SOCIETAL APPLICATIONS

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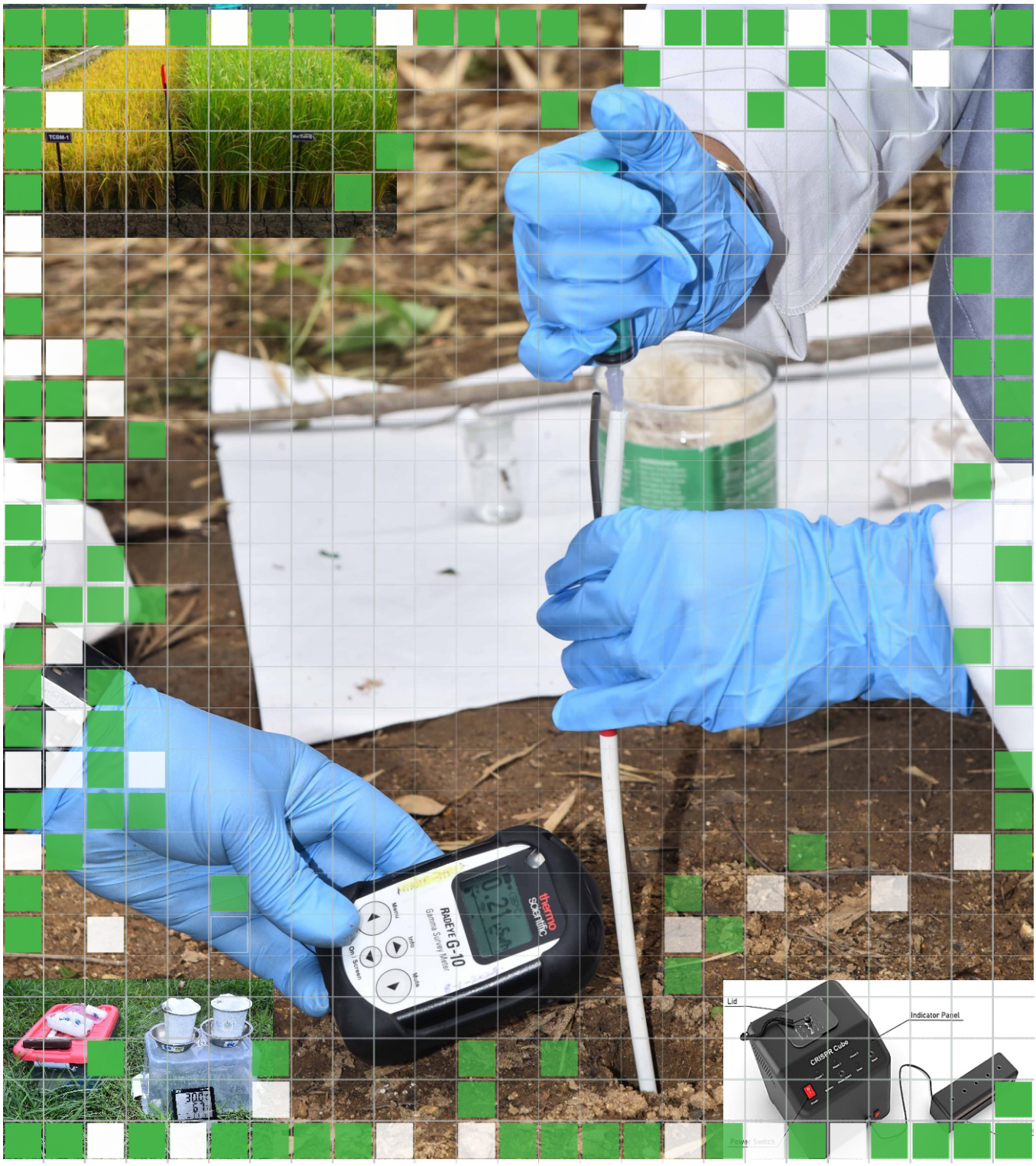


THE SOCIETAL APPLICATIONS

vertical of DAE's Vision Programme entails initiatives that encompass agricultural, medical, environmental, and industrial applications of nuclear science and technology to enhance societal and national capacity. Under Crop Variety Development, efforts are being continued in BARC on radiation-induced mutagenesis and speed breeding to create high-yield, climate-resilient crops, while engineering plant–microbe interactions aims to boost nutrient uptake and reduce chemical fertilizer dependence. In Food Preservation by Irradiation, novel accelerator-based and radionuclide irradiator designs are planned to ensure safe, large-scale preservation of food and to strengthen national food security.

In the activities of Nuclear Medicine and Radioisotope emphasis is placed on indigenous production of diagnostic and therapeutic radiometals for advanced imaging and cancer therapy. In research for Cancer Medicine, clinical studies on chlorophyllin and DSePa continue in BARC. Nanoparticle-based targeted therapies, tumour-on-chip prognosis models, and point-of-care optical devices will aid early detection and therapy optimization.

In Water and Waste Management, BARC advances desalination and purification through hybrid MSF-MED-SWRO plants, membrane technologies, electron beam wastewater treatment, and radiation hygienisation of sludge besides isotope hydrology investigations. These will enable water security, zero-liquid discharge, and clean reuse.

Collectively, these programs aim for self-reliance in food and water security, advanced healthcare, sustainable environment management, and technological leadership in the Amrit Kaal.

Crop Variety Development

Oilseeds: To advance the goal of achieving self-reliance in oilseeds, several new and improved Trombay varieties have been developed and released in crops such as mustard, groundnut, and sesame.

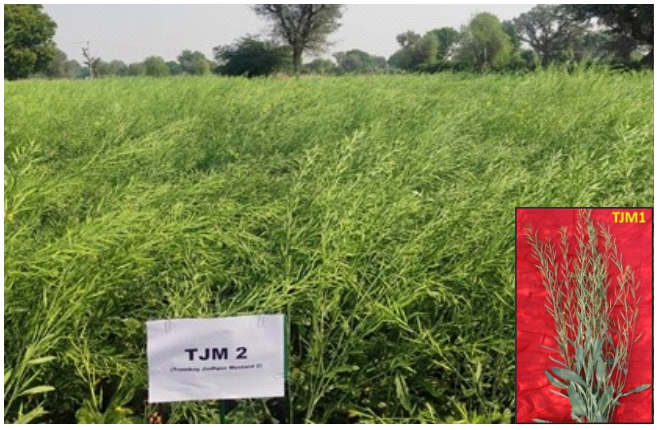
In mustard, two high-yielding varieties have been introduced for irrigated conditions in Rajasthan. The breeding line TM 267-3 was released as Trombay Jodhpur Mustard 2 (TJM 2), offering a yield advantage of 10–14%.

Similarly, the previously developed line TM 108-1 initially bred in Maharashtra demonstrated a 12–13% higher seed yield and was released as Trombay Jodhpur Mustard 1 (TJM 1). TJM 1 is a tall variety with high siliqua density, a maturity period of 112–118 days, and a thousand-seed weight of 3.80 gm. Its brown seeds contain 39.4% oil, comprising 12.6% oleic acid, 19.16% linoleic acid, and 12.29% linolenic acid. The variety has shown field tolerance to aphid infestation and powdery mildew disease. In contrast, TJM 2 is semi-dwarf with constricted pods, 118–128 days to maturity, and a thousand-seed weight of 5.37 gm. Its brown seeds contain 39.0% oil, with 11.68% oleic acid, 18.13% linoleic acid, and 10.26% linolenic acid.

For the first time, BARC has developed a sesame gamma ray mutant, TL 10, released as Trombay Latur Til 10 (TLT-10). This variety is suitable for both rainy and summer cultivation seasons in Maharashtra, and later extended to Telangana. TLT-10 offers 17–24% higher seed yield, 13–16% greater oil yield, and 4–14% more oil content compared to existing varieties. It features bold seeds, medium plant height, 90–95 days maturity, elongated capsules, and moderate resistance to major pests and diseases.

In groundnut, a new mutant derivative, TG 88, has been found suitable for both rainy and summer cultivation seasons due to its 15–20% yield superiority. It has been released as Chhattisgarh Trombay Mungfali (CGTM) for the state of Chhattisgarh. TG 88 is a semi-dwarf variety with 105–110 days maturity, 50–55 gm hundred-seed weight, and a 72% shelling percentage. Nutritionally, it contains 24.5% protein and 49.0% oil, with 48% oleic acid and 33% linoleic acid.

Improved Varieties in Cereals: In rice, a newly developed mutant derivative, BARCKKV 16 has been released as 'Trombay Konkan Khara' for cultivation in coastal saline soils of Maharashtra. This variety exhibits tolerance to soil salinity levels up to 6–7 dS/m and produces about 15% higher grain yield under saline conditions. It is semi-dwarf, non-lodging, and



The plant of TJM1 (Mustard) in the inset; and a field view of Trombay mustard.

matures in 125–130 days. The variety also displays excellent milling and head rice recovery, long slender grains, and resistance to stem borer.

Another gamma-ray-induced mutant derived from the popular soft-cooked rice landrace Luchai of Chhattisgarh has been released as 'Bauna Luchai-CTLM'. This variety retains the soft-cooking quality of its parent line while exhibiting lodging resistance, early maturity, and higher grain yield.

Additionally, a selection from a traditional therapeutic rice landrace of Chhattisgarh has been released as 'Sanjeevani'. Its slender, scented brown grains are noted for immune-boosting and cancer-suppressive properties. The variety possesses intermediate amylose content, while its bran oil contains moderate levels of gamma oryzanol, contributing to its nutritional and health benefits.

In wheat, two high-yielding breeding lines, TAW 153 and TAW 155, have been developed with multiple disease resistance and good chapati-making quality for irrigated, timely sown conditions. TAW 153, which outyields check varieties by 14%, has been released as 'Trombay Jodhpur Wheat 153 (TJW 153)' for cultivation in Rajasthan. It is a medium-tall variety producing amber, semi-hard, bold grains with superior grain quality traits viz., 11% protein content, medium gluten strength, and 39.7 ppm iron. The variety shows resistance to leaf and stem rust, Karnal bunt, loose smut, powdery mildew, and flag smut.

The TAW 155 variety, yielding 11% more grain than the check variety, has been released as 'Trombay Raj Vijay Wheat 155 (TRVW 155)' for cultivation in Madhya Pradesh. It is characterized by medium plant height, lodging resistance, a waxy plant type, and dark green foliage that enhances heat stress tolerance. The variety also possesses medium protein content, medium gluten strength, and elevated levels of iron and zinc. It exhibits broad-spectrum resistance to wheat blast, stripe rust, leaf rust, stem rust, Karnal bunt, loose smut, powdery mildew, and foot rot.

Sorghum Mutant Variety: A novel mutant variety of sorghum has been developed through gamma ray-induced mutagenesis at the Bhabha Atomic Research Centre (BARC). F_1 hybrid seeds were irradiated, leading to the development of a new variety designated as Raichur Trombay Sorghum-43 (RTS-43). This variety is recommended for medium to deep black soils of the transitional zone under rainfed conditions of northern Karnataka.

RTS-43 demonstrates a 9–15% increase in grain and fodder yield, coupled with early maturity, synchronized flowering, a waxy coating on stems and leaves, semi-compact panicles, and bold, straw-colored seeds. The flour produced from RTS-43 yields rotis with superior palatability and consumer acceptability, attributed to its favorable organoleptic, sensory, physical, and functional characteristics. From a nutritional perspective, RTS-43 exhibits enhanced levels of iron, zinc, crude fiber, protein, and fat, making it a nutritionally valuable crop. Additionally, it shows moderate resistance to major diseases such as charcoal rot, blight, and rust.

Improved Trombay Crop Varieties

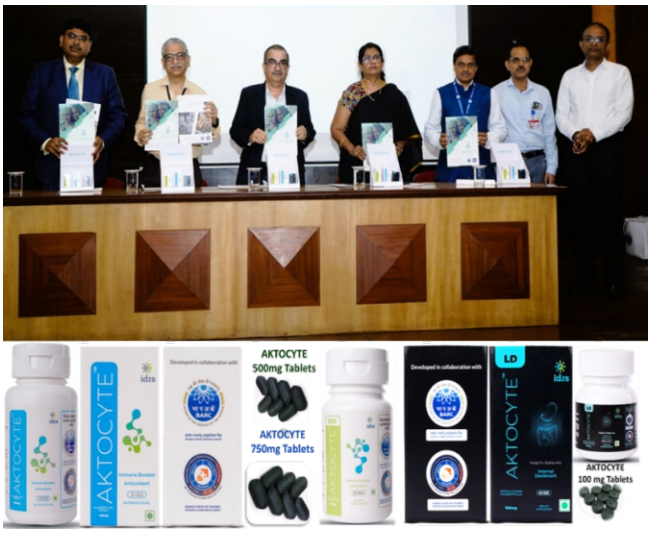
Groundnut 17	Sorghum 3	
Rice 10	Cowpea 2	
Mungbean 9	Soybean 2	Wheat 2
Mustard 9	Banana 1	Sesame 1
Urdbean 8	Linseed 1	Sunflower 1
Pigeonpea 5	Jute 1	

Through a combined approach of radiation-induced mutagenesis and conventional crossbreeding, BARC in a joint collaboration with several crop research organizations within the country, developed 72 improved crop varieties and more are in the offing. These varieties are now widely cultivated across India, substantially contributing to enhanced agricultural productivity, farmer welfare, and national food security.

Food Preservation by Irradiation

New and Tailor-made Irradiators: Food preservation through irradiation is a vital research initiative aimed at strengthening India's national food security. Currently, 28 food irradiation facilities operate across the country: five managed by the government and twenty-three privately-owned. To address the rising demands of the agricultural produce market, five customised irradiator designs are under development. Research is also focused on evaluating Bismuth-207 (Bi-207) as a potential alternative to the commonly used Cobalt-60 (Co-60) and Cesium-137 (Cs-137) sources for food irradiation. Another major goal is to design and develop novel low-energy electron and X-ray systems, up to 300 keV, for surface food treatment.

Efforts are underway to conceptualise and deploy radionuclide-based irradiators tailored for diverse food products. Additionally, innovative product handling systems will be designed, alongside detailed studies on dosimetry and process control to ensure



Release of AKTOCYTE (Chlorophyllin) Oral Tablets.

precise and safe application of irradiation. The production of Bi-207 will be explored using charged-particle bombardment, specifically by irradiating lead (Pb) targets with a high-power 20 MeV proton beam to generate residual activity.

These accelerator-based systems and customised irradiators are expected to significantly enhance India's capacity for safe and effective food preservation. By enabling long-term storage, reducing food wastage, and maintaining nutritional quality, this programme will play a pivotal role in achieving comprehensive national food security.

Research for Cancer Medicine

Radioprotective and Regenerative Action of Chlorophyllin in Cancer Patients: Pelvic radiotherapy often induces hemorrhagic cystitis due to radiation-mediated tissue, vascular, and inflammatory damage. Chlorophyllin (CHL), recognized for its antioxidant, immune-stimulatory, chemoprotective, and radioprotective functions, was evaluated clinically. In a Phase II trial, CHL tablets resolved hematuria in 83.3% of patients with grade II–IV cystitis. Treatment reduced systemic inflammatory indices (NLR, PLR, SII) and cytokines (IL-1α, IL-1β, IP10, IL-6, IL-8, IL-33, MIP-1α, MIP-1β). Proteomics and metabolomics analyses confirmed modulation of complement activation, wound repair, and coagulation pathways. Long-term follow-up showed sustained relief and improved quality of life. CHL tablets (AKTOCYTE) are now available as nutraceuticals approved by the Department of Atomic Energy.

Molecular Prognostic Markers in Neuroendocrine Tumors: Peripheral blood RNA sequencing of **Neuroendocrine Tumors** (NET) patients undergoing 177Lu-DOTATATE therapy identified 30 dysregulated Cancer Hallmark pathways, 14 overlapping with tumor tissue profiles. Elevated activity in heme metabolism (>0.3) and IL2/STAT5 signaling correlated with early disease progression and significantly shortened progression-free survival, conferring a five-fold higher risk.

Somatic Mutation Profiling via cfDNA in Lung Cancer: Ultra-deep sequencing (10,000X) of plasma cfDNA revealed actionable mutations, including EGFR variants, indels, and gene fusions (ALK, ROS1, RET). Parallel studies developed cfDNA extraction from cell-conditioned media to elucidate release and fragmentation biology. These findings validate cfDNA as a non-invasive, clinically informative biomarker for targeted lung cancer therapy.

Nanobody Development for Thyroglobulin Detection: Two human thyroglobulin-specific nanobodies (KT75, KT76) were developed (BARC-RMC collaboration). Crystal structures at 1.3Å and 1.6Å indicated intrachain disulfide bonds conferring high thermal stability. Binding affinities measured by ITC and SPR yielded KD values of 2 nM for KT75 and 10 nM for KT76, underscoring their diagnostic potential for sensitive Tg assays in thyroid cancer.

CRISPR based Diagnostics for Blood Pathogens and Mycobacterium: A single-pot CRISPR-based assay was designed to simultaneously detect HIV, HCV, Treponema spp., and Plasmodium spp. using conserved nucleic acid targets and optimized guide RNAs. Fluorescent visualization under blue light (~520 nm) enables rapid, eye-visible detection. Extended assays for Mycobacterium demonstrated high sensitivity on synthetic targets. The portable CRISPR-CUBE device facilitates on-site testing and visualization, proposing a unified, sensitive alternative to conventional TTI screening in blood banks.

Nuclear Medicine and Related Radioisotopes

Advanced Diagnostic and Therapeutic Patient Services: In alignment with recent innovations in molecular imaging and targeted radionuclide therapy, RMC Mumbai–BARC Hospital has introduced five advanced diagnostic radiopharmaceutical studies over the past two and a half years. These include four 68Ga-labeled PET tracers and one 99mTc-based SPECT agent, complemented by a novel 177Lu-labeled FAPI-2286 therapeutic radiopharmaceutical.

These agents have been successfully integrated into patient care protocols for a wide spectrum of clinical indications, including RAI-refractory thyroid carcinoma, parathyroid adenoma, peripheral vascular disease, head and neck squamous cell carcinoma (SCC), medullary thyroid carcinoma, insulinoma, multiple myeloma, adrenal adenoma, Parkinson's disease and other movement disorders, as well as metastatic manifestations of medullary thyroid, breast, and gastric carcinomas.

Production of Advanced Medical Isotopes: During 2025 so far, around 650 Ci of Lu-177–based radiopharmaceuticals were produced using nearly 45 mg of enriched Lu-176 through efforts in BARC, contributing to the treatment of over 2,600 patients across India. Additionally, for the first time, Ytterbium-168 has been enriched from 0.126% to over 30%, producing around 4 mg of material to support the development and pre-clinical evaluation of Yb-169 based radiopharmaceuticals for the emerging application in nano-scale brachytherapy. Further, Yb-176 was isotopically enriched in-house to 96.8% and used as target to make no-carrier Lu-177. which was then utilized in combination with PSMA-617 and DOTA-TATE at TMH for radionuclide therapy of prostate and neuroendocrine cancers, respectively.

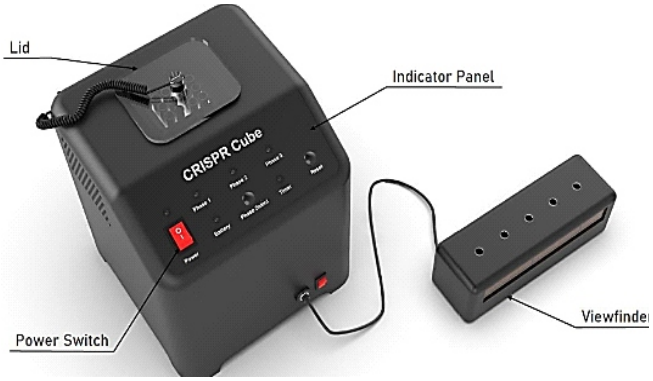
Facilities and Treatment Services at RMRC: The Radiation Medicine Research Centre (RMRC) at Kolkata, is a state-of-the-art Nuclear Medicine facility established under the aegis of BARC. The centre aims to provide affordable, cutting-edge diagnostic and therapeutic nuclear medicine services to patients across the country, particularly in the Eastern and North-Eastern regions of India.

In addition to routine PET-CT services, I-131 therapies for thyroid cancer patients have been conducted regularly since July 2025. MD residents and consultant physicians visit the centre regularly to provide clinical patient care. Furthermore, 177Lu-based treatments have recently commenced for metastatic castration-resistant prostate cancer (mCRPC) patients.

To facilitate seamless integration & data sharing, connectivity work with RMC Mumbai is underway in collaboration with the TMH. It will extend EMR of TMH with RMRC Kolkata, enabling both centres to access & review treatment records in real time.

Water and Waste Management

For effective water resources management, the Isotope Hydrological Program in BARC continued its sustained focus on pan-India isotope investigations to identify groundwater recharge sources, supported by rainwater harvesting measures for improving groundwater sources. In this pursuit, isotope hydrological activities were carried out by roping in several leading governmental and non-governmental agencies in the country and abroad.



Prototype CRISPR-CUBE designed by tech transfer partner based on BARC know-how.

River–Groundwater Interaction Studies: A collaborative study with NOIDA, Uttar Pradesh, examined groundwater recharge dynamics within the Yamuna (YFP) and Hindon (HFP) floodplains. Isotopic analyses indicated that wells between 12 and 30 m bgl receive significant and consistent recharge during both seasons, primarily from rainfall, shallow subsurface flow, and river infiltration. Deeper wells (>30 m bgl) are mainly sustained by older lateral flows. River and rainfall contributions to groundwater in HFP are found to be minimal.

Groundwater Recharge via Defunct Dug Wells: In partnership with WaterAid, isotope hydrological investigations in Gaya (Bihar) and Nuapada (Odisha) revealed that defunct dug wells effectively facilitate rainwater recharge. Stable isotope data ($\delta^{2}H$, $\delta^{18}O$) and End Member Mixing Models estimated rainwater contributions of 39±7% in Nuapada and 32–55% in Gaya. These findings highlight the potential of artificial recharge through abandoned wells for economic & sustainable groundwater management.

Field sampling work by BARC at a recharge well of Nuapada in Odisha.

The Seawater reverse osmosis plant established by BARC at OSCOM in Odisha.

Estimation of Natural Rainwater Infiltration: Under NAQUIM 2.0, a radiotracer (HTO) study in Bengaluru city quantified natural recharge rates across three catchments. Radiotracer injection (50–70 cm depth) before monsoon and tritium activity profiling during post-monsoon yielded recharge estimates of 1.5–13.5%. These results inform quantification of monsoonal recharge critical for aquifer sustainability as well as indicate potential recharge zones for undertaking artificial measures.

Radiation Technology for Remediation & Detection of Water Pollutants: Different functional materials have been synthesized through radiation induced graft polymerization process and employed for remediation and detection of water pollutants (textile dyes and metal ions) in water streams. Radiation Assisted Adsorbent Technology for Textile Effluent Decoloration, developed for removing ionic dyes from cotton textile wastewater, has been successfully scaled up and validated through a 75 KLD industrial plant installed at Jodhpur, Rajasthan. The system was demonstrated to industry representatives from Surat, Chennai, Hapur, and Balotra, along with BARC tech licensees from Ahmedabad and officials from Pollution Control Boards of Gujarat and Rajasthan. The treated, decolored water was fully reused by the host industry. Following a detailed evaluation, RSPCB, Jaipur granted the 'Consent to Establish' for the technology, which has since led to four additional tech licensees.

Textile Effluent Decoloration treatment plant (75KLD) installed at Jodhpur (Top).

Electron Beam accelerator for wastewater treatment(Right).

For trace detection of Chromium(VI), paper-based analytical devices (PADs) offer a low-cost, portable solution. Acid-free PADs (Af-PADs) incorporating diphenylcarbazide (DPC) were developed via gamma radiation–induced grafting of poly(acrylic acid) onto Whatman filter paper, followed by DPC loading. The grafted acidic groups create localized acidity needed for the chromogenic reaction between Cr(VI) and DPC, eliminating the need for external acid addition and enhancing safety and usability in on-site detection.

Desalination (Nuclear) and Membrane Technologies: The Multi-Stage Flash (MSF) distillation plant operated continuously, producing 513.13 million liters of high-quality water with TDS ranging between 5–50 ppm. Of this, 237.86 million liters were supplied to the Madras Atomic Power Station, and the remainder was delivered to the IGCAR/BARC reservoir as potable water. The seawater reverse osmosis (SWRO) plant, employing indigenous membranes, produced 26.78 million liters of potable water for the same reservoir. BARC's 5 MLD seawater reverse osmosis plant at OSCOM, Odisha, achieved stable operation and consistently produced water conforming to IS:10500 standards. Based on its proven reliability, 1.5 MLD of desalinated water is now distributed to Aryapalli and Matikhalo villages under a certified public supply program, inaugurated in August 2025 by the Hon'ble Union Minister. A hollow-fiber ultrafiltration (UF) membrane developed at BARC effectively treats turbid, microbiologically contaminated water, reducing turbidity from >100 NTU to <1 NTU and achieving a 5-log E. coli reduction. The technology, suitable for offline and online systems, has been transferred to two Indian industries. Additionally, a lab-scale Air Gap Membrane Distillation (AGMD) unit using hydrophobic membranes was developed and validated through mathematical modeling. It efficiently recovers distilled water from seawater (50 mS/cm) and concentrated brine (120 mS/cm), demonstrating potential for high-recovery desalination applications where conventional methods are limited.

EB Accelerator for Waste Water Treatment: A 1 MeV, 100 kW Electron Beam (EB) accelerator for wastewater treatment has been tested up to 50 kW. It safely and efficiently reduces chromaticity, COD, and BOD by applying 5–16 kGy radiation to dye effluents. The system pumps effluent from an ETP aeration tank through the beam exit port, circulating until COD ≤ 250 ppm and BOD ≤ 30 ppm, then discharges as a thin water film. Compared to conventional methods, EB enables rapid oxidation of non-biodegradable matter and supports the National Clean Ganga Mission.