remote and rural areas.

The know-how of these technologies/ products has been transferred to several parties for wider deployment in a commercially viable manner and is available on non-exclusive basis through technology transfer.

Similarly, services in design, engineering, installation, commissioning, operation, and troubleshooting of brackish water and seawater desalination and effluent treatment plants are available through consultancy.

III. International Cooperation

(i) ***Civil Nuclear Cooperation****:* Inter-Governmental Agreement (IGA) for co-operation in peaceful uses of nuclear energy have been signed with the following 18 countries: Argentina, Australia, Bangladesh, Canada, Czech Republic, European Union, France, Japan, Kazakhstan, Mongolia, Namibia, Republic of Korea, Russia, Sri Lanka, United Kingdom, United States of America, Vietnam and Ghana.

(ii) Significant progress has been made in India's bilateral engagement in civil nuclear cooperation with major partners as follows:

Russia:

Rosatom, is constructing 6 units of VVER reactors each with a capacity of 1000 MW at Kudankulam site. Kudankulam Nuclear Power Plant KKNPP-1 and KKNPP-2 already have started commercial operations in 2014 and 2017 respectively. Construction of KKNPP 3&4 and KKNPP 5&6 are progressing well.

France:

Inter-Governmental Agreement is signed between NPCIL and EDF to construct six Evolutionary Power Reactor (EPR) units (1650 MW x6), at Jaitapur, Maharashtra. A Techno-Commercial Offer (TCO) was submitted by EDF in April 2021 on which discussions are ongoing to address safety and regulatory issues. Discussions are underway to resolve the CLND issues through G-G participation. Also, the French Govt has submitted the DOI for a partnership between the Government of India and France for development of AMRs and SMRs.

U.S.A:

The Kovvada Nuclear Power Project with 6 units of AP1000 reactors (6 x 1208 MW gross capacity, 6 x 1110 MW net capacity) is planned to be implemented under the inter-governmental "Agreement for cooperation between the Government of India and Government of United States of America concerning peaceful uses of Nuclear Energy," (Inter-Governmental Agreement (IGA)), signed in October 2008. Government of India granted In-principal approval on 8.10.2009 for 6x1000 MW reactors by GEH at Kovvada site. Later in Jun 2016, the Kovvada site was re-allocated to Westinghouse Electric Company (WEC). The capacity of Kovvada site was subsequently revised as 6 x 1208 MW, in 2016.

Discussions are underway with Westinghouse on Division of Responsibility, Civil Nuclear Liability and other pre-construction activities. Also, both the governments are discussing for development of SMRs in collaborative mode.

Bangladesh:

DAE is providing technical/consultancy and capacity building support to Bangladesh Atomic Energy Commission for the Rooppur Nuclear Power Project (RNPP). Indian company HCC has won a contract worth USD 110 million for the civilian works in RNPP. Another Indian company Paharpur has won along with a Bangladesh company, a contract for the construction of cooling tower.

(iii) ***Progress in procurement of uranium from major global*** **suppliers**: Fuel/ UOC (uranium ore concentrate) supply contract agreement has been signed with major global suppliers such as Kazakhstan, Canada, Russia and Uzbekistan.

(iv) ***Localisation of manufacturing for foreign-collaborated nuclear power projects:*** In line with **"Make in India"**, a joint Programme of Action has been signed with Russia for Localization of manufacturing in India for Russian-designed NPPs.

(v) India has gifted a Cobalt teletherapy machine (Bhabhatron) for cancer treatment to Mongolia, Kyrgyzstan, Tanzania, Kenya, Madagascar, Uganda, Vietnam, Myanmar and Nepal.

(vi) Project cooperation signed between DOE and ***DAE institutions*** for High Intensity Superconducting Radio Frequency Linear Proton Accelerators, referred to as "HISPA" in January 2015

(vii)Collaboration with Fermilab- India entered the construction phase of the Fermilab project under this cooperation and will supply components worth about ₹ 900 crores in this phase.

(viii) **ITER (International Project at France)**:

Indian 'In-kind contribution' towards the ITER participation is divided into nine packages.
Deliveries for four of these, viz., (1) Cryostat, (2) Vacuum Vessel In-Wall Shields, (3) Cooling Water Systems, and (4) Cryodistribution and Cryolines System are either complete or nearing completion. The remaining packages involves substantial R&D and required later. Prototype and development activities in Indian laboratory are in progress.

India has already received about 69% of its in-kind contribution Credits (in kIUA) for the deliveries made so far. Total expenditure incurred so far for procuring these deliveries is about 45% of the sanctioned cost for in-kinds.

Apart from supply of equipment made in India, Indian nationals are also working in ITER. Presently, about 25 staff from Indian research organizations are employed in ITER. Apart from these, about 175 personnel are deputed by Indian industries for short tenure to support on specific areas.

Indian industries are also promoted to seek business from ITER through competitive route, orders worth over Rs.1000 Cr. have been received by Indian entities so far. These include the income from deputation of short-term personnel deputed by industries.

(ix) Project signed between DoE and ***DAE*** for cooperation in high energy physics and related applications, referred to as the "Neutrino Physics Collaboration" in April 2018.

(x) In-principle approval obtained for the LIGO India (RRCAT), an advanced gravitational wave observatory project in February 2016 and financial sanction in April 2023, at an estimated cost of ₹ 2600 Cr.

(xi) In-principle approval obtained for India's participation in the international Mega Science Project, Square Kilometre Array (NCRA-TIFR).

(xii) New collaboration launched between DAE & Science & Technology Facilities Council, UK (STFC-UKRI).

(xiii) DAE's research and development institution Global Centre for Nuclear Energy Partnership (GCNEP) has conducted over 56 international programs, including training courses, workshops and technical meetings, drawing more than 500 foreign participants from around 60 countries besides more than 1000 Indian participants. GCNEP has also signed 14 memorandums of understanding with various countries and organizations, including IAEA, United States of America, France, Russian Federation, United Kingdom of Great Britain and Northern Ireland, Argentina, Uzbekistan, Ghana, African Commission on Nuclear Energy, Bangladesh, Vietnam, Bulgaria, Kazakhstan, & republic of Malawi for strengthening global nuclear security.

xiv) Discussions with Transmutex/ Switzerland for co-development and co-deployment of 800 MeV cyclotron in India have been initiated.

IV. Nuclear Security

India is a party to all the thirteen universal international instruments pertaining to nuclear security. The department implements all the binding obligations with respect to international instruments to all its nuclear facilities and nuclear materials. The department maintains a robust nuclear security culture and implements physical protection systems for all nuclear facilities.

BARC has indigenously developed various physical protection systems (PPS) for detection delay and access control to mitigate any event with respect to nuclear security. These PPS systems include Fibre optics and multisensory perimeter intrusion detection systems, Secure network access system portal monitors, surveillance systems, Container/cargo scanners, and radiation detectors. The department has also installed radiation portal monitors at all the major ports in the country.

Pursuant to the declaration of the Hon'ble Prime Minister at the Nuclear Security Summit in 2016, the department has constituted an inter-ministerial Counter Nuclear Smuggling Team (CNST) which has representations from the Ministry of External Affairs, IB, BSF, Assam Rifles, NDRF, Customs department, etc., to strengthen the nuclear security regime by covering prevention, detection, and investigation including forensic support, and prosecution of the act of smuggling, and to strengthen the inter-agency platform for the exchange of information, coordination, cooperation to counter nuclear smuggling incidents.

The Department has established a robust mechanism to maintain Nuclear Material Accounting and Control (NUMAC) for the nuclear material in the country. The department also has a very strong control mechanism for the import and export of prescribed substances and equipment. As a part of the Nuclear Detection Architecture in India, 25 no. of Emergency Response Centres (ERC) are in a state of readiness to respond to any radiation emergency situation in the public domain. In addition, 10 more ERCs have been set up which are manned by the NDRF. The department has also developed “State of the Art” Radiation Monitoring Systems for search, detection, and quick qualitative and quantitative assessment of orphan radioactive sources of large areas with radioactive contamination in case of nuclear and radiological emergencies/threats. Training courses on 'Preparedness and Response to Radiation Emergencies' are routinely carried out for the response agencies and radiation emergency exercises are conducted at regular intervals. Enhanced radiological surveillance is carried out at Seaports, Airports, and Land borders to prevent illicit movement of radioactive material. The Crisis Management Group (CMG), is a standing committee within the Department of Atomic Energy to coordinate the department’s response to a nuclear or radiological emergency in the public domain.

The department also administers various provisions of the WMD Act 2005 and UAPA Act with regard to export control and nuclear security respectively. The department has conducted various workshops, training programs, and exchange programs in the field of nuclear security with various partner countries like the USA, UK, Bangladesh and IAEA. The experts from the department participate in the drafting and review of Nuclear Security Series (NSS) documents at IAEA. India has also contributed (1 M USD) towards the Nuclear security fund to IAEA to support nuclear security activities.

V. Nuclear Safety

1. Safety Upgrades post Fukushima

Post the Fukushima nuclear accident in March 2011, AERB revisited the safety of all its Nuclear Power Plants (NPP) and upcoming projects to assess the safety margins available against the extreme external hazards and to ensure the availability of vital safety functions for a prolonged duration. The exercise reconfirmed the inherent strengths in design, operating practices and safety regulation followed in India. The exhaustive periodic safety reviews which are carried out once in every ten years, have resulted in further enhancement of the safety in nuclear power plants of the country. However, as an extra precaution, AERB had recommended additional safety upgrades pertaining to availability and reliability of power supply and water supply backups for handling severe accidents, which were progressively implemented in all Nuclear Power Plants. India was one of the foremost countries of the world to have implemented these safety upgrades in a time bound manner and the strengthening measures were appreciated by the international community during the peer review of the National Reports to Convention on Nuclear Safety.

2.0 Revision of Emergency Preparedness & Planning Requirements

A major lesson learned from the Fukushima accident was the importance of prompt decision-making in an emergency situation which should aim at doing better than harm. Keeping this aspect in mind, AERB has updated its regulatory requirements with respect to emergency preparedness and response. As per the updated requirements, the responsibility of making decisions during an emergency situation now rests with the plant management, which is based on technical assessment of various plant and environmental parameters. The implementation of emergency response actions, as decided by plant management, will be the responsibility of district authorities. This model has been put into place in the Disaster District Management Plans of respective NPP sites.

3.0 Strengthening of Regulatory Inspection programme

To enhance its regulatory oversight, AERB posted resident site observer teams at various construction sites of nuclear power plants in the country. Further, AERB had also restructured and strengthened its inspection programme taking inputs from safety review, incident reporting, and feedback from stakeholders, and updated the categorization scheme of inspection findings based on safety significance. These changes helped AERB in devising and carrying out remote regulatory inspections so

as to ensure continuity in the regulatory oversight during the COVID-19 pandemic situation when physical inspections could not be performed.

4.0 Enhanced stakeholder engagement and inter-ministerial coordination

In the recent past, AERB has taken various initiatives for enhanced stakeholder engagement such as inviting public comments on draft Safety Codes prior to its publication, organizing the annual National Conference on Regulatory Interface to obtain feedback from stakeholders to improve its regulatory effectiveness and efficiency, making provision for help desk and contact forms on the website to facilitate prompt redressal of the applicants' difficulties and concerns, conducting public outreach programmes near vicinity of nuclear power plant sites, etc. Further, to streamline the regulatory interfaces, AERB is actively engaging in various inter-ministerial coordination activities for seamless regulation in matters related to the regulation of ionizing radiation sources, medical exposures, etc.

5.0 Enhanced International Cooperation in the Field of Nuclear Safety

AERB has also strengthened its technical cooperation activities with international bodies by entering into bilateral arrangements, the elevation of India's membership status in NEA's Committees from 'adhoc invitee' to 'participant' and leveraging various multilateral forums of IAEA. One such forum was the Integrated Regulatory Review Service (IRRS) Mission of IAEA. In 2015, Government of India hosted the initial mission. The team had made various recommendations and suggestions. A follow-up IRRS mission with extended scope was hosted in June 2022. The team noted "*India's regulator showed a strong commitment and professionalism to ensure nuclear and radiation safety in the country" and observed, "AERB has acted on all of the recommendations and suggestions of the initial mission of 2015 and, as a result, significant improvements have been made in many areas".*

Further, during the Joint 8th and 9th Review Meeting (RM) of the Convention of Nuclear Safety (CNS) held in Vienna, Austria from March 20-31, 2023 all challenges and suggestions that emanated from the 7th RM were closed and no new challenge was identified for India by the Country Group.

Additional Significant Initiative with respect to Licensing of Radiation Facilities

Institution of an online licensing system for radiation applications

For increasing transparency and accountability, AERB has instituted an online web-based e-licensing system (e-LORA) for efficient and transparent licensing of the use of radiation sources for societal benefits. The e-licensing of Radiation Applications has contributed significantly to the tracking of applications and information on the inventory of radiation sources at any given moment. It has also eased the process of obtaining licenses from AERB. It is a unique state-of-art regulatory tool that promotes minimum government and maximum governance. Prior to e-LORA, i.e. before 2013, there was only about 5,000 medical X-ray equipment registered with AERB and presently more than one lakh X-ray equipment have been registered in e-LORA.

VI. Industrial Achievements

a. Indian Rare Earth Limited (IREL)

1. IREL (India) Limited, a public sector unit under Department of Atomic Enenrgy, has shown phenomenal growth in the last decade from a loss making to profit making CPSE, with a growth of six times in revenue from operations and has registered profit before tax of Rs. 1144 crore for the first time since inception. Further, the MoU rating has been 'Excellent' since the last five years and the provisional MoU for the year 2022-23 is also 'Excellent'.
2. In line with 'Self Reliant India' initiatives, IREL has set up first such facility in BARC Campus, Vizag for production of Rare Earth Permanent Magnets (Samarium-Cobalt) based on laboratory level technology developed by BARC/ DMRL. The permanent magnets would be used in the strategic sector by DAE & DRDO.
3. Similarly, first such facility for production of Rare Earth Metals has been established in Rare Earth & Titanium Theme Park in Bhopal wherein industrial engineering has been carried out to upscale the scientific principles developed by BARC in the laboratory. The facility will also house industrial plants for recovery of Rare Earths from end-of-life magnets, production of lamp phosphors, etc. The objective of the theme park is to encourage entrepreneurs to gain hands on experience in the operations and set up commercial plants. Further, in line with 'Skill India' mission of the Government, the facility will develop the skilled workforce for the industrial plants of future.
4. IREL has also established facilities for production of Dysprosium and Gadolinium, which are heavy Rare Earths found in Indian source in traces for use by DAE. IREL has also established facility for production of 6N pure neodymium oxide which is used in lasers as a doping agent. IREL through its inhouse R&D initiatives has

developed thermal barrier coating (TBC) material which are used by Defence as a part of import substitution.

5. IREL has received the highest Export Award for 2021-22 from Chemical & Allied Products Export Promotion Council. IREL received the award from Shri Om Birla, Hon'ble Speaker, and Government of India. IREL received this award for 5th consecutive year starting from 2017-18, 2018-19, 2019-20 & 2020-21.
6. Recently, IREL received the FIEO "Export Excellence Award" Gold for the year 2019-20 and Silver for 2018-19 from Smt. Anupriya Patel, Hon'ble Minister of State for Commerce & Industry, Government of India.

B. Heavy Water Board

1. Heavy Water Board (HWB) a constituent unit of Department of Atomic Energy, carries the mandate of supporting the Three stage Indian Nuclear Power Program by production of Heavy Water (Deuterium Oxide) & specialty materials like Enriched Boron, Nuclear grade sodium, Nuclear solvents for front end and back end fuel cycle, etc.

2. HWB has developed, demonstrated, optimized and deployed the complex production technology of Heavy Water using H2S-H2O Bi-thermal process and NH3-H2 Mono-thermal process. India is only country to master in the design & operation of both processes. HWB has also developed and successfully demonstrated the first NH3 – H2O exchange process to attain fertilizer independent operation of Ammonia based HWPs if need arises.

3. Starting in 1963 with pilot plant at BARC, now Heavy Water Board has 7 different units across India to reach its mandate. The journey of HWB has **transformed India into the largest producer of best quality Heavy Water in the world** and is not only meeting in-house Heavy Water requirements for the Indian Nuclear Power Program but is also exporting to various countries. It has exported around 100 MT of Heavy Water to various countries like USA, France, Japan and S. Korea, earning USD 43.02 Million in past 9 years (till October-2023) and around 219 MT order under approval process.

4. Apart from the above, HWB has opened avenues for development and promotion of Non-nuclear applications of Heavy Water and Deuterium. These applications in the field of Life Sciences, Exploration, Nutritional Studies, Optical fiber industries, Analytical Science, Medicinal Chemistry in Pharmaceuticals, etc. would benefit the society at large and support India one step ahead into the Make in India Campaign.

5. **HWB** Successfully developed and deployed technology for production of O-18 water required in nuclear medicine & diagnostic scanning techniques. The facility is operational at HWP, Manuguru and product is at par with international standard and certified successfully by end users.

6. **HWB** has produced and purified 7 MT sodium to nuclear grade using indigenously developed closed cell and purification process. The supplied sodium is under testing at Sodium test facility, IGCAR, Kalpakkam.

7. **HWB** has successfully produced Boron Carbide pellets of different B-10 IP (50%, 67% and 90%); supplied pellets of 50% B-10 IP to IGCAR to increase reactor power of FBTR to 40 MWth. Pellets of 90%B-10 IP are ready to be supplied to IGCAR for FBTR operation.

8. **In HWB** ^{10}B and ^{11}B enriched (>90% enrichment) elemental boron is produced for experiments at TIFR-BARC Pelletron facility.

9. Deuterium Depleted water, which is an effluent / waste from Heavy Water Plant, Manuguru is being sold to few interested private parties for its application in healthcare industry. As on date, 171 MT of DDW is sold for non-nuclear applications.

10. **HWB** has taken-up developmental work with MS University, Baroda and ACTREC, Navi Mumbai for assessing potential of DDW in developing deuterated API's and its effect on cancer treatment.

11. **HWB** has successfully synthesized new solvent – CC6 based on BARC technology, for its application in extraction of Cs-137 from spent fuel. Quality of the same has been well accepted by BARC for intended application.

12. **HWB** has successfully set-up 150 KLD Sewage Treatment Plant (STP) at Surat, which is based on Hybrid Granular Sequencing Batch Reactor (hgSBR) technology developed by BARC. This is compact, efficient plant, requiring less specific energy, low footprint area and clean process for sewage treatment.

13. **HWB** has successfully installed and operated Solvent Production Plants for production of various Organo phosphorous solvents, namely TBP, D2EHPA, TOPO, TAPO, DNPPA, as per demand.

VII **New measures and initiatives that the Department thinks, could be taken to further India's interest abroad:**

India would like to collaborate in the following area:

- PWR based fuel fabrication technology
- Joint manufacturing of equipment such as Control Rod Drive Mechanism (CRDM), pumps, turbines, HP/HT valves

- Design, development and deployment of PWR based SMR, liquid metal cooled SMR, molten salt reactor, micro reactors/nuclear, high temperature reactor technology for clean hydrogen production
- Technology for nuclear desalination/industrial scale food irradiation
- Technical collaboration in Uranium Mining
- Decommissioning of NPPs
- Partnership in the global supply chain of PHWR
- Collaboration in rare earth mineral processing
- Partnership in the development of radio-isotopes
- Exports of Radio-isotopes, Heavy Water
- Export of PHWR base reactor technology
- PWR technology such as APR-1400
- Technical consultancy and capacity building in third country
- LEU-Th based fuel fabrication and supply
- Collaboration for the development of Accelerator driven sub-critical system for Thorium utilization.

Science and Technology Development at BARC in last 5 to 10 Years

1.0 Clean Hydrogen

1.1 BARC has indigenously developed the Alkaline Water Electrolysis Technology for high purity Hydrogen (10 Nm^3/h) production. BARC has designed and fabricated a prototype module for performance demonstration of 0.5 MW alkaline water electrolyser cell module.

1.2 The four-step Copper-Chlorine integrated facility has been commissioned and demonstrated in metallic equipment at a throughput of 5 NLph for a period of 40 hours. It has several distinctive advantages and novel features making it the first-of-its-kind integrated Copper-Chlorine facility operational in the world. Work on scaling-up is underway.

1.3 Closed loop I-S process in glass/quartz material has been demonstrated at 30 Nlph. Catalyst for decomposition of sulphuric acid and hydriodic acid have been developed indigenously. Hydrogen has been produced at 150 Nlph in closed loop I-S process. Work on scaling-up of the technology is underway. BARC has designed and

commissioned the closed loop hybrid-sulphur process demonstration facility (HSDF) of 10 Nlph H_2 production capacity.

2.0 Materials development including Permanent Magnate

Production of Rare Earths Permanent Magnets broadly consists of preparation of required alloy powder & conversion of this alloy powder into permanent magnets. BARC has developed technology for the production of Sm-Co alloy powder using IREL produced raw material. The Sm-Co magnet has been produced at DMRL using alloy powder synthesised by BARC for the DAE application. Based on this technology, IREL has set-up a 3 t/yr capacity rare earth permanent magnet plant in BARC Campus, Vizag to meet demand for strategic applications.

Similarly, BARC has developed calciothermic reduction technology using indigenous raw material for the production of Neodymium (Nd) or Didymium (Nd-Pr) metals required for the production of NdFeB magnet. NdFeB magnet produced at DMRL, using BARC produced Nd and Nd-Pr metals, was found to be at par with imported Nd-Fe-B magnets. BARC technology has been transferred to private entrepreneur for the production of 3 t/y Nd-Pr metal.

BARC has also developed and demonstrated the technology for the production of Dysprosium (Dy) and Terbium (Tb) metal using indigenous raw materials produced by IREL. These metals are required for the production of higher grade NdFeB magnets.

3.0 Bhabha Kavach

Bhabha Kavach is a series of indigenously designed Ballistic Resistant Jackets (BRJs), weighing 6.8 kg, which is less than the designated weight of a BRJ as per BIS-5 (7.4 kg). Bhabha Kavach variants are designed as per the operational requirements and the cost of the Bhabha Kavach is nearly half of that of an imported BRJ. Bhabha Kavach uses BARC developed technology of hot-pressed boron carbide as the strike face. It uses in-house developed carbon nanotube (CNT) dispersed ultra-high molecular weight polyethylene (UHMWPE) as the backing material in hard armour plates (HAP). Another unique feature of Bhabha Kavach is the modular design of boron carbide tiles in the HAP, which confines the damage caused by a bullet within a narrow zone and provides the better multi-hit capability. Bhabha Kavach has been extensively qualified as per NIJ 06 and BIS standards & field trials by BSF, CRPF, CISF and Northern Command. The technology for the indigenous manufacturing of Bhabha Kavach has been transferred to several industries. Development of “Advanced Bhabha Kavach” capable of giving protection against snipper rounds is being pursued.

4.0 BLDC Pumps

BLDC Motors of more than 2 HP capacity are not indigenously available in India. BLDC motor based 5 HP Solar Pumps, both Surface and Submersible type, are developed at BARC & installed at various DAE sites**.** These pumps are solar powered, operational over wide voltage range and have efficiency of more than 90% over wide speed range. It can give 20% more output compared to AC pump of same rating at the same place and climate. Bulk production cost of these pumps is comparable to AC pumps. The technology has been transferred to three entrepreneurs.

5.0 MACE Telescope

MACE (Major Atmospheric Cherenkov Experiment) telescope has been installed & commissioned in 2021 at Hanle, Ladakh to explore gamma-ray sky in the energy range above 20 GeV. It is the only telescope in the world fully operating on green (solar) energy. Most of the subsystems of the telescope have been designed & developed within the country partnering with Indian industry, which resulted in spin-off technologies such as diamond turning of large size metallic mirror facets and high-speed data acquisition system. Apart from the regular detection of gamma-ray signal from the standard candle Crab Nebula and other potential sources, MACE has detected very high energy photons from the radio galaxy NGC 1275 during the recent historical giant gamma-ray flares during December 2022 - January 2023. This is the first ever result from the MACE telescope which is well recognized and cited by the international community.

6.0 Development of core catcher

An innovative core catcher has been developed containing lining of a special sacrificial material which can absorb the heat by melting and mixing with the corium and subsequently cooling it from bottom, indirectly through the vessel and/or directly from top. The sacrificial material has been developed indigenously from waste produced in aluminium industry. The design of the core catcher has been validated with experiments conducted at temperatures exceeding 2500 °C with 500 kg simulated melt mass and also with decay heat. These experiments demonstrated that, corium can be cooled in core catcher within stipulated time.

7.0 Other Developments

7.1 BARC has developed compact, light-weight, portable and cost effective optical Spectrometer to measure the spectrum of light ranging from 400 nm to 1100 nm. No mechanical scanning required to capture the spectrum, which makes it fast and wear free. Technology has been transferred to three entrepreneurs.

7.2 BARC has indigenously developed Single-stage thin-film composite based Sea Water Reverse Osmosis (SWRO) membrane which is capable of removing more than 99% salinity from sea water in a single stage. This is first time the single-stage SWRO membranes are made in India using the indigenously developed technology. The indigenous membrane modules offer comparable performance with commercially available imported membrane modules. The technology has been transferred to three Indian firms.

NFC contribution for India's nuclear power programme and other fields

NFC has the mandate of supplying Nuclear Fuel and Core Structural to Pressurized Heavy Water Reactors (PHWRs) and Boiling Water Reactors (BWRs) operating and further proposed in the country. In order to achieve these, NFC has been manufacturing Uranium Oxide Fuel from domestic & imported Uranium raw materials and Zircaloy core structural from indigenous raw materials. Both Nuclear fuels as well as core structural are produced through high end technology processes and manufacturing facilities integrated with state of art equipment and automation systems.

Through continual automation of manufacturing facilities, material handling systems and inspection systems, NFC achieved quality, productivity, safety and reduced radiation exposure, on par with the best standards in the industry.

NFC also developed and manufactured various special products for strategic purposes or as import substitutes for Space, Defense, Naval and other applications. In addition, NFC has also indigenized several of its manufacturing facilities/ infrastructure (for eg. – Plasma Melting furnace/ VAR furnace), thereby improving availability/ reliability and cost saving.

During the period 2019-23, the notable contributions of NFC are –

(A) Nuclear Power Program:

- NFC supplied 3803 tons of PHWR Fuel to 19 nos. of operating reactor & 208 nos. of BWR fuel assemblies to 2 nos. of BWRs.
- NFC supplied core structural viz. two reactor charge of Calandria tubes & Garter Springs & two reactor charge of Reactivity Mechanism assemblies for 700MWe PHWRs. Further, NFC also supplied four reactor charge of Enmasse Coolant Channel Replacement (EMCCR) for 220MWe PHWRs.
- NFC supplied four sets of Alloy 800 Steam Generators tubes for upcoming 700 MWe PHWRs.

(B) Other fields (Space/ Defense/ Naval/ Non-power):

- Super-Ni 42, Nimonic 75, TITAN 24 tubes for submarine application.
- Titanium half alloy & Alloy 600 tubes for PSLV / GSLV application

- Alloy 617 & SS304HCu tubes for Advanced Ultra Super Critical Thermal Power Project.
- AL-Mg alloy tubes for BrahMos application.
- MDN-250 & 350 for Defense application
- NFC developed CO-NU bundles for large scale production of low specific activity Cobalt-60 for medical & industrial applications.

During the period 2014-19, the notable contributions of NFC are –

(A) Nuclear Power Program:

- NFC supplied 3435 tons of PHWR Fuel to 18 nos. of operating reactor & 333 nos. of BWR assemblies to 2 nos. of BWRs.
- NFC supplied core structural viz. four reactor charge of Coolant tubes & Garter Springs & two reactor charge of Reactivity Mechanism assemblies for 700MWe PHWRs.
- 18 Cr-Oxide Dispersion Strengthened Steel clad tubes for future Fast Breeder Reactors (FBRs)

(B) Other fields (Space/ Defense/ Naval/ Non-power):

- MDN 400B for MIDHANI for strategic application.
- New alloy grade of 30KHGCA for BrahMos application.

Human Resource Development by HBNI for Indian nuclear programme

The main objective of Homi Bhabha National Institute (HBNI) is to encourage the pursuit of excellence in indigenous nuclear science and technology, covering the complete range of nuclear technologies based on indigenous efforts, through its academic programs. The content of the courses and topics for research are designed to create human resources to address Science and Technology of direct relevance to DAE and allied fields.

HBNI provides a framework to encourage multidisciplinary research and integration of basic research (strengths in Grant in Aided Institutions of DAE) with technology development (strength in R&D Units of DAE). HBNI is generating highly technically skilled manpower for the Indian Nuclear Program through its academic program.

(1) All the trainee officers (engineering graduates and science post-graduates) of DAE are given an intensive one-year course on Nuclear Science and Engineering under Post Graduate Diploma in Nuclear Science and Engineering. Further

engineering trainees, carry out research projects in various aspects of Nuclear Science and Engineering for their M.Tech degree.

(2) In the last five years, HBNI has awarded more than 1100 PhD degrees. Majority of the thesis research topics pertain to Nuclear Science and Allied areas.

(3) In the last five years 2018-2022, HBNI published more than 12,000 research papers in peer-reviewed journals.

(4) 41 patents were granted to the innovations made by HBNI faculty and students.

(5) Based on the high quality of publications in high-impact Journals, the Nature Index 2023 placed HBNI in the second position among all academic institutions in India, and in the first position with regard to publications in physical sciences.

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