# Atomic Energy in India : A Perspective





Government of India
Department of Atomic Energy

*Bhabha Atomic Research Centre, Mumbai crossed an important milestone when the refurbished research reactor CIRUS attained its full power operation of 40 MW (thermal) on November 10, 2004 at 1830 hrs. on the eve of festival of lights, Deepavali. The cost of refurbishment was just about five percent of the cost to build a similar new reactor. Also, a Desalination unit of 30,000 litres per day capacity was integrated with the reactor towards demonstration of utilization of waste heat from nuclear reactors. Supply of radioisotopes from CIRUS will augment the production from DHRUVA reactor to meet the growing requirement of radioisotopes in the country for various industrial, medical and agricultural applications. After refurbishment, CIRUS has now got a new lease of life of at least 15 years and its continued contribution in meeting the societal needs.*

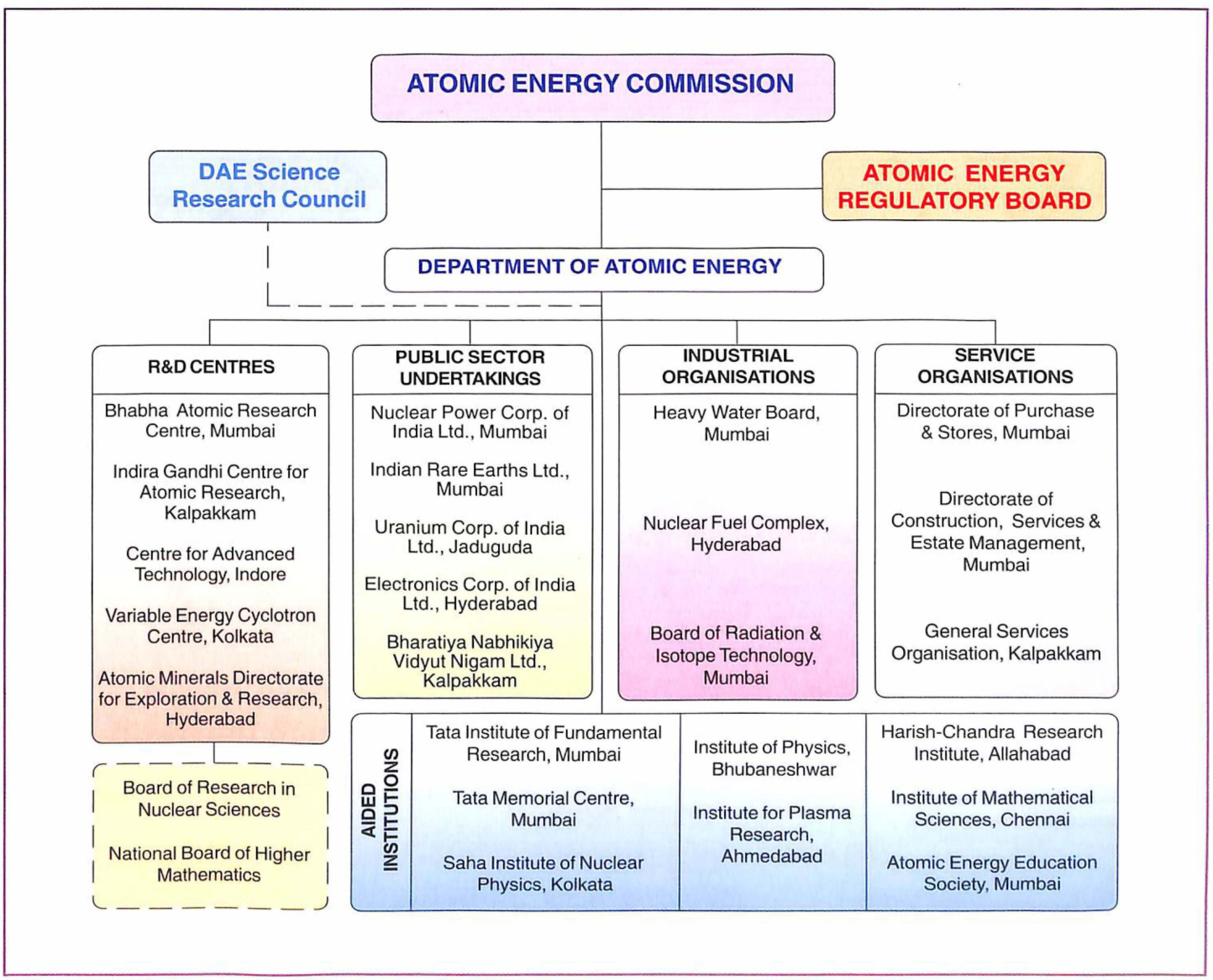
December, 2004

# Introduction

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 research.

An integrated group of organizations, the Department comprises five Research Centres, three Industrial Organisations, five Public Sector Undertakings and three Service Organisations. It has two Boards for promoting and funding extra-mural research in nuclear and allied fields, and mathematics.

It also supports seven 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. The organizational structure of the Department is given below, and broad profile of the its activities is described ahead.



# Atomic Energy Establishments in India

# DAE's Major Programmes

## NUCLEAR POWER PROGRAMME – STAGE I

### Higher Share for Nuclear Power

*Competitive Capacity Addition*
*Sustain and Improve Capacity Utilisation*
*Move towards Financing Capability through Internal Resource Generation*
*Sustained Excellence in Safety Performance*

## NUCLEAR POWER PROGRAMME – STAGE II

### Commercial Demonstration of Fast Breeder Technology

*Early setting up of Prototype Fast Breeder Reactor (PFBR) and associated Fuel Cycle Plants*
*Advanced Fuel Cycle with Higher Breeding Gain*

## NUCLEAR POWER PROGRAMME – STAGE III

### Technology Demonstration for Large Scale Thorium Utilisation

*Advanced Heavy Water Reactor (AHWR)*
*Technology Road Map on Shaping the Third Stage*

## RADIATION TECHNOLOGY APPLICATIONS

### Deployment Over Large Scale

*Desalination of Water*
*Nuclear Agriculture*
*Radiation Processing of Food, Industrial and Medical Products*
*Health Care and other Industrial Applications*

## RESEARCH AND DEVELOPMENT

### Broad based R&D in Nuclear Sciences and Technologies involving scientific groups within DAE and outside including Universities

## RESEARCH EDUCATION LINKAGE

### Mutual strengthening of Education and Research in Nuclear Sciences and Technologies and allied disciplines

# Nuclear Power Programme

DAE has been pursuing a 3-stage Nuclear Power Programme as follows:

- The first stage comprises setting up of pressurised heavy water reactors (PHWRs) and associated fuel cycle facilities.

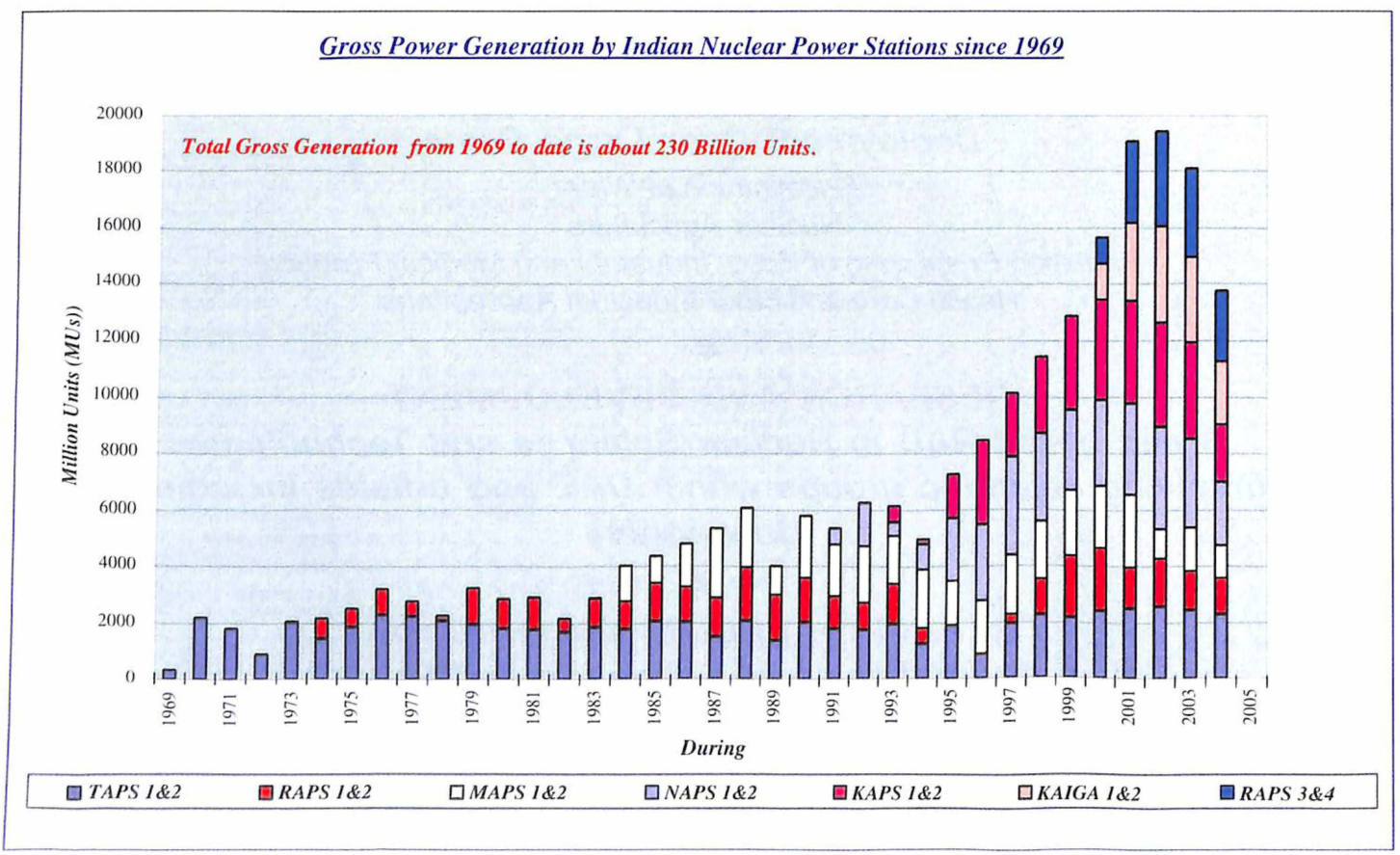
- The second stage envisages setting up of fast breeder reactors (FBRs) backed by reprocessing plants and plutonium-based fuel fabrication plants.

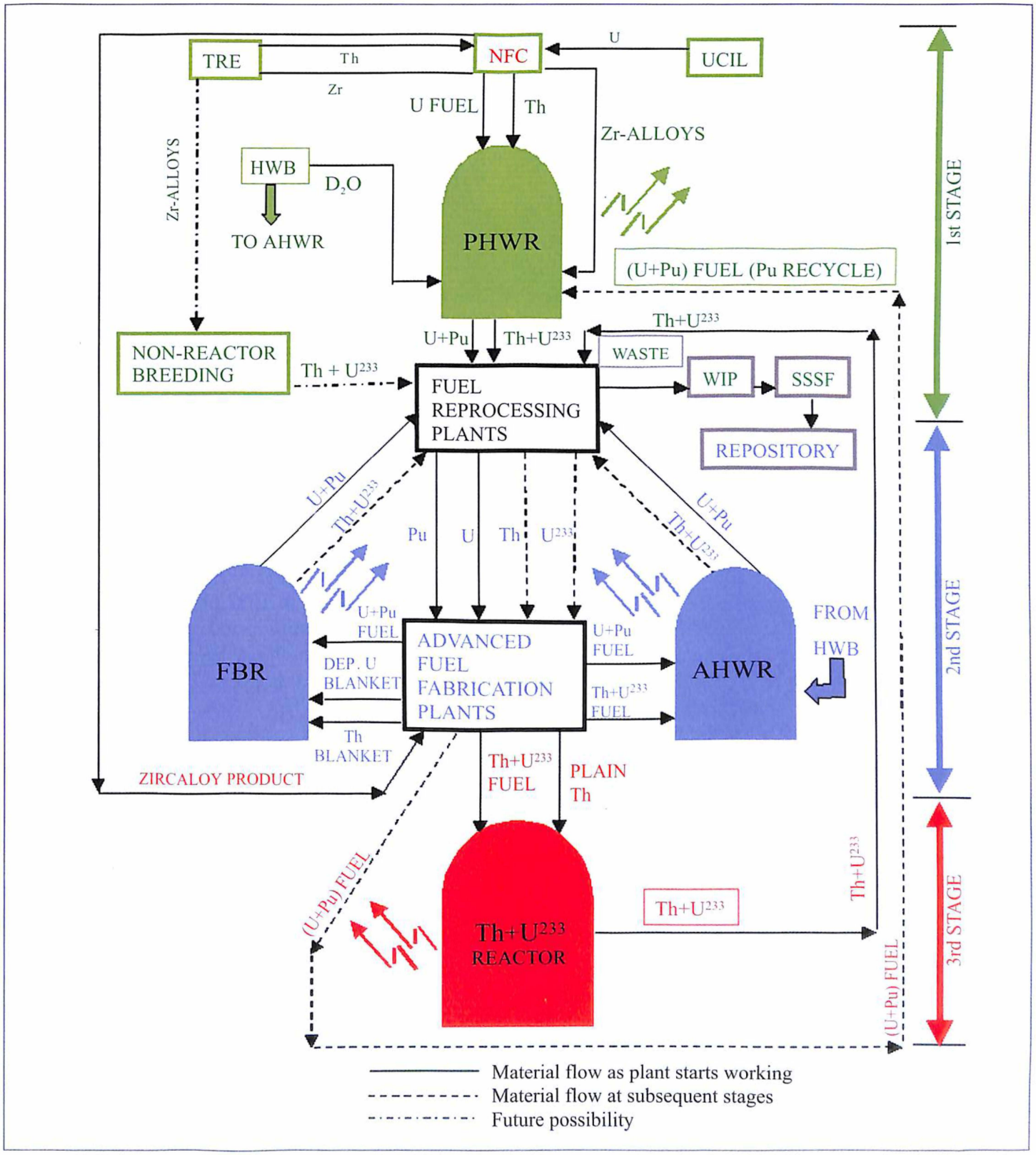
- The third stage will be based on the thorium-uranium-233 cycle. Uranium-233 is obtained by irradiation of thorium.

The Nuclear Power Corporation of India Ltd. (NPCIL), a public sector undertaking of DAE, is responsible for the design, construction and operation of nuclear power reactors. The NPCIL operates 14 reactors (2 Boiling Water Reactors and 12 Pressurised Heavy Water Reactors) with a total capacity of 2770 MWe. It is constructing six PHWRs and two light water reactors, that will add 3960 MWe to the power generating capacity.

To meet the growing demand for electricity, the Indira Gandhi Centre for Atomic Research (IGCAR) is engaged in the design and development of liquid sodium cooled fast breeder reactors. This centre has successfully developed the FBR technology and completed design of a 500 MWe Prototype Fast Breeder Reactor (PFBR). A new company BHAVINI has been formed for implementing the project. This company relies on IGCAR for expertise in technology, and on NPCIL for expertise in project management.

The ongoing development of 300 MWe Advanced Heavy Water Reactor (AHWR) at BARC aims at developing expertise for thorium utilization and demonstrating advanced safety concepts. Thorium based systems such as AHWR will be set up on commercial scale only after a large capacity, based on fast breeder reactors, has been built up.






*3 Stages of the Indian Nuclear Power Programme*

# NUCLEAR POWER PROGRAMME : STAGE-I

## PRESSURISED HEAVY WATER REACTORS

The Indian Nuclear Power Programme took off in the sixties. PHWR was the reactor of choice for the first stage of the programme, however, to gain operational experience, initially an atomic power station consisting of two boiling water reactors (BWR), was set up at Tarapur, Maharashtra, as a collaborative venture with the General Electric of USA. The station, commissioned in 1969, is still in operation.

The first two PHWRs, built at Rawatbhata, Rajasthan (partly with the Canadian collaboration), had commenced commercial production in 1972 and 1980. Subsequently, the R&D endeavour of DAE orgnisations, with the support of the Indian industry, led to the indigenisation of PHWR which was marked with the successful commissioning of two 220 MWe reactors at Kalpakkam near Chennai, Tamil Nadu in the years 1984 and 1986. Later, the design of the 220 MWe PHWR was standardized and two reactors of this design were commissioned at Narora, Uttar Pradesh in 1989 and 1991. The design standardisation has markedly reduced gestation period of new reactors.

The indigenous technology of PHWR reached commercial maturity with the commissioning of two 220MWe PHWRs at Kakrapar in 1992 and 1995. In the years 1999 and 2000, two state-of-the-art 220MWe PHWRs came online, each at Kaiga (Karnataka) and Rawatbhata (Rajasthan).

The growing experience of NPCIL in nuclear technology, has resulted in improving performance of its nuclear power plants.

The electricity generation has risen from 3000 million units in the year 1981-82 to 17,861 million units for the year 2003-04.

### *New Projects*

A total capacity of 4460 megawatt is under construction. It comprises two 540 MWe pressurized heavy water reactor at Tarapur (TAPP-3&4), two 220 MWe pressurised water reactors each at Rawatbhata (RAPP-5&6) and Kaiga (Kaiga-3&4), and one 500 MWe prototype fast breeder reactor (PFBR) at Kalpakkam.

To provide a parallel stream for faster growth of nuclear power, India had entered into an agreement with the Russian Federation for setting up an atomic power station comprising two pressurised water reactors of 1000 MWe capacity each, at Kudankulam (Tamil Nadu). Construction of these reactors had begun on March 31, 2002.

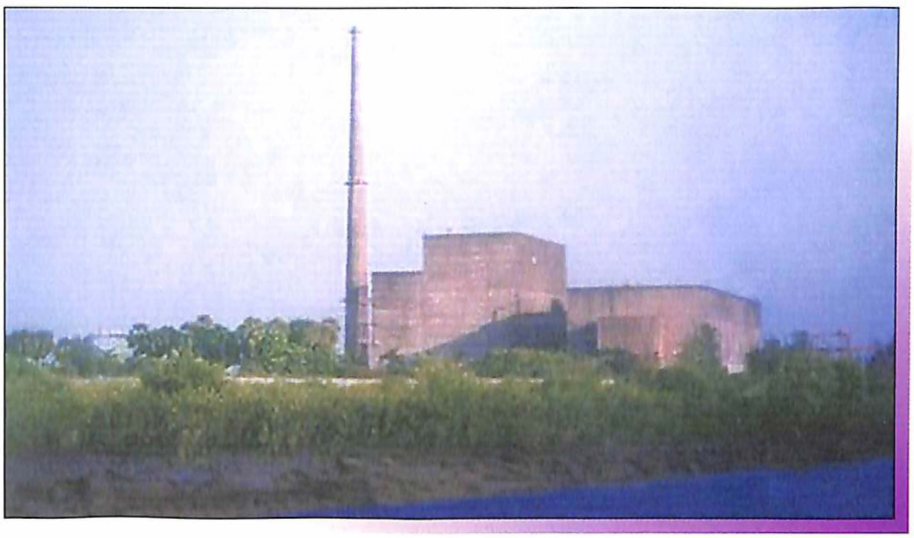
DAE has an ambitious nuclear power programme aiming at achieving an installed nuclear power capacity of 20,000 MWe by the year 2020.

## NUCLEAR FUEL CYCLE

The Stage-1 of the Nuclear Power Programme has a number of ancillary operations which form Nuclear Fuel Cycle. The Front-End of the Cycle includes mineral exploration, mining and processing of ore, and fabrication of fuel. The Back-End of the Cycle covers reprocessing of spent uranium fuel, and management of nuclear waste.

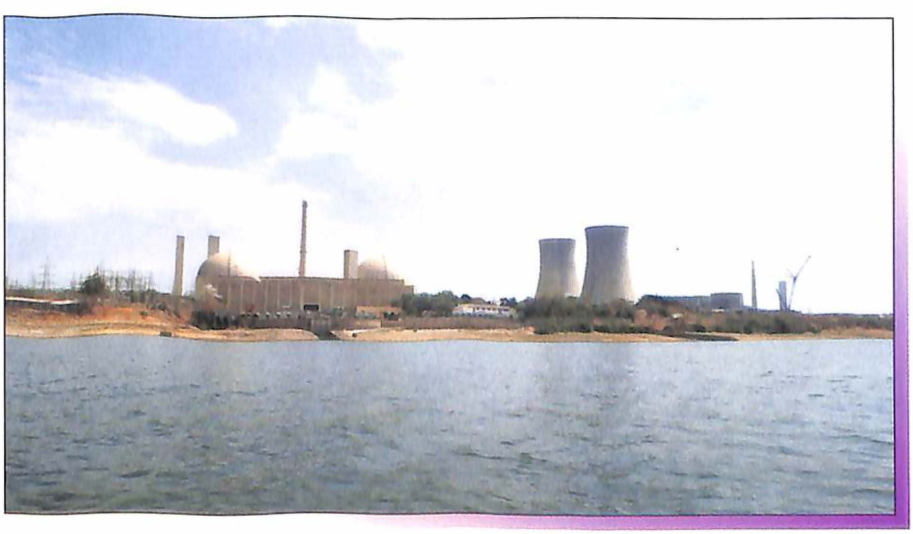
India has acquired comprehensive capability in the PHWR design, construction and operation of associated plants/facilities covering the entire nuclear fuel cycle of the nuclear power programme based on pressurized heavy water reactors. Since heavy water is used as moderator and coolant in PHWRs, its production is also an important ancillary operation associated with Nuclear Fuel Cycle.

The DAE organizations contributing to the Front-End of the Nuclear Fuel Cycle Programme are the Atomic Minerals Directorate for Research and Exploration (AMD), Hyderabad, Uranium Corporation of India Ltd. (UCIL), Jaduguda (Jharkhand), Nuclear Fuel Complex (NFC), Hyderabad, and Heavy Water Board (HWB)-Mumbai. BARC and IGCAR administer the Back End of the Cycle.



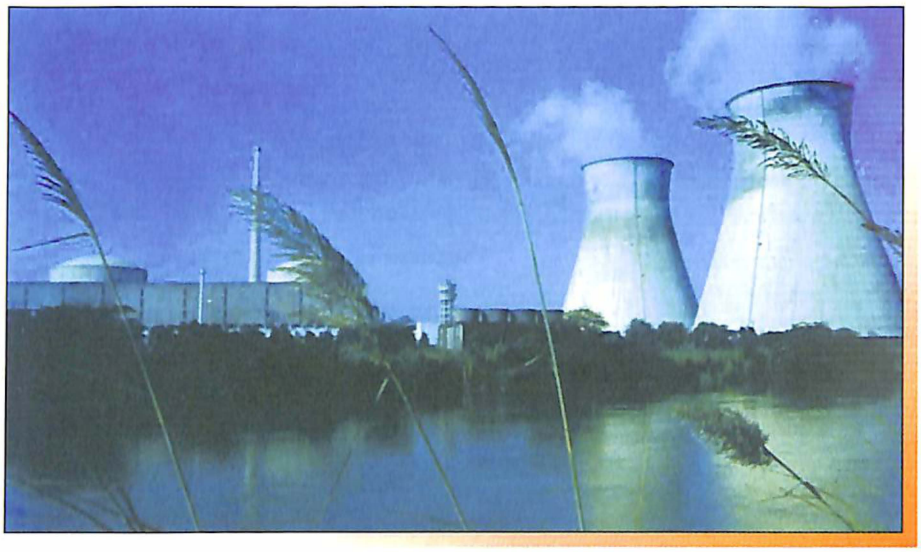
*Tarapur atomic power station*

*Madras atomic power station*

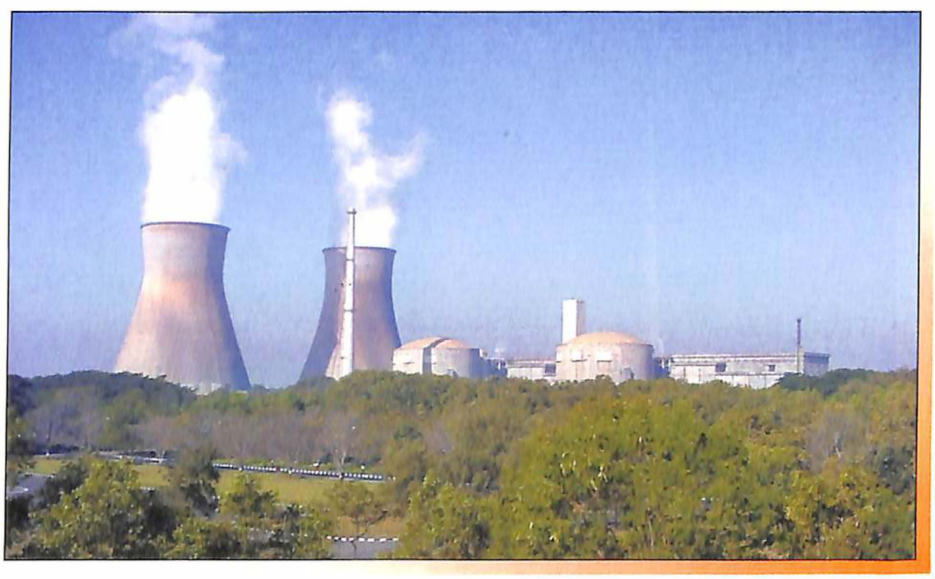


*Rajasthan atomic power station*

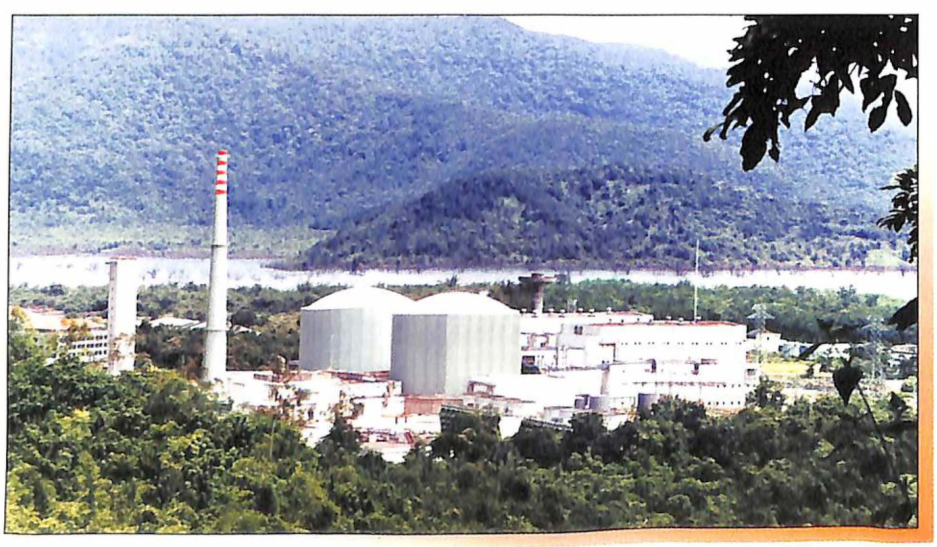
# Operating reactors



*Narora atomic power station*



*Kakrapar atomic power station*



*Kaiga generating station*

*Tarapur atomic power project 3&4*

*Kaiga atomic power project 3&4*

# Reactors under construction

*Rajasthan atomic power project 5&6*

*Kudankulam atomic power project*

*Prototype fast breeder reactor*

## Front End of Fuel Cycle

### Heavy Water Production

Heavy Water is used as moderator and coolant in PHWR. The Heavy Water Board (HWB) of DAE is responsible for building and operating heavy water plants in the country. The Board has set up 7 heavy water plants in the country. The performance and safety record of all the operating Heavy Water Plants (HWPs) has been excellent. Besides meeting domestic needs of heavywater, the Board has exported heavy water.

The Board is engaged in its energy conservation programme to further reduce specific energy consumption per kilogramme of heavy water produced. Recognizing the efforts put in by the Board in the field of energy conservation and energy management, the Bureau of Energy Efficiency of the Ministry of Power, assigned to the Board a lead role to carry out energy management and conservation for fertilizer, petroleum & chlor alkali sector industries to achieve the national goal of energy conservation.

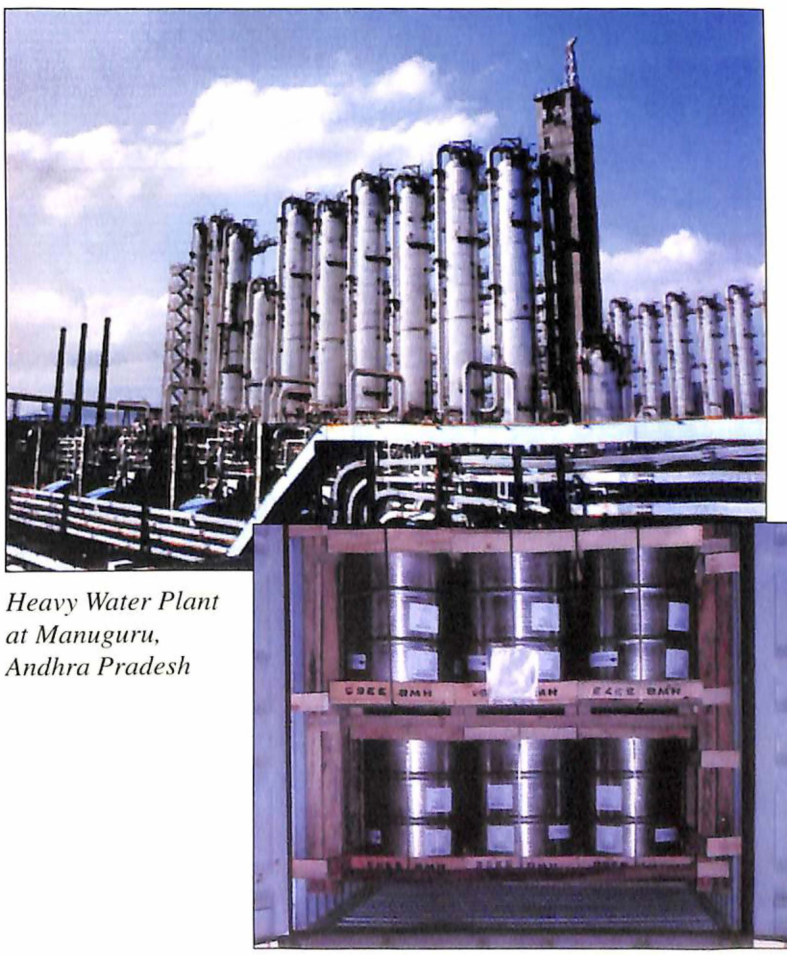
*Heavy Water Upgrading*

For upgrading the degraded heavy water from research reactors, a heavy water upgrading facility was set up at Trombay in 1962. Through continuing research, BARC has developed heavy water upgrading technology for use on commercial scale. The technology employs indigenously developed tower internals in vacuum distillation columns. Based on this technology, at present 23 upgrading final enrichment towers are in operation at various sites and many more are under construction.

### Survey and Exploration

The Atomic Minerals Directorate for Exploration and Research (AMD) is engaged in survey, exploration and evaluation of resources of uranium, thorium, niobium, tantalum, beryllium, zirconium, lithium, yttrium, and rare earth elements required for the indigenous atomic energy programme, and geological studies related to the selection of nuclear power

*Tri-Butyl Phosphate (TBP) facility at Talcher, Orissa*



*Heavy Water Plant at Manuguru, Andhra Pradesh*

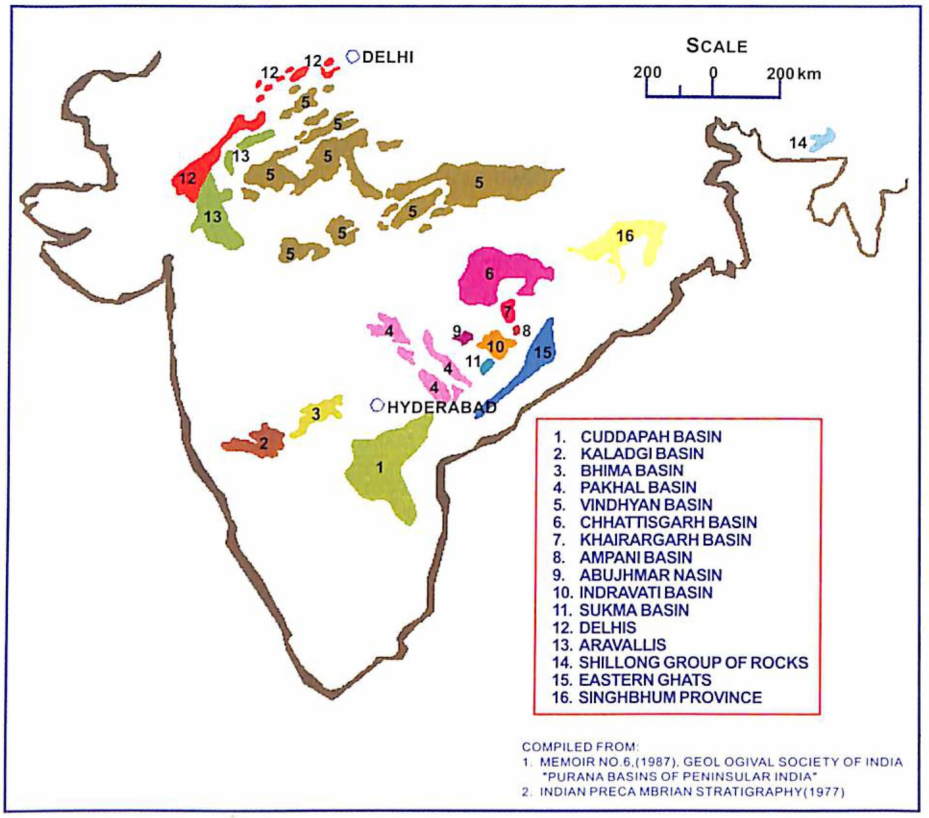
*Heavy Water being shipped to the Korea Electric Power Corporation (KEPCO).*

plant sites and repositories for the disposal of nuclear wastes.

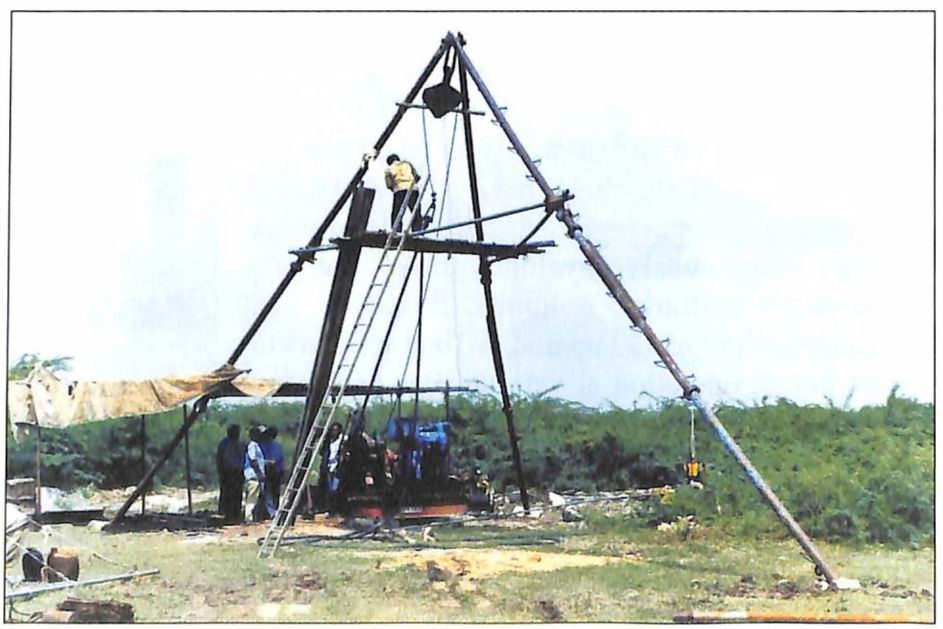
Survey and exploration activities had commenced in 1949. Over the years, uranium deposits have been located at Jaduguda, Bhatin, Narwapahar, Turamdih (East and South), Banduhurang (Turamdih West), Central Keruadungri, Bagjata, Kanyaluka, Mohuldih, and Nandup in Jharkhand; Domiasiat and Wahkyn in Meghalaya; Lambapur-Peddagattu, Koppunuru and Tummalapalle in Andhra Pradesh; Gogi in Karnataka, and Rohil in Rajasthan.

The Proterozoic basins, the prime targets for high-grade unconformity-related uranium deposits currently under exploration, include Cuddapah basin in Andhra Pradesh; Delhi basin (fold belt) in Rajasthan, Bhima basin in Karnataka, Chhattisgarh basin in Chhattisgarh, Gwalior basin in Madhya Pradesh and Kunjar basin in Orissa. The Mesozoic and Tertiary basins, which are the targets for large tonnage sandstone type of uranium deposits under active exploration, are Mesozoic basin in Meghalaya and Tertiary Pre-Siwalik basin in Himachal Pradesh.

Columbite-tantalite (niobium-tantalum), lepidolite and spodumene (lithium), and beryl (beryllium) are recovered from the alluvial soils derived from the potential pegmatites identified in Andhra Pradesh, Rajasthan, Bihar, Orissa and Chhattisgarh through field recovery units and are stockpiled.




*Potential high grade uranium targets in Proterozoic basins of India*



*Drilling operations for exploration of minerals*

AMD has also established a number of beach sand deposits, containing ilmenite, rutile and leucoxene (titanium), sillimanite, garnet and monazite (thorium and some rare earth elements) along the East and West Coasts in parts of Orissa, Andhra Pradesh,

## Physical Attributes of Achievements (1950-2002)

**URANIUM INVESTIGATIONS**

- 4.75 lakh sq km ( Rec.Survey)
- 5.53 lakh sq km ( AGRS Survey)
- 9500 sq km ( (Detailed survey)
- 1.92 lakh sq km ( Geochem. Survey)
- 2590 sq km ( Geophy. Survey)
- 1030 km (Dept. drill)
- 240 km (Contract drill)

**BEACH SAND INVESTIGATIONS**

- 2600 sq km ( Survey)

**RMRE INVESTIGATIONS**

- 22,200 sq km (Survey)
- 3177 tonnes ( Lepidolite)
- 4196 tonnes ( Beryl)
- 114 tonnes ( Nb-Ta)

Tamil Nadu, Kerala, and Maharashtra as well as in the inland Teri sand of Tamil Nadu and riverine placers of Bihar and West Bengal. New areas of heavy mineral concentration have been located in parts of Thiruvananthapuram and Kollam districts of Kerala, West Godavari and Krishna districts of Andhra Pradesh and Puri district of Orissa.

AMD also issues the monazite test certificate to the exporters of beach sands minerals, which is mandatory for exporting the mineral consignments, as they are associated with monazite, a prescribed substance defined under the Atomic Energy Act.

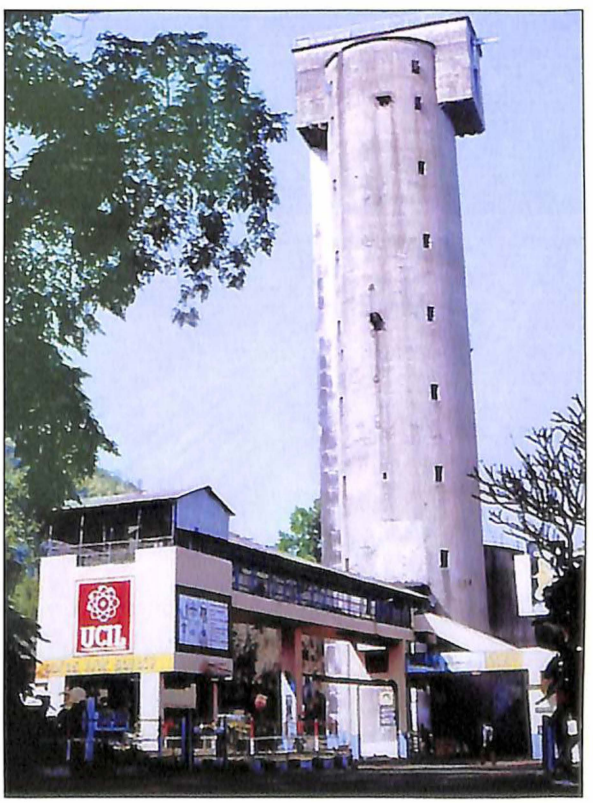
### Mining and Ore Processing

The exploratory efforts of AMD have led to the opening of uranium mines at Jaduguda, Bhatin and Narwapahar, all in Singbhum (East), Jharkhand state. These mines, being operated by the Uranium Corporation of India Ltd. (UCIL), have been meeting the needs of the Indian Nuclear Power Programme. A new mine has been commissioned at Turamdih in Singbhum during the year 2003.

To meet the projected demand of the nuclear power programme, UCIL has taken up the pre-project activities to develop mines at Banduhurang and Bagjata (both in Jharkhand), Lambapur (Andhra Pradesh) and Domiasiat (Meghalaya). DAE is also working to exploit other secondary resources.

UCIL operates a Uranium Mill for processing of uranium ores to produce uranium concentrates, known as yellow cake, which is further sent to NFC for fuel fabrication. In addition, magnetite present in the uranium ore is recovered as a by-product in the uranium process plant.

The research and development in the field of ore processing is done at Trombay.



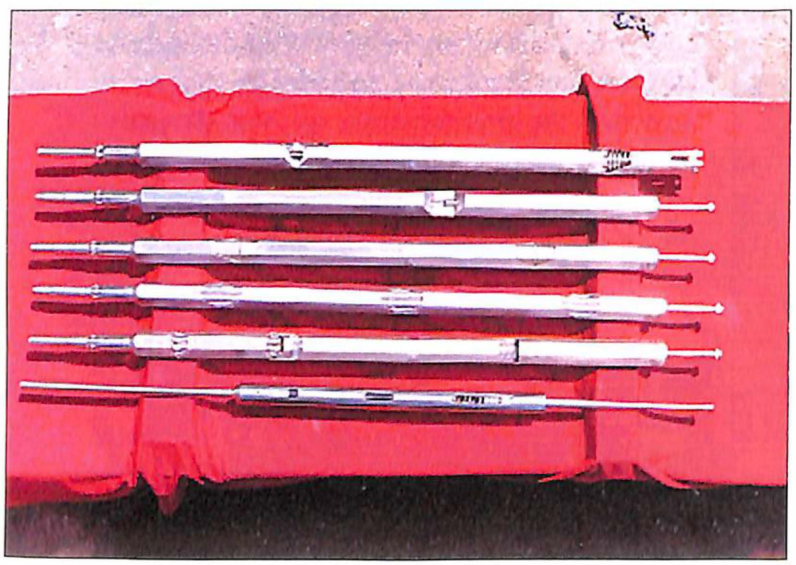

*Uranium Mine at Jaduguda, Jharkhand*

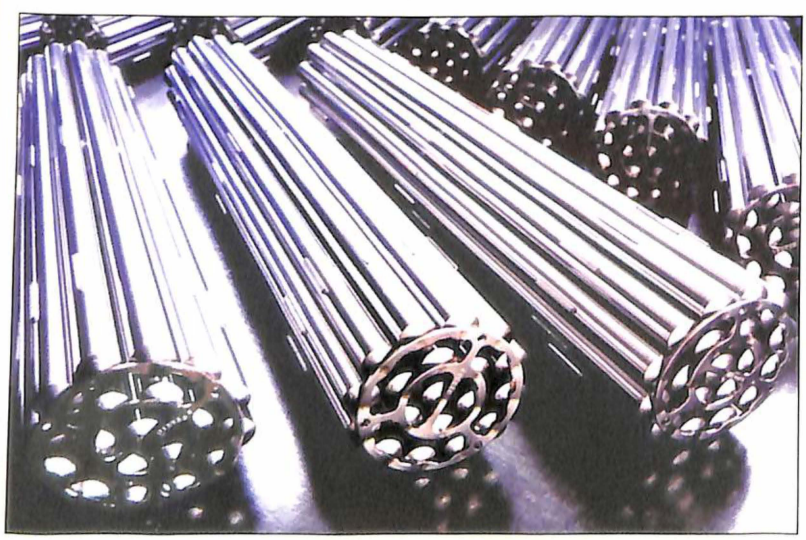
### Nuclear Fuel Fabrication

Nuclear fuel fabrication for power reactors and research reactors is done respectively at the Nuclear Fuel Complex, Hyderabad, and BARC. In the development of new fuels, BARC and IGCAR are engaged.

The Indian PHWR uses natural uranium based fuel. The indigenous effort of conversion of yellow cake to fuel grade uranium and fabrication of fuel elements for power reactors, had achieved a major milestone, with the fabrication of the first fuel element at Trombay in 1959.

For industrial scale manufacture of nuclear fuel assemblies and zircaloy structural components for power reactors, the Nuclear Fuel Complex (NFC) was set up at Hyderabad in 1971. NFC, now an ISO 9001 organisation, is responsible for manufacturing zircaloy-4 clad natural and depleted uranium oxide and thoria bundles for pressurised heavy water reactors, zircaloy-2 clad enriched uranium oxide fuels for boiling water reactors and stainless steel clad thoria and depleted uranium oxide blanket sub-assemblies for liquid metal-cooled fast breeder reactor. NFC also manufactures zirconium alloy structural components for the above reactors. In addition, NFC produces seamless stainless tubes hexcans and other structurals for fast reactor core assemblies and special alloy tubes. It also caters to the demand of high quality stainless steel tubes and pipes for critical and strategic applications in nuclear power plants and re-processing plants in atomic energy.





*FBTR Fuel Subassemblies with cut sections, and PHWR fuel assemblies manufactured at Nuclear Fuel Complex*

Recently NFC has successfully initiated fabrication campaign of 37 element fuel bundles for the forthcoming 540 MWe PHWR unit at Tarapur (Tarapur-4).

The plants of NFC have been meeting their annual production targets consecutively for the last six years and some of the plants have even crossed their plant capacities.

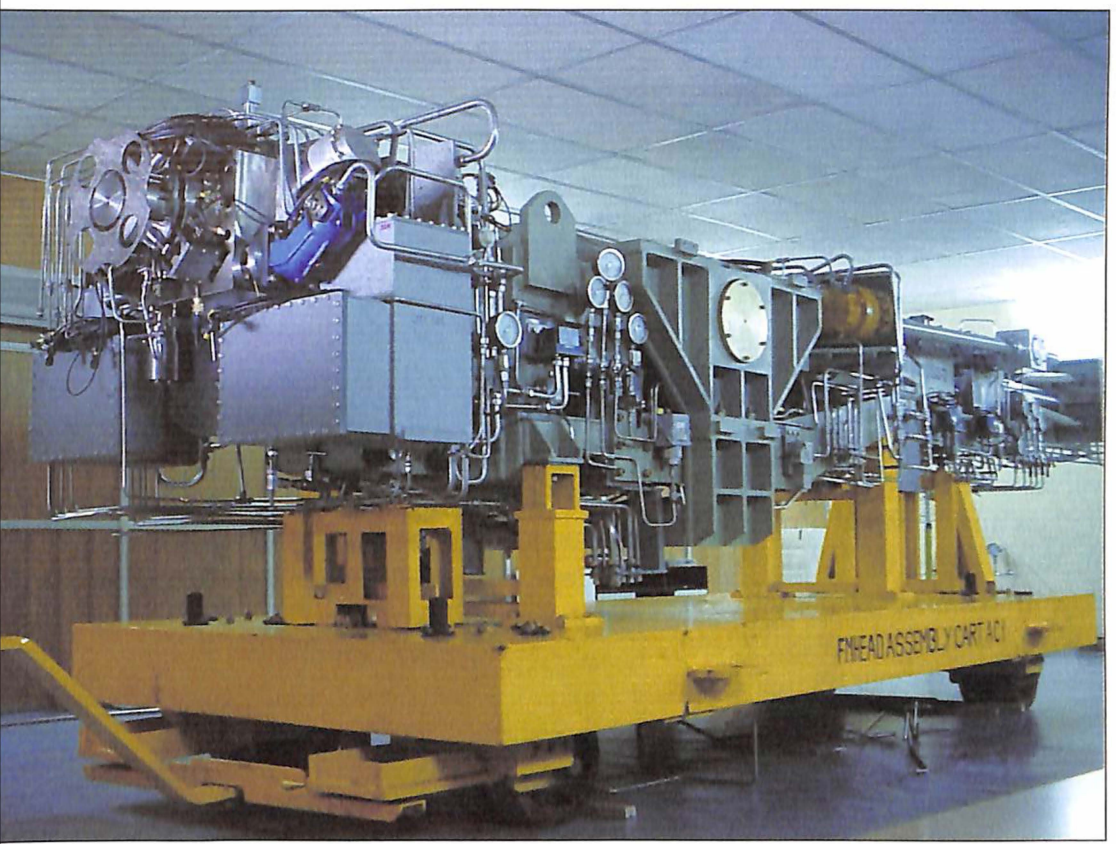
At BARC a wide variety of fuels have been developed and fabricated on industrial scale. For fabrication of indigenous mixed oxide (MOX) fuel assemblies for boiling water reactors at TAPS, the Advanced Fuel Fabrication Facility (AFFF) was set up by BARC at Tarapur. The MOX fuel produced here has given satisfactory performance.

## Back-End of Nuclear Fuel Cycle

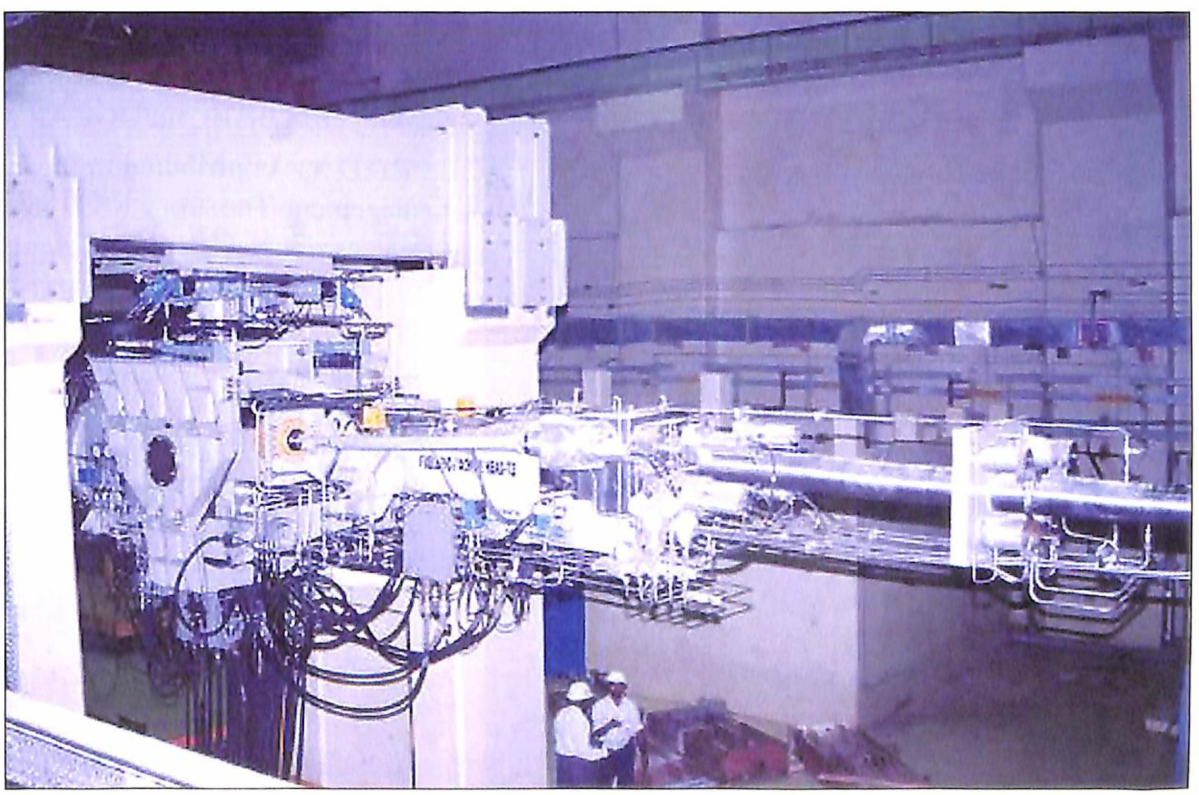
### Fuel Reprocessing

The Indian nuclear power generation programme is based on a closed-cycle approach that involves reprocessing of spent fuel and recycle of Plutonium and Uranium-233 for power generation.

Development of fuel reprocessing technology had commenced from the inception of DAE's nuclear power programme. Now it has a Pilot Plant for fuel reprocessing at Trombay and industrial scale plants at




*Fuelling machine head assembly*



*Fuelling machine head testing in progress*

Tarapur and Kalpakkam. The plant at Trombay processes spent fuel from research reactors while the other two plants process spent fuel from power reactors.

## Nuclear Waste Management

The radioactive wastes generated at various stages of nuclear fuel cycle are catagorised as low, intermediate and high level wastes. The plants for management of all types of radioactive wastes have been in operation at many nuclear facilities. The low and medium level liquid radioactive wastes are treated in eco-friendly ways using various processes.

The high level wastes, that are generated in very small quantities, are fixed in glass matrix using vitrification technology. Based on this technology, two Waste Immobilisation Plants (WIPs) have been operating at Tarapur and Trombay. BARC is constructing an Advanced Vitrification System at Tarapur for high level waste immobilisation based on Joule Melter Technology.

*Pouring of molten glass from cold crucible into canister*

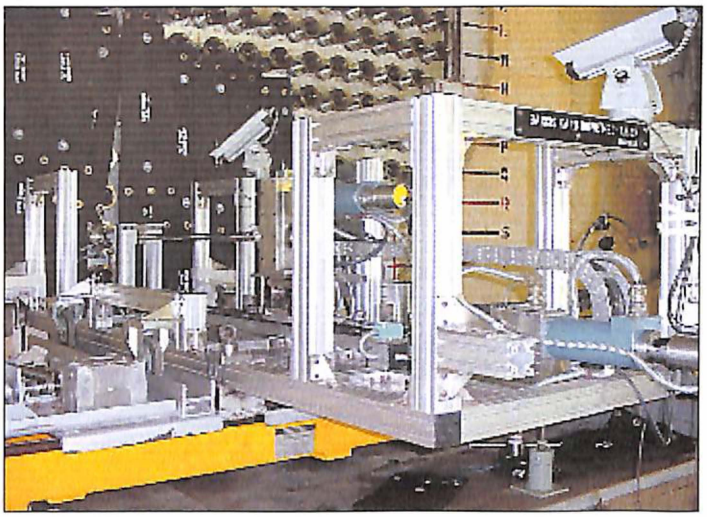
Vitrified waste is stored in a specially designed solid storage surveillance facility for about 30 years prior to its disposal in deep geological formation. The first such storage facility has been in operation at Tarapur since 1999. For final disposal of immobilised high-level radioactive wastes, a programme of siting a repository in suitable deep geological formations is being pursued.

## R&D Support to Nuclear Power

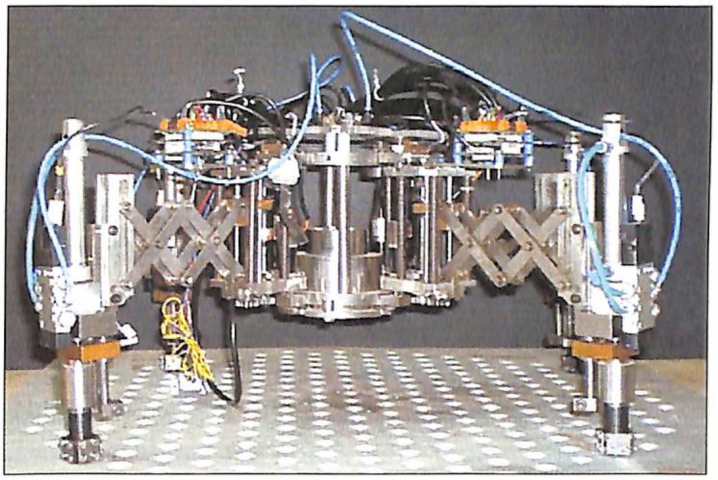
The research & development relating to PHWR programme encompasses practically all the aspects of design, manufacture, construction, commissioning, operation and maintenance of power plants. Thrust on indigenisation of equipment and components has led to the development of technologies for operation and maintenance of power reactors. The technologies that emerged from the research and development include automation, monitoring, inspection, and repair systems, equipment and gadgets. Special Purpose Machines have been designed, developed and successfully used for carrying out in-situ precision machining and cutting operations for the upgradation/maintenance of reactors. A number of state-of-the-art instrumentation and control systems for reactors and heavy water plants have been developed at BARC and IGCAR.

R&D has contributed immensely to the plant life management. The strong R&D base has led to a number of successes notably repair of overpressure relief device of RAPS-1, En-masse removal and replacement of coolant channels of RAPS-2; Management of Calandria inlet manifold, End-shield repair; Steam generator hair-pin removal, Development of BARCIS system for in-service inspection of coolant channels, and System to relocate garter springs in coolant channels. A number of new technologies, such as servo-manipulators, image processing based alignment system, and others have been developed. From KAPS-2 onwards, improved coolant channel material and modified channel design have been adopted for longer life of coolant channels.

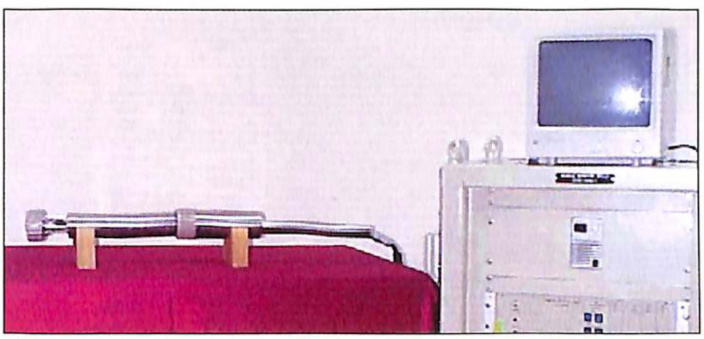
Robotics is one of the major thrust area of R&D programme both at BARC and IGCAR. The Bilateral Master Slave Servo Manipulators, manufactured under



*Automated BARC Channel Inspection System (BARCIS) developed for in-service inspection of coolant channels in PHWRs*



*High-tech four-legged walking robot with its on-board controller on a mock-up tube sheet for inspection of critical nuclear components*



*Miniature underwater radiation resistant closed circuit television (CCTV) Camera developed at BARC, for remote inspection of coolant channels of PHWRs*

*Remotely Operated Hydraulic Trolley with Manipulator developed at BARC*

collaboration between BARC and HMT, Bangalore, have undergone field trials. A five-degree-of-freedom Robot for deployment in radioactive chemical laboratories, a six-degree-of-freedom Robot and a mobile Robot have been developed at Trombay. At IGCAR, for automation of nondestructive evaluation, various devices have been developed. These include a Mobile Scanner (MOBSCAN), a Remotely Operated Power Manipulator (ROPMAN), and a Robot for capping and decapping bottles.

Various tools and equipment developed by BARC helped in improving the safe operating life of coolant channels from seven to more than nine effective full power years.

The 2 MW in-pile loop in Dhruva Reactor installed for nuclear fuel studies is a major stride. A remotely Operated Hydraulic Trolley & Manipulator (ROHYTAM) developed for handling of nuclear power plant emergencies, successfully completed its test run. To meet the stringent quality needs of the nuclear programme, several nondestructive testing techniques and equipment have been developed by BARC and IGCAR.

DAE has been promoting technology relating to quality assurance. Over a period, this approach has paid dividends to the nation by upgrading quality levels of the Indian industry.

## Electronics & Instrumentation

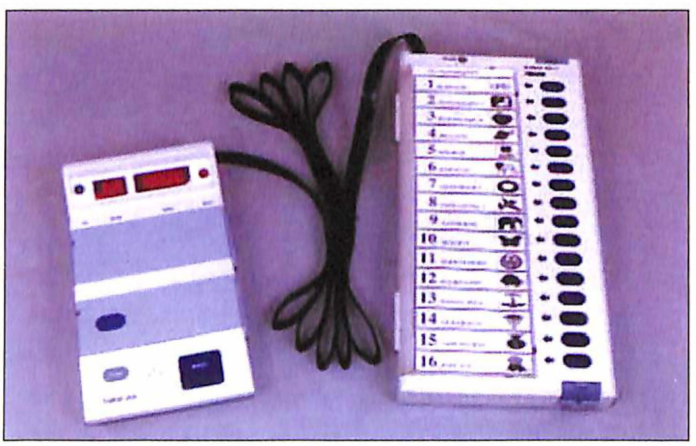
To meet the hi-tech instrumentation needs of the nuclear technology, a strong R&D base was created in electronics and instrumentation, first at TIFR and later at BARC. The knowhow and the products developed at Trombay in the area of electronics had led to the setting of the Electronics Corporation of India Ltd. (ECIL) at Hyderabad in 1967. The company pioneered the electronics and computer revolution in India. During seventies and eighties, ECIL had led the television revolution in the country by bringing out indigenous black & white and colour television sets and also rural rebroadcast systems.

ECIL is now a multi-product and multi-disciplinary organisation providing key technology inputs, system integration and system solutions in the areas of information technology, strategic electronics, communications, control and automation, instrumentation and components.

ECIL, through its software expertise, has contributed to automation in the banking sector, control room and dial-100 automation for the police, message switching systems for defence and telecom sectors, management information systems for the ports, municipal corporations and market yards and others. The company has provided countrywide SPC telex networks, message switching networks and maintenance systems for telephone exchanges, and contributed to the technology solutions, in the areas of command, control, communications, computers & information/intelligence systems. Nuclear and thermal power plants, steel plants and process industries are equipped with ECIL's control systems developed through in-house R&D.

The DAE research centres are engaged in the development of sophisticated electronic systems, instruments and components for nuclear power programme and various other applications.

*Data Acquisition System for One-Fourth Reactor Assembly Model*



*Electronic Voting Machine developed by Electronics Corporation of India Ltd.*

## FAST REACTOR PROGRAMME

The second stage of nuclear power generation envisages setting up of fast breeder reactors (FBRs) backed by reprocessing plants and plutonium-based fuel fabrication plants. These fast breeder systems produce more fuel than what they consume. FBRs can increase fuel utilisation by about sixty times of what is possible with PHWRs. Thus FBRs generate electricity and build up fuel inventory. They match our needs as multiplication of fissile inventory is needed to establish a large power generation with thorium in the third stage of DAE's programme.

The Indira Gandhi Centre for Atomic Research (IGCAR) of DAE, had started breeder programme with the setting of a Fast Breeder Test Reactor (FBTR) at Kalpakkam in October 1985. This reactor, operating with indigenously developed mixed uranium-plutonium carbide fuel has achieved its technology objectives.

The eleventh irradiation campaign with 38 plutonium-uranium carbide fuel sub-assemblies was completed in December 2003. The reactor operated at a power level of 17.4 MWt and the turbo-generator was connected to the grid, feeding 1.8 million units of electricity. The fuel has reached a burn up of 1,23,000 megawatt day per tonne (MWd/t), that is more than four times the originally designed value.

Based on the experience gained with this reactor and with active cooperation of academia and industry, IGCAR has completed detailed design and technology development of the 500 MWe Prototype Fast Breeder Reactor. The Cabinet Committee on Economic Affairs, Government of India, has accorded its administrative approval and financial sanction in September 2003, for the construction of PFBR, after various statutory clearances. A new company Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) was formed in October 2003 for taking up the construction activities of PFBR. Site excavation for the PFBR project has been completed and constructions of the reactor has been launched on 23 October, 2004.

The thrust of the R&D programme at IGCAR is oriented towards the design validation of PFBR, and subsequently, the design optimisation for future FBRs, to reduce the cost.

### Fast Reactor Fuel Fabrication

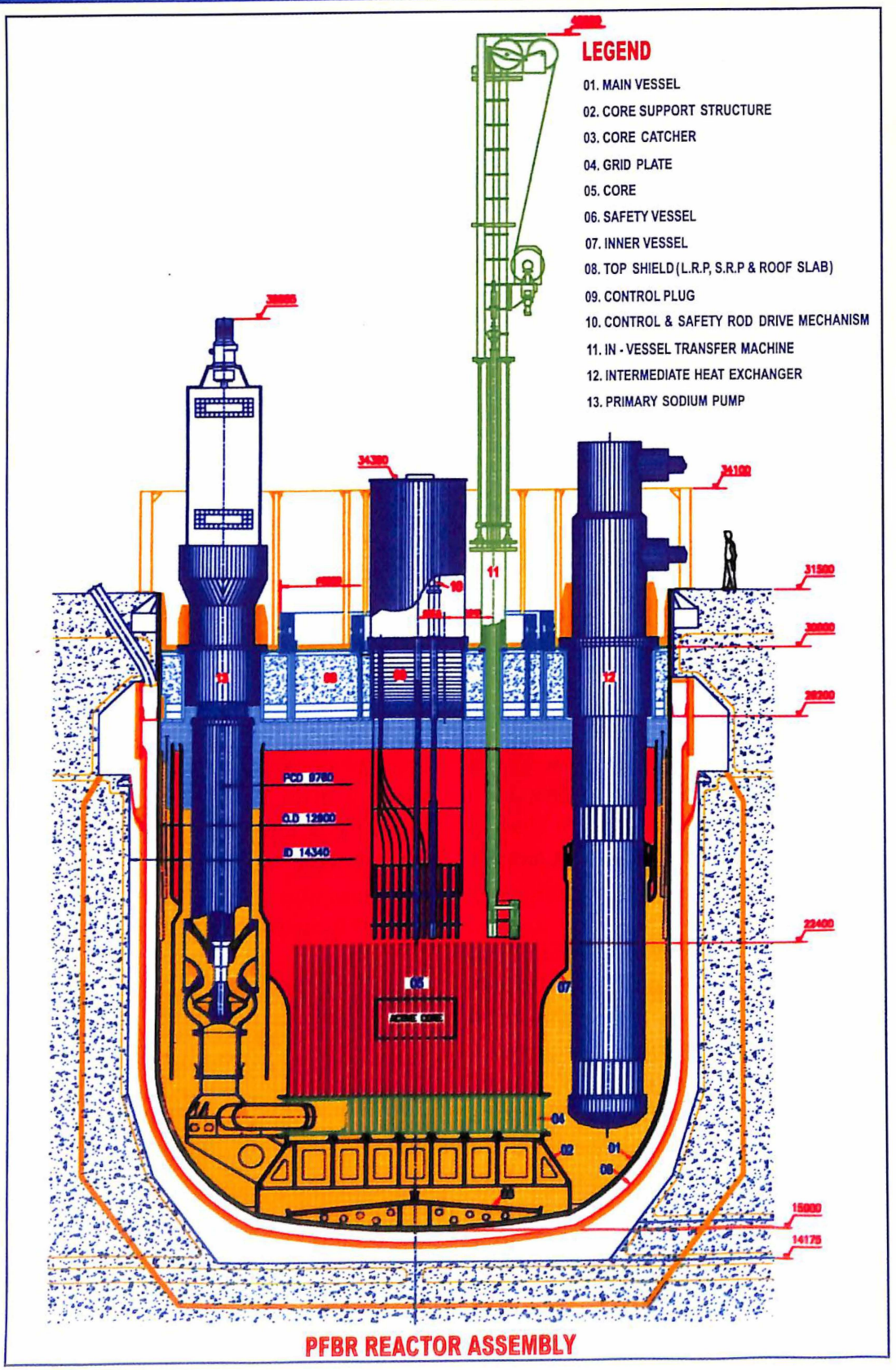
The Mark-I mixed carbide fuel core, with high plutonium content, has been developed for the first time in the world.

Fabrication of Mark-II core is progressing at Trombay. A number of PFBR MOX fuel elements for making experimental PFBR subassembly, for irradiation in FBTR, have been fabricated by BARC. A PFBR test subassembly was loaded into FBTR in July 2003 and it reached a burn up of 25,700 MWd/t.

### Fast Reactor Fuel Reprocessing

For reprocessing of FBTR fuel, the Lead Mini Cell, has been commissioned at Kalpakkam. It aims at establishing the fast reactor reprocessing process flow sheet. For reprocessing of fuel from fast breeders, IGCAR is setting up the Fast Reactor Fuel Reprocessing Plant (FRFRP). A comprehensive procedure has also been evolved at the centre for the recovery of uranium and plutonium and separation of the radioactive fission products from the spent fuel solutions.

*Lead Mini Cell Fuel Reprocessing Plant at Kalpakkam, Tamil Nadu*



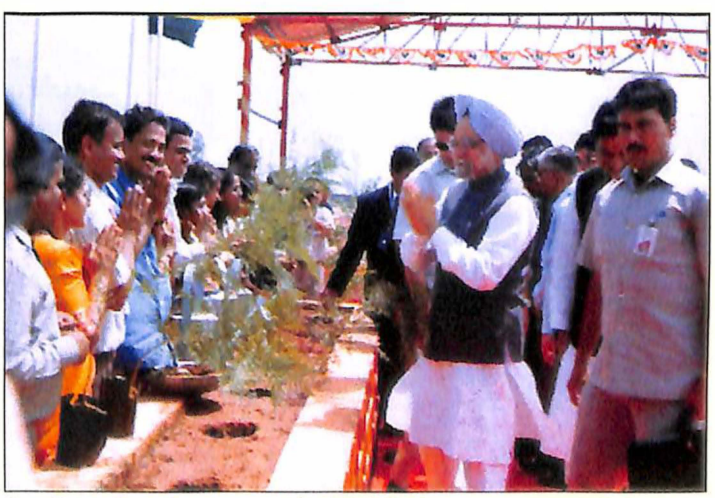

*Schematic of Prototype Fast Breeder Reactor being set up by IGCAR*

## Launch of construction of the 500 MW Prototype Fast Breeder Reactor Project at Kalpakkam, Tamil Nadu by the Hon'ble Prime Minister Dr. Manmohan Singh on October 23, 2004.

*Unveiling of foundation stone for FBR Project*

*Rebar laying of Reactor Containment Building & Steam Generator Building*

*Prime Minister looking at Technology Development Exhibits*

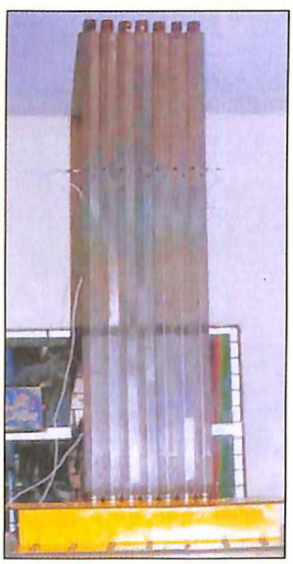


*Saplings for planting at the PFBR site*

*Steam Generator Test Facility*

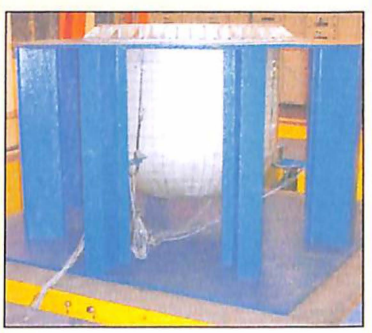
*Pool Hydraulics – Prototype Fast Breeder Reactor ¼th Model*

*Isotope Separation Plant*

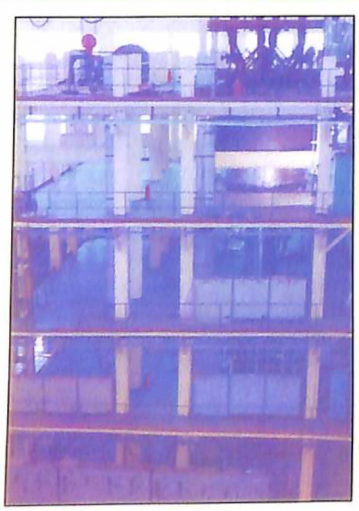


*Seismic tests in progress on Core Sub-assembly*

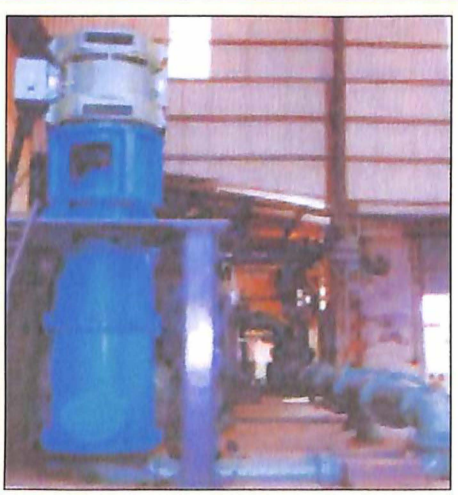
# ENGINEERING DEVELOPMENT FOR PROTOTYPE FAST BREEDER REACTOR



*Seismic tests in progress on reactor assembly model*



*Large Component Test Facility*



*Sodium Pump Development*

*Control & Safety Rod Drive Mechanism Testing*

*Mud mat filling at Prototype Fast Breeder Reactor excavation*

## Fast Reactor Technology Development

IGCAR is pursuing engineering related research & development such as thermal hydraulic and structural mechanics studies, development of components such as control and safety rod drive mechanism and various test facilities such as sodium water reaction test facility, and steam generator test facility. The Boron Plant is operating at Kalpakkam achieving 78% Boron-10 enrichment.

*Electrolytic setup used for the extraction of boron*

## THORIUM BASED REACTORS

Thorium utilisation is the long term core objective of the Indian Nuclear Power Programme for providing energy security on sustainable basis. The third stage of the Indian Nuclear Power Programme is thus based on the Thorium-Uranium-233 cycle.

A small beginning has already been made by introducing thorium in a limited way, in research reactors and in pressurised heavy water reactors.

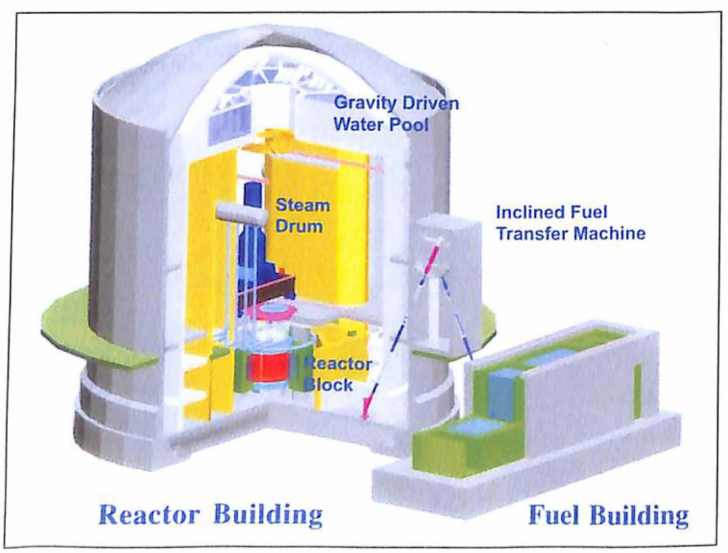
The research reactor KAMINI, operating upto a nominal power of 30kW for neutron radiography of various materials, at Kalpakkam, uses Uranium-233 fuel which is derived from thorium. This fuel is bred, reprocessed and fabricated indigenously.

BARC is engaged in developing 300MWe Advanced Heavy Water Reactor (AHWR). This R&D endeavour aims at developing expertise for thorium utilization and demonstrating advanced safety concepts.

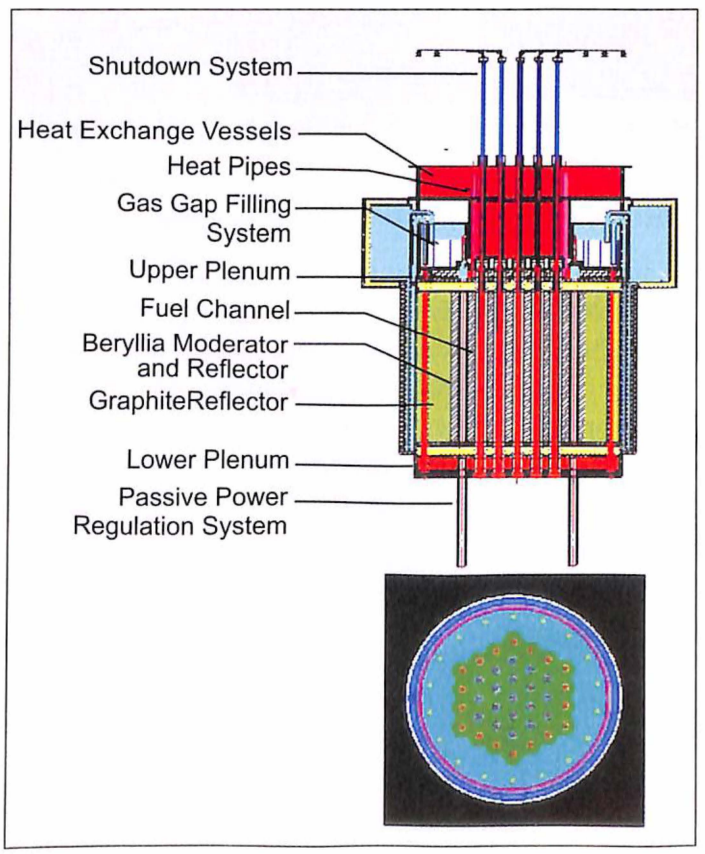
The design of this reactor incorporates several advanced safety features. The engineering development activities related to AHWR are continuing at Trombay. Mixed Thoria-Urania and Thoria-Plutonia are the candidate fuels for the AHWR. The fuel pellets have been successfully fabricated by the conventional powder metallurgy route.

To address specific application areas, such as electricity generation in remote places, production of alternative transportation fuel such as hydrogen, and refinement of low-grade coal and oil deposits to recover fossil fluid fuel, a Compact High Temperature Reactor (CHTR), with 100kW thermal power rating, is being developed at BARC.

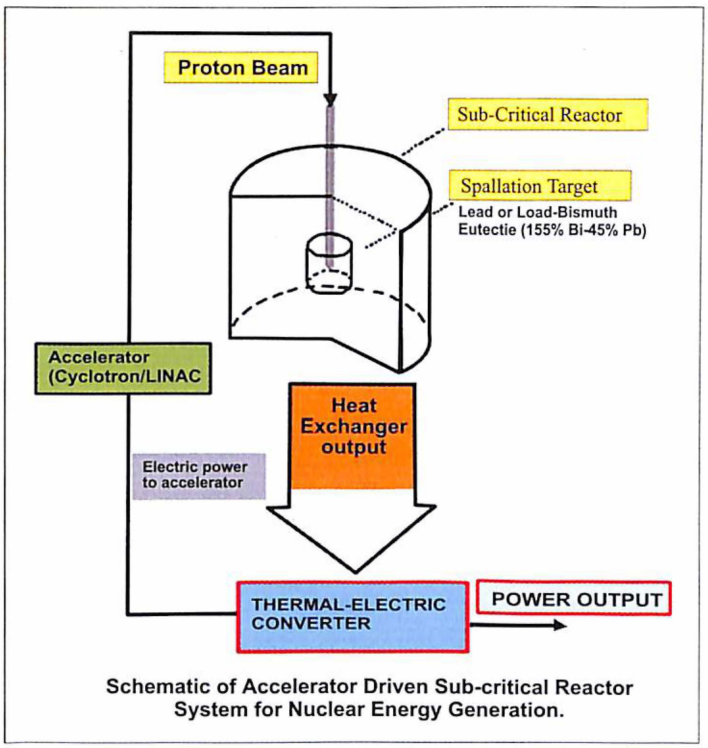
For breeding fissile Uranium-233 from Thorium, development of Accelerator Driven Sub-Critical Systems (ADS) for nuclear reactor is the latest addition to the Indian nuclear programme. This endeavour offers the promise of shorter doubling time of fuel inventory with Thorium-Uranium-233 systems, and incineration of long lived actinides and fission products, thereby reducing the technical complexities of geological repositories for




*Schematic of advanced heavy water reactor*




*Compact high temperature reactor*




**Schematic of Accelerator Driven Sub-critical Reactor System for Nuclear Energy Generation.**

*Schematic of accelerator driven sub-critical reactor system for nuclear energy generation*

storage of long-life high-level radioactive wastes. Significant progress has been made in detailed analysis of this complex system.

ADS can provide a strong technology base for large scale thorium utilization. As a first step towards realization of ADS, DAE has launched development of Proton Injector. To carry out experimental studies on sub-critical assemblies, a 14 MeV neutron generator has also been upgraded with a higher current ion source.

In the Thorium Fuel Cycle activities, separation of Uranium-233 is a vital link. For the separation of Uranium-233 from irradiated Thorium fuel on a plant scale, a Uranium-Thorium Separation Facility is in operation at Trombay.

## SAFETY & ENVIRONMENT

The safety operations from prospecting and mining of ores to management of waste, encompass all the aspects of safety viz. radiological safety, industrial safety, occupational health, fire safety and environmental protection.

In all the nuclear installations, care is taken to protect operating personnel, public and the environment. An independent body, the Atomic Energy Regulatory Board (AERB) monitors safety. The safety standards formulated by AREB are on par with those recommended by the international bodies such as the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP).

NPCIL is a member of the World Association of Nuclear Operators (WANO). The Association has conducted peer reviews of the atomic power stations at Kakrapar and Narora. From time to time, Indian experts have also participated in peer reviews in a number of countries including USA, Japan and South Korea.

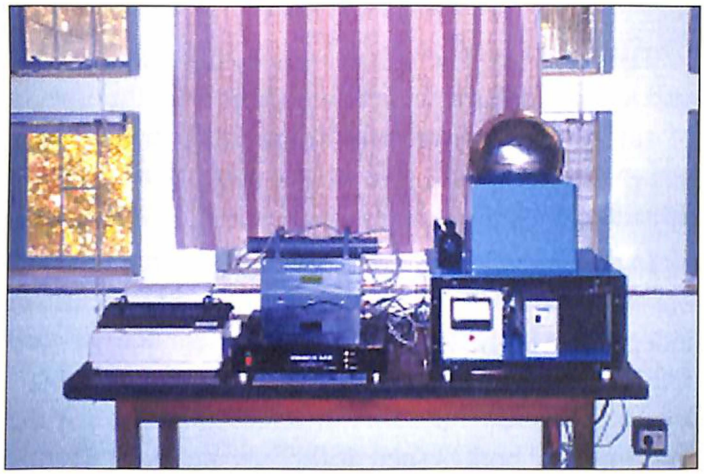
The International Safety Advisory Group (INSAG), the Nuclear Safety Advisory Group (NUSAG) along with several committees of the International Atomic Energy Agency (IAEA), which prepare safety codes and standards, have Indian scientists as members.

Safety surveillance inspections are regularly carried out and comprehensive Emergency Preparedness and Response Plans to handle postulated emergency scenarios are in action at the DAE facilities.

BARC and the laboratories accredited by it, conduct countrywide personnel monitoring in about 3000 industrial, medical, research and DAE organisations which benefit over 30,000 radiation workers annually.

Environmental radiation monitoring and environmental surveillance are the regular features of the environmental protection programme of DAE.

At different sites, the Environment Survey Labs (ESLs) of BARC continuously monitor environment, and collect site related meteorological data. Sophisticated weather monitoring SODAR systems operate at Kaiga, Kalpakkam, Tarapur and Trombay.



*Indian environmental radiation monitoring network (IREMON)*

Indian environmental radiation monitoring network (IREMON), a nationwide network of environmental radiation monitoring stations detects radiation releases. Interfaced with global positioning system, a Compact Aerial Radiation Monitoring System (CARMS) for estimation of large area contamination using unmanned aerial vehicle, is also in operation at Trombay.

DAE is committed to preserving the environment and its further enrichment. All the operating nuclear power plants and heavy water plants now have the ISO environment certificate.

To educate the public living around nuclear power plants, public awareness programmes by DAE organisations are organised on a regular basis.

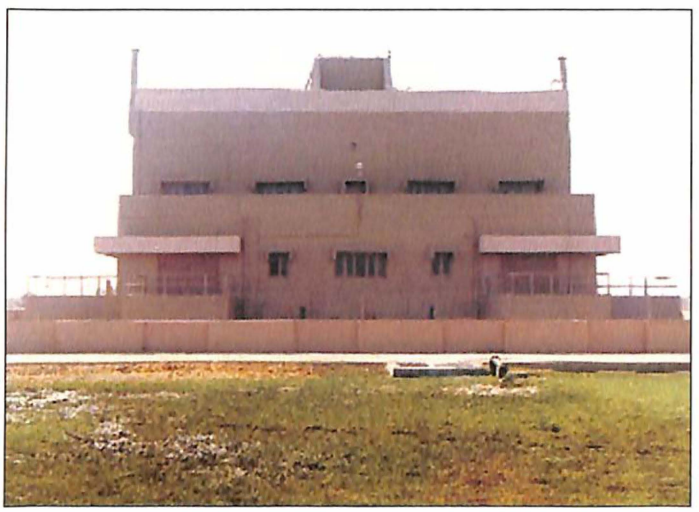
*Nisargaruna plant operating at Trombay*

## Environment Friendly Technologies

DAE is a pioneer in conducting comprehensive thermal ecology studies in India. The flue gas conditioning technology developed by Heavy Water Board is now helping to reduce fly ash emission from thermal boilers.

The Nisargaruna technology developed at BARC is helping to convert biodegradable solid waste into useful manure and methane. A number of such plants have been set up at various places.

The *Sewage Sludge Hygeinisation* plant (SHRI) at Vadodara continued to provide dried hygeinised sludge for use by farmers.



*Sludge hygienization research irradiator (SHRI) facility at Vadodara, Gujarat*

*Commercial plasma pyrolysis system developed at the Institute of Plasma Research, Ahmedabad*

# Radiation Technologies & Applications

DAE's programme relating to radiation technologies & applications, covers building and operation of research reactors for production of radioisotopes, setting up of other sources of radiation such as accelerators and lasers, and developing and deploying radiation technology applications in the field of medicine, agriculture and industry.

## Research Reactors

The research reactor programme of DAE provides R&D support to nuclear power programme, produces radioisotopes for use in healthcare, agriculture, industry and research, and provides manpower training.

The research reactors set up by DAE so far, include APSARA (1MW, Fuel: Enriched Uranium-Aluminium alloy), CIRUS (40MW, Fuel : Natural Uranium), ZERLINA (zero energy, Natural Uranium), PURNIMA I-III (Fuel : Plutonium/Uranium-233), DHRUVA (100MW, Fuel: Natural Uranium) at Trombay (Maharashtra), and KAMINI (30kW, Fuel : Uranium-233-Al alloy) and Fast Breeder Test Reactor (40MW, Fuel : Uranium-Plutonium carbide) at Kalpakkam (Tamil Nadu). Of these research reactors, ZERLINA was decommissioned in 1984, and PURNIMA series made way for KAMINI.

DHRUVA, CIRUS and APSARA are used for producing radioisotopes besides their use in research and development relating to nuclear technologies and materials, applied and basic research, and training. KAMINI is used mainly for radiography of various materials, and FBTR is the test bed for the development of fuel, blanket and structural materials for fast breeder reactor programme.

*Research reactors DHRUVA and CIRUS at Trombay*

The new ventures include the development of a Critical Facility at Trombay for reactor physics experiments relating to AHWR & 540 MWe PHWR, and a 20MWt Multi Purpose Research Reactor — a pool type reactor that will use low enriched uranium fuel.

## Radioisotope Production & Processing

India is a leading producer of radioisotopes in the world. Radioisotopes are produced in the research reactors at Trombay, atomic power reactors of NPCIL and the cyclotron of VECC at Kolkata.

BRIT processes radioisotopes produced at Trombay and at the nuclear power stations of NPCIL. These products include radiopharmaceuticals, labeled compounds, radiochemicals, radiobiomolecules, radiosources and a number of devices using radioisotopes.

The radioisotope based products and services are now commercially available through BRIT.

*APSARA reactor at Trombay*

## Applications of Radioisotopes

The radioisotopes produced at Trombay find wide applications in the fields of agriculture and food, medicine and healthcare, industry, and research. Based on these applications, following programmes have been establishing in the country :

*Experimental setups around DHRUVA Reactor at Trombay*

## Nuclear Agriculture

The Nuclear Agriculture Programme of DAE focuses on the use of radiation technology for the development of high yielding crop seeds, radiation processing of food items, fertilizer and pesticide related studies, and other areas. These technologies are benefiting Indian farmers and traders.

*Crop Improvement*

For decades, BARC, in collaboration with agricultural universities, has been engaged in research and development in the field of crop improvement. This Centre has successfully developed and released 24 high yielding crop varieties for commercial cultivation. These include 10 groundnut, 10 pulse and 2 mustard varieties, and one variety each of jute and rice.

During the year 2003-2004, the share of Trombay groundnut varieties in national breeder seed indent was 28% and that of black gram was 40%.

BARC has successfully developed green manure crop – Sesbania rostrata. Use of this variety is highly cost effective for small farmers.

*Sesbania rostrata*

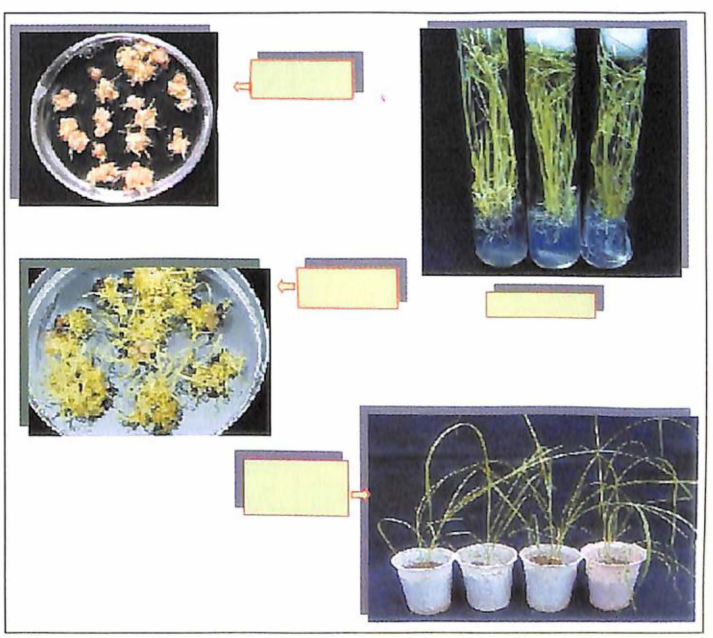
In tissue culture, tissues are grown artificially in a special sterile culture medium. BARC has developed a tissue culture based protocol for rapid multiplication of some commercial cultivars of banana. This technology has been transferred to the Maharashtra State Seeds Corporation.

Using micropropagation technology, the BARC has standardised large-scale multiplication of pineapple. Micropropagation protocol has also been standardized in three varieties of sugarcane.

*Pineapple developed by tissue culture technique*

The Centre has made good progress in developing hardened plants for Acacia Victoriae - a plant suitable for desert area. Here, several insect pheromones have been synthesized and techniques for determination of nutrients in soils have been developed.

To ensure that technologies developed by the DAE organisations are widely deployed, DAE has set up an interface with the Ministry of Agriculture.



*Micropropagation of Sugarcane*

## *Mutant crop varieties developed at BARC, released and notified for commercial cultivation*

| Name | Year of Release | Maturity (M) Yield (Y) & Yield increase (YI) | Released for | Remarks |
|---|---|---|---|---|
| **GROUNDNUT** *(Seengdana, Moongphali)* TG-1 | 1973 | M: 130-135 days<br>Y: 2400-2500 kg/ha<br>YI: 15-20% | Maharashtra, Gujarat | Large seed |
| TG-17 | 1985 | M: 115-120 days<br>Y: 1700-2000 kg/ha<br>YI: 15-20% | Maharashtra | Less branches |
| TG-3 | 1987 | M: 110 days<br>Y: 2000-2500 kg/ha | Kerala | More branches |
| Somnath (TGS-1) | 1989 | M: 110-125 days<br>Y: Kharif 2000 kg/ha<br>YI: 23% | Gujarat | Large seed,<br>Spreading habit |
| TAG-24 | 1991 | M: Kharif:100-105 days<br>Summer:112-117 days<br>Y: Kharif: 1300 kg/ha<br>Summer: 2500 kg/ha<br>YI: Kharif:24%<br>Summer:50% | Maharashtra<br>Karnataka<br>West Bengal<br>Rajasthan | Most popular in all groundnut growing states, Identified as national variety. High yield potential (9000-10,000 kg/ha)<br><br>Semi-dwarf habit, Early maturity, High harvest index, High partitioning efficiency, Wider adaptability |
| TG-22 | 1992 | M: Kharif:115-120days<br>Y: Kharif:1677 kg/ha<br>YI: 30% | Bihar | Medium-large seed,<br>Fresh seed dormancy |
| TKG-19A | 1994 | M: 120-125 days<br>Y: Summer 2000-2500 kg/ha<br>YI: 12-13% | Maharashtra | Large seed,<br>Fresh seed dormancy |
| TG-26 | 1995 | M: 110-120 days<br>Y: Summer 2500 kg/ha<br>YI: 23-39% | Gujarat,<br>Maharashtra,<br>Madhya Pradesh | Semi-dwarf, Early maturity, High harvest index, High partitioning efficiency, Fresh seed dormancy<br><br>Second popular TG variety, High yielding ability (9000 – 10,000 kg/ha), Wider adapt-ability. |
| TPG-41 | 2003 | M: 120 days<br>Summer 2338 kg/ha<br>YI: 18% | All India | Large seed (65 g 100 seeds)<br>Fresh seed dormancy<br>On farm trials 4551 kg/ha, 49% increase |
| TG-37A | 2004 | M: 114 days<br>Kharif 1993 kg/ha<br>YI: 26% | Rajasthan, Punjab, Haryana,<br>Uttar Pradesh | Fresh seed dormancy,<br>Oil 51% |

## *Mutant crop varieties developed at BARC, released and notified for commercial cultivation*

| Name | Year of release | Maturity (M) Yield (Y) & Yield increase (YI) | Released for | Remarks |
|---|---|---|---|---|
| **BLACKGRAM** *(Urid)* TAU-1 | 1985 | M: 70-75 days<br>Y: 800-1000 kg/ha<br>YI: 24% | Maharashtra, Karnataka, | Large seed<br>Most popular variety in Maharashtra |
| TAU-2 | 1991 | M: 70 days<br>Y: 800-1000 kg/ha<br>YI: 18% | Maharashtra | |
| TPU-4 | 1992 | M: 70-75 days<br>Y: 900-1000 kg/ha<br>YI: 22% | Maharashtra, Madhya Pradesh | |
| TU-94-2 | 1997 | M: 70 days<br>Y: 900-1000 kg/ha<br>YI: 19-37% | Andhra Pradesh, Karnataka,Kerala, Tamil Nadu | Resistant to Yellow Mosaic Virus |
| **GREENGRAM** *(Moong)*TAP-7 | 1983 | M: 60 days<br>Y: 700-800 kg/ha<br>YI: 23% | Maharashtra, Karnataka | Tolerant to Powdery Mildew |
| TARM-2 | 1992 | M: (Rabi 90 days)<br>Y: 1000-1100 kg/ha<br>YI: 80% | Maharashtra | Resistant to Powdery Mildew |
| TARM-1 | 1996 | M: 80 days<br>Y: 1200 kg/ha<br>YI: 45% | Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, Orissa | Resistant to Powdery Mildew |
| TARM-18 | 1996 | M: 65-70 days<br>Y: 1051kg/ha | Maharashtra | Resistant to Powdery Mildew |
| **PIGEONPEA** *(Tur)*TT-6 (Trombay-Vishakha 1) | 1983 | M: 135-140 days<br>Y: 1200-1300 kg/ha<br>YI: 15% | MP, Maharashtra, Gujarat, Andhra Pradesh,Tamil Nadu, Karnataka, Kerala | Large seed |
| TAT-10 | 1985 | M: 110-115 days<br>Y: 900-1000 kg/ha | Maharashtra | Early maturing |
| **MUSTARD** *(Rai)* TM-2 (Black Seed) | 1987 | M: 90 days<br>Y: 1370 kg/ha<br>YI: 25% | Assam | |
| TM-4 (Yellow Seed) | 1987 | M: 95 days<br>Y: 1470 kg/ha<br>YI: 35% | Assam | |
| **RICE** Hari (TR-RNR-21) | 1988 | M: 135-140 days<br>Y: 6000 kg/ha<br>YI: 20% | Andhra Pradesh, BARC, Mumbai | |
| **JUTE** Mahadev (TKJ-40) | 1983 | M: 125-130 days<br>Y: 2800-3100 kg/ha<br>YI: 10-13% | Orissa | |

*Food processing*

The Department has set up plants for demonstration of high and low dose applications of radiation. These are Radiation Processing Plant set up by BRIT at Navi Mumbai for high dose radiation processing of spices, and KRUSHAK (Krushi Utpadan Sanrakshan Kendra), set up by BARC at Lasalgaon near Nashik, for low dose applications of radiation for food preservation. This plant processes onion, pulses, rawa and turmeric.

The Government of India has approved radiation processing of certain food items both for export and domestic consumption.

The major thrust given to the area of setting up of new radiation processing plants for medical, food related and allied products, has shown very encouraging results in the recent times and about eight private parties signed MoU with BRIT for setting up plants. The first of these by M/s. Organic Green Foods Ltd., Kolkata has become operational recently.

BRIT has also developed an install-and-operate type Irradiator for radiation processing of food, which is undergoing evaluation tests.

*Various food items that are processed by radiation*

*Radiation processing plant, Navi Mumbai, Maharashtra*

*KRUSHAK, (Krushi Utpadan Sanrakshan Kendra) Lasalgaon, district Nashik, Maharashtra*

*"Vikiran" Plant set up by Organic Green Foods Ltd., at Kolkata, in collaboration with BRIT*

DAE is working with the Ministry of Health for notifying items for radiation processing for approval of additional items and other related issues.

Research at BARC is focused on radiation processing

for preservation of cereals and pulses, fruits and vegetables, meat and meat products and seafood. A process for making shelf-stable meat products using gamma radiation, has been standardized. The effects of combinations of radiation, packaging, and low temperatures, for extension of shelf-life of a number of fruits and vegetables and coffee beans, are under extensive study.

## Nuclear Medicine and Healthcare

Radioisotopes and their formulations find wide applications in diagnosis, therapy and healthcare. BARC and BRIT are the main centres of this activity.

BARC has successfully developed radiation-processed hydrogel for treating burn, wounds and leprosy; Holmium-166-Hydroxy Apatite (HoHa) and Samarium-153-Hydroxy Apatite (SmHa) radio-pharmaceuticals for treatment of arthritis, and radiolabeling of phosphonates with Luthinium-177 for internalised radiotherapy.

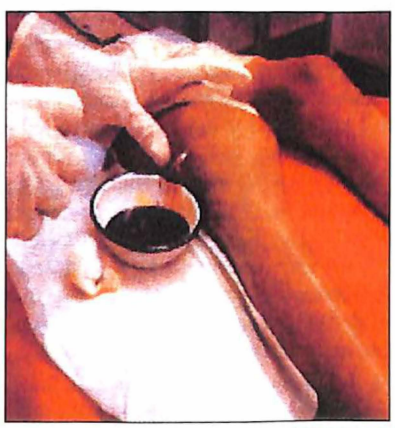
At BARC, Cesium-137 based brachytherapy sources

*Brachy-therapy being given to a patient*

are routinely produced. For treatment of cancer of eye, radiation sources of extremely tiny size – of the size of rice grain - containing 2-3 millicurie of Iodine-125, have been produced here. This miniature source was tried for the first time for treating eye cancer at Sankara Netralaya, Chennai.

To provide a low cost alternative teletherapy unit for the improved teletherapy unit being imported, a Cobalt-60 Teletherapy Machine has been developed at BARC. The machine that is undergoing trials at Advanced Centre for Treatment, Research and Education in Cancer (ACTREC), Navi Mumbai, is much cheaper than the imported one of similar class.

Another salient development is the digital medical imaging system based on a Charge Coupled Device.



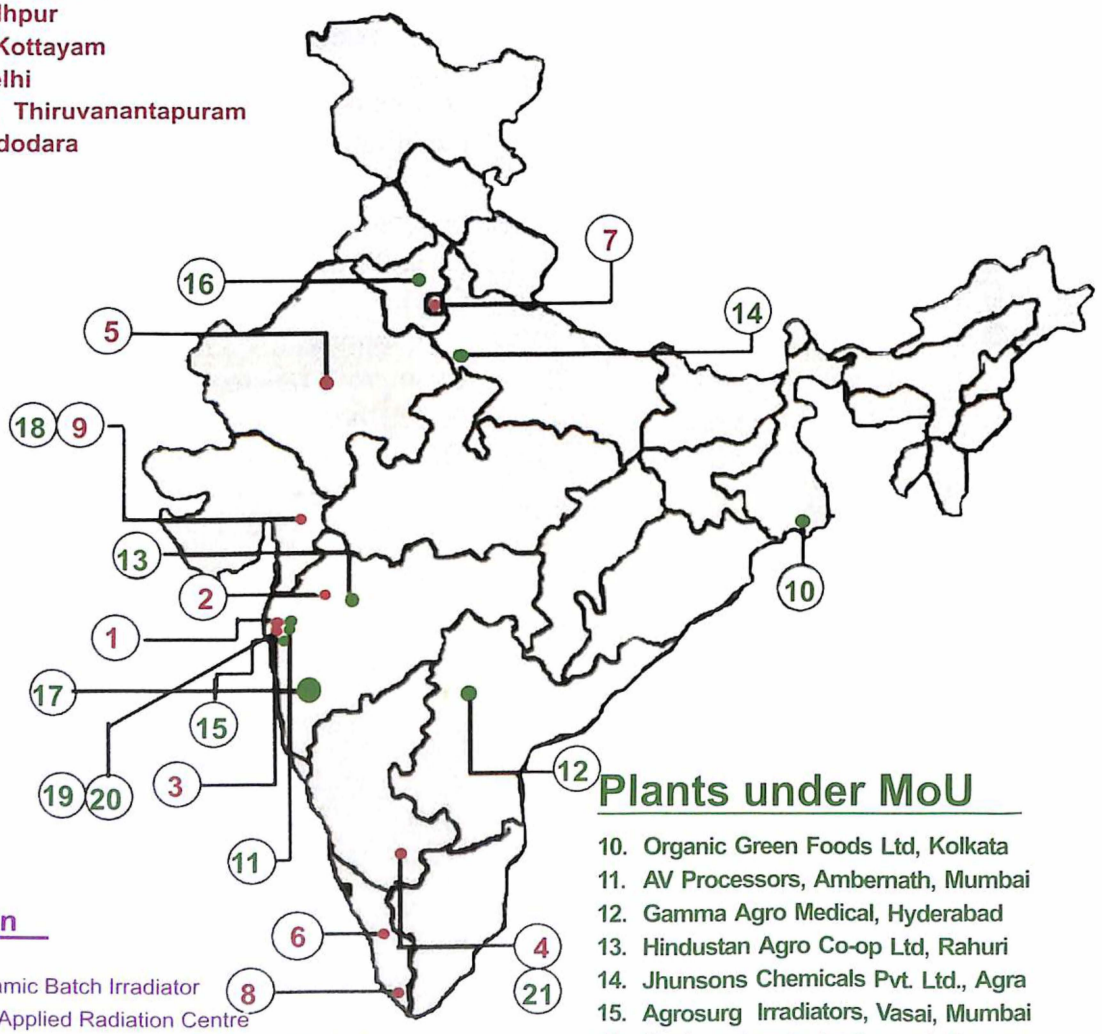
*Radiation synovectomy procedure using holmium based radionuclide and the scintigraphic images of the injected joint*

*Cobalt-60 teletherapy machine at ACTREC, Navi Mumbai*

# RADIATION PROCESSING PLANTS IN INDIA
## (Co-60 based)

## Existing Plants

1. ISOMED, FIPLY, PANBIT, Mumbai
2. KRUSHAK, Lasalgaon
3. Radiation Processing Plant, Navi Mumbai
4. RASHMI, Bangalore
5. RAVI, Jodhpur
6. RVNRL, Kottayam
7. SARC, Delhi
8. SCTIMST, Thiruvanantapuram
9. SHRI, Vadodara




## Plants under MoU

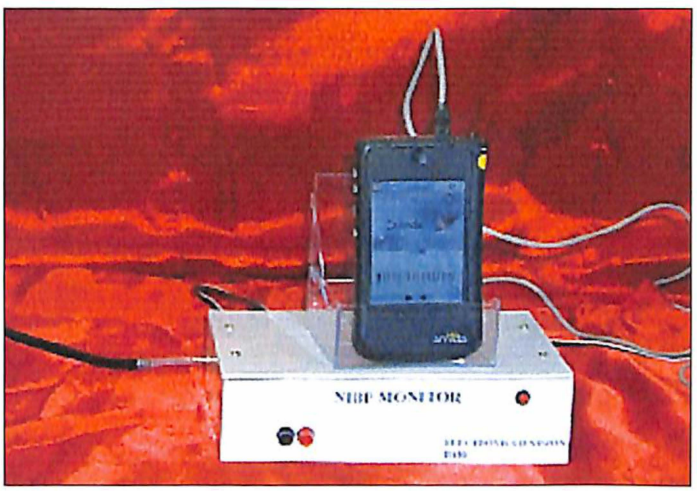
10. Organic Green Foods Ltd, Kolkata
11. AV Processors, Ambernath, Mumbai
12. Gamma Agro Medical, Hyderabad
13. Hindustan Agro Co-op Ltd, Rahuri
14. Jhunsons Chemicals Pvt. Ltd., Agra
15. Agrosurg Irradiators, Vasai, Mumbai
16. Vardaan Agrotech, Sonepat, Haryana
17. SM Shethimel Sanstha, Kolhapur
18. Universal Medicap Ltd., Vadodara
19. Matulya Mills Ltd., Mumbai
20. Technology Options (I) Pvt. Ltd., Mumbai
21. Microtrol Sterilization Services Pvt. Ltd, Mumbai (Plant in Bangalore)

## Abbreviation

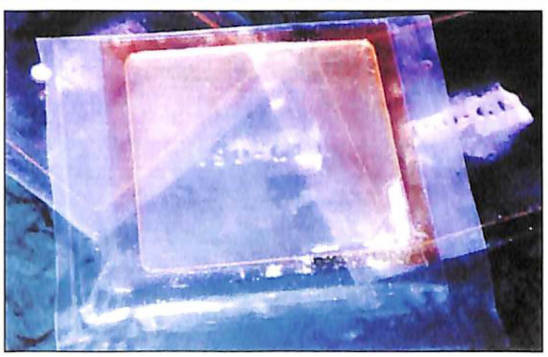
**PANBIT**- Panoramic Batch Irradiator
**SARC**- Shriram Applied Radiation Centre
ISOMED – Irradiation Sterilisation of Medical Products
**KRUSHAK** – Krishi Utpadan Sanrakshan Kendra
**RAVI** – Raksha Anusandhan Aur Vikas Irradiator
**RVNRL**- Radiation Vulcanization of Natural Rubber Latex
**FIPLY** – Food Irradiation Processing Laboratory
**SHRI**- Sludge Hygienization Research Irradiator
**SCTIMST**- Shree Chitra Thirunal Institute of Medical Science & Technology

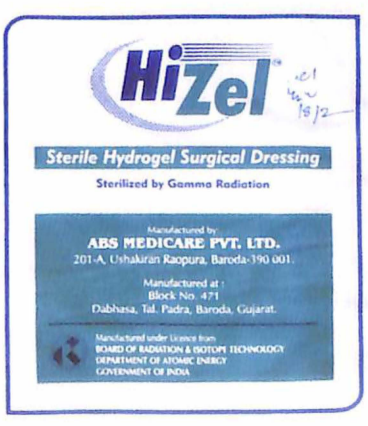
Tuberculosis is a major health problem in India. For detection of disease infection, BARC has developed a sero-diagnostic test-kit. X-ray imaging using a three dimensional cone-beam tomography, is another important development at BARC.

BARC's Radiation Medicine Centre (RMC) in Mumbai is involved in research and development in nuclear medicine and allied sciences. The centre offers diagnostic and therapeutic services using radioisotopes, and promotes human resource development in nuclear medicine. It is a regional referral centre of the World Health Organisation, and the International Atomic Energy Agency (IAEA).




*Non-invasive blood pressure monitor developed at BARC*






*Hydrogel developed at BARC*

Radioimmunoassays (RIA) and related procedures are used for the measurements of hormones, enzymes, certain serum proteins, and others. RMC is a major provider of RIA services in the country, to thyroid patients. This centre annually dispenses of 90,000mCi of Technetium based radiopharmaceuticals, and carries out 8000 radiodiagnostic investigations and 9000 radioimmunoassays.

For diagnosis of diseases such as cancer, cardiac and neurological disorders, special radioisotopes of very short life are required. To meet this need, BARC has established a medical cyclotron at RMC. This cyclotron is coupled to a positron emission tomography (PET) scanner for radioimaging.

For the radiodiagnosis needs in the Eastern part of the country, the Regional Radiation Medicine Centre (RRMC) is operating at Kolkata. The Centre carries out nuclear imaging and hormone estimations.

BRIT processes and formulates radioisotopes produced in the research reactors DHRUVA and Apsara at Trombay and also in the power reactors of NPCIL. These products are supplied to nearly 2000 institutions in the country for applications in agriculture, healthcare, and supporting research in life sciences and bio sciences. BRIT also manufactures radiation technology based equipment, and provides radiation processing services to medical sector.

Annually, BRIT supplies about 14,000 consignments of radiopharmaceutical products, and over 41,000 cold kits to nearly 120 nuclear medicine centres. With the help of these radiopharmaceutical products and cold kits, nearly 3 lakh diagnostic imaging studies are performed annually. A number of patients are treated for thyroid disorders and thyroid cancer using radioiodine products supplied by BRIT. In addition, radiopharmaceutical products of Phospohorus-32

*A view from radioimmunoassay laboratory at Vashi, Navi Mumbai*

*JONAKI laboratory at Hyderabad*

and Samarium-153 are used for treatment of bone cancer and pain palliation in severe cases.

Radioimmunoassay (RIA) is a versatile in-vitro technique for the measurement of hormones, vitamins, drugs and other substances present in biological fluids. Another technique known as immunoradiometric assay (IRMA) is also used for such estimations.

Nearly 10,000 RIA/IRMA kits of different hormones are supplied to more than 300 RIA centres in the country. The newly developed T3/T4 magnetic particle based RIA kits have been introduced in the market for thyroid hormone investigations. About 5 lakh patient sample analysis are carried out every year using these radioimmunoassay kits.

The RIA Centres of BRIT at Bangalore and Dibrugarh conduct 6000 and 5000 radioimmunoassays annually. BRIT's regional centres at Bangalore and Delhi process ready-to-use Technetium-99m radiopharmaceuticals for use in hospitals of their regions.

Labeled compounds are versatile tools for research and tracers. Important labeled compounds supplied by BRIT include Phosphorus-32 and Phosphorus-33 labeled nucleotides, Sulphur-35 labeled amino acids, Carbon-14 labeled compounds, Tritium labeled compounds, and others, and cold kits for biological research/nonradioactive labeling.

BRIT's biomolecule producing laboratory Jonaki at Hyderabad supplies over a dozen labeled nucleotides and molecular biology kits to user institutions across the country on a regular basis.

Radiochemicals are used as tracers for studying mechanisms of chemical reactions, leakage and flow rate measurements in pipelines and sediment studies. BRIT produces a number of radiochemicals to facilitate such studies.

### *Radiation Technology Equipment*

The radiation technology equipment manufactured by BRIT for use in industry include radiography camera for ascertaining internal defects of welding, casting etc., Gamma chamber, a compact self shielded Cobalt-60


*Blood irradiator developed by BRIT*

research irradiator for irradiating samples, and Blood Irradiator for radiation processing of blood and blood products by gamma rays to eliminate the risk of post-transfusion graft versus host disease.


*Gamma chamber manufactured by BRIT*

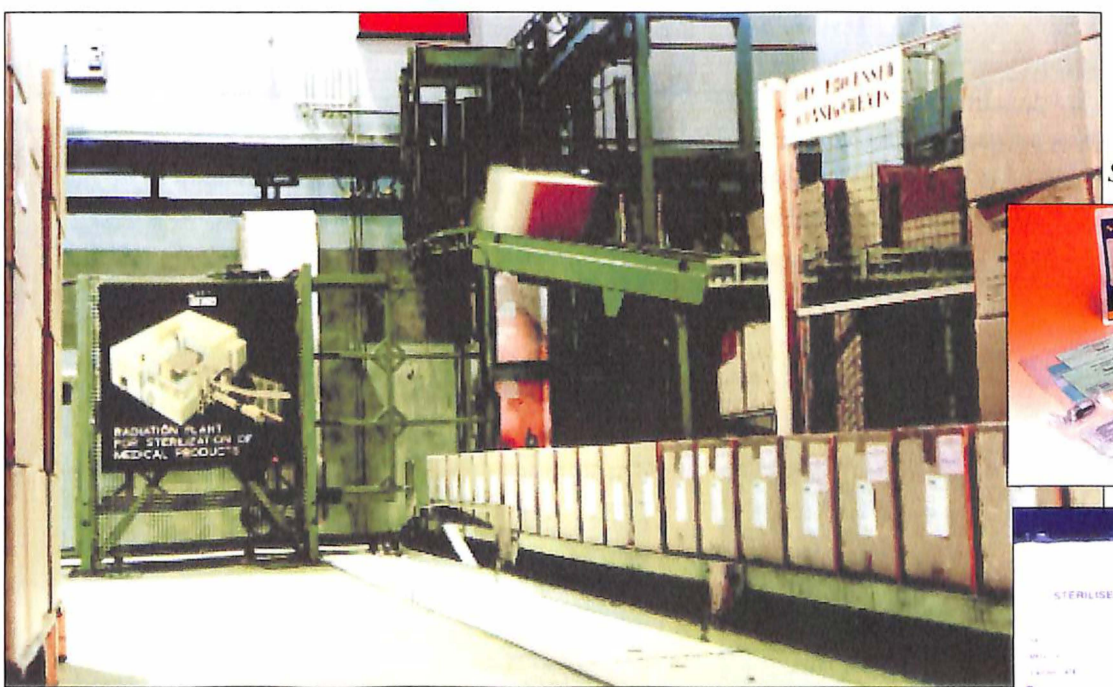
A large number of radiography cameras and gamma chambers manufactured by BRIT are already in the use of Indian Industry. Blood irradiator developed at BRIT is used in hospitals and blood banks. Such units have also been installed at the regional centres of BRIT in Bangalore and Delhi.

BRIT produces and supplies sealed radiation sources of Cobalt-60 and Iridium-192 to a number of radiotherapy centres in the country, for cancer treatment.

### *Radiation Processing*

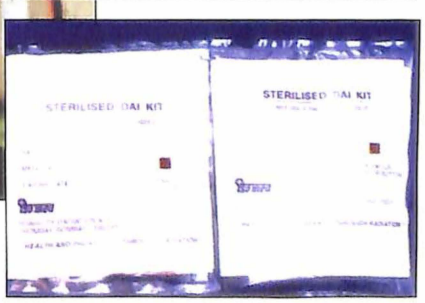
BRIT has been operating radiation sterilization plant ISOMED, now ISO-9002 accredited, at Trombay. The plant provides radiation sterilization services to over 1500 users.

Over two million Dai (midwifery) kits and delivery packs have been radiation sterilized at ISOMED plant of BRIT, and distributed for use in rural areas for preventing infection of mothers and helping to minimize infant mortality rate, through rural health programmes funded by WHO. In a study, the International Institute of



*ISOMED plant at Trombay*

*Sterilized medical products*

Population Studies, Mumbai, has found that the infant mortality rate has fallen by 25-30 % in Rajasthan, Madhya Pradesh, Maharashtra and Uttar Pradesh, as a result of distribution of the kits in these areas.

Similar to ISOMED, plants are also in operation at the Shriram Centre for Industrial Research, Delhi, and Kidwai Memorial Institute of Oncology, Bangalore. A plant for R&D purposes has been in operation at the Defence Research and Development Organisation, Jodhpur, Rajasthan.

## Water Management

BARC has developed a number of desalination technologies based on multi-stage flash (MSF) evaporation, reverse osmosis (RO) and low temperature evaporation (LTE). Using these technologies, desalination plants have been developed for providing potable water in rural areas and on ships, and water for industrial uses.

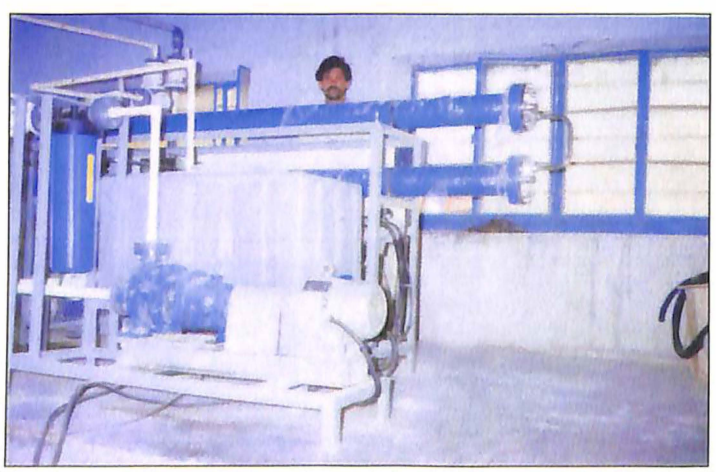
To utilize low pressure steam and waste heat from nuclear reactors, BARC is setting up a 6300 cubic metre/day combined MSF-RO Nuclear Desalination Demonstration Plant (NDDP) at Kalpakkam, Tamil Nadu. The plant will utilize seawater, steam and power from Madras Atomic Power Station (MAPS) for achieving cost effective desalination of sea water.

The 1800 cubic metre/day desalination stream of the plant, which is based on reverse osmosis (RO) process, has been commissioned. It is now producing potable water from seawater. The MSF based stream is under construction.

A small (30 cubic metre/day) desalination unit, based on low temperature evaporation technology, and using waste heat of CIRUS, has been set up and commissioned at Trombay.

A 30 cubic metre/day brackish water RO plant operates at Satlana village Jodhpur District, Rajasthan for providing drinking water to the villagers.

BARC has also introduced in commercial market an On-line Domestic Water Purifier.



*Reverse osmosis (RO) based plant set up by BARC at Satlana village, Jodhpur, Rajasthan*

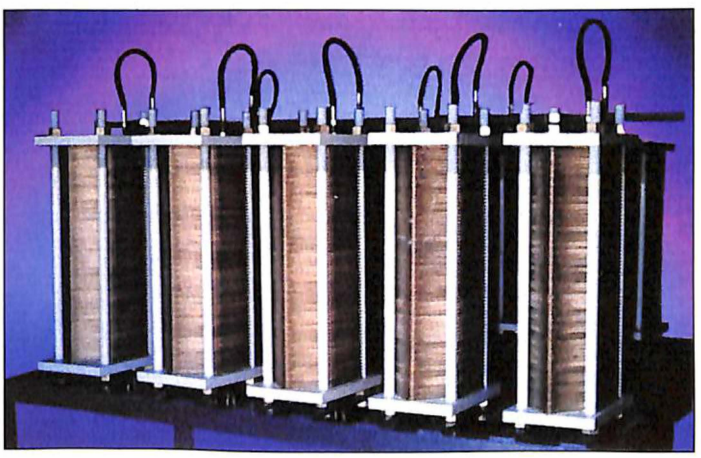
## Industrial applications of Radioisotopes

The studies conducted by BARC have immensely contributed to the detection and recharge conditions of ground water bodies. Some of these include evaluation of the groundwater recharge conditions in the Delang-Puri sector of coastal Orissa, determination of the origin of thermal waters in the geothermal areas in Madhya Pradesh, Uttar Pradesh and Himalayas, and establishment of the ancient course of the legendary 'Saraswati' river in Western Rajasthan.

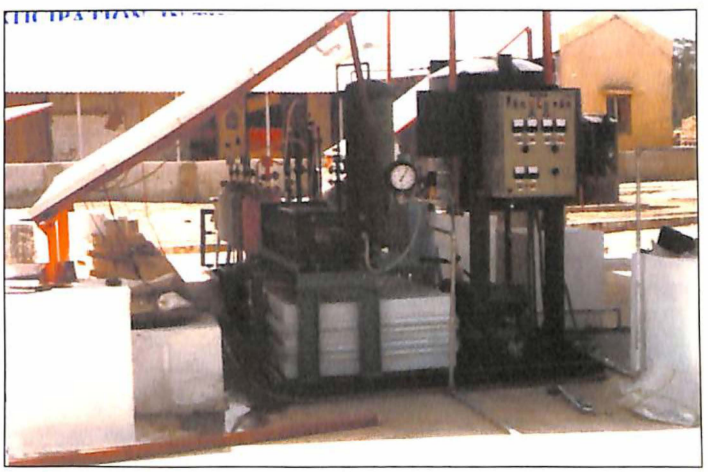
*Radiotracer studies being done by BARC on a trickle bed reactor of a factory*

*Nuclear desalination demonstration plant (Capacity : 6300 cubic metre per day) set up at Kalpakkam, Tamil Nadu*

*Reverse osmosis module (Capacity : 30 cubic metre per day) set up at Sheelgan village, district Barmer, Rajasthan*



*Reverse osmosis module (Capacity : 25 cubic metre per day) for industrial use*



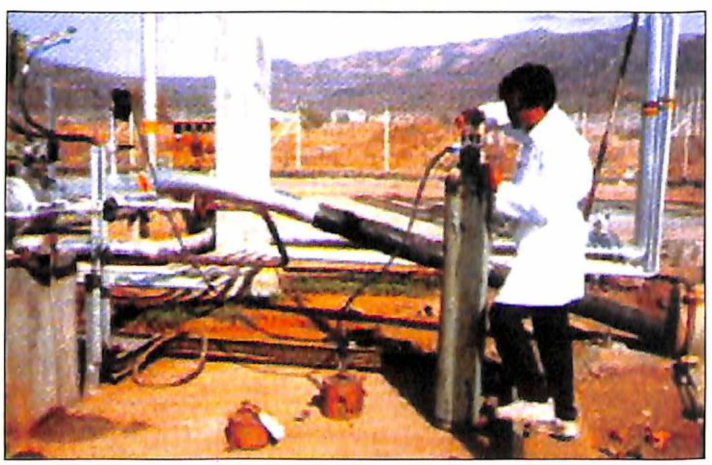
*Reverse osmosis demonstation plant (Capacity : 5 kilolitre per day) that runs on solar energy*

*Ultrafiltration membrane water purifier device developed at BARC*

*Low temperature evaporation desalination plant (Capacity: 30 cubic metre per day)*

Major activities relating to hydrology cover evaluation of recharge measures at coastal fresh groundwater system of Thiruvadanai, Tamil Nadu; sustainability of deep ground waters at Kuttanad, Kerala; detection of fluoride contamination in ground waters of Karnataka; solution of leakage/seepage problems of a few dams in Kerala and Rajasthan; origin of groundwater along paleo-channels in Jaisalmer district, Western Rajasthan, and seepage and source of salinity in the Indira Gandhi Nahar Pariyojana Command Area, Hanumangrah, Rajasthan.

Studies conducted by BARC on sediment transport at almost all the major ports have resulted in increasing the intervals between desilting campaigns which saved



*Leakage in pipe being detected with the help of radiotracer*

huge cost of desilting operations. Studies on bed load transport at Kolkata and Karwar ports have helped in port-expansion programmes. A nucleonic suspended sediment concentration gauge developed at Trombay, has proved to be a useful tool of the dredging operation in ports.

Using radioisotope tracer techniques, a major study on the dilution and dispersion of the sewage disposed off into sea at the Colaba outfall in Mumbai, was conducted by BARC.

BARC's expertise in gamma scanning is being used by major petrochemical industries for troubleshooting in process equipment, detecting leaks in buried pipelines, industrial process controls etc.. Other noteworthy studies carried out by BARC include detection of leakage points in 350 km long natural gas pipeline

*Radiotracer testing in action in a sugar mill*

of the Gas Authority of India, and gamma scanning of distillation and degasser columns for Mumbai and Baroda based companies.

Using radiotracing techniques, leaks in the heat exchangers of the Indian Oil Corporation's Panipat Refinery, Haryana and Tamilnadu Petroproducts Ltd. Chennai, Tamil Nadu were detected. These techniques were also used in the effective management of the oil fields of the Oil and Natural Gas Commission.

BARC's radiotracing expertise is being used by the industrial units in many diverse ways. Gamma scanning is an indispensable non-destructive technique for solving online problems in industrial process columns. Using this technique, BARC has successfully conducted investigations on a depropaniser column of the Reliance Industries Ltd., Hazira, Gujarat, and carried out shielding integrity tests for different DAE facilities.

Gamma scanning technology developed at Trombay, is used for troubleshooting and process optimization in a number of process industries in the country. This has resulted in minimizing production losses, which could be of the order of several crore of rupees per day for such big units.

BRIT processes Cobalt-60 at RAPPCOF, Kota, Rajasthan, and manufactures radioisotope based equipment for industrial and other applications. For radiography examination of industrial products, it supplies Iridium-192 sealed sources and remotely operated

radiography cameras (ROLI-1).

The Board also exports radioisotopes and related equipment to countries such as United Kingdom, Germany, Bangladesh, Egypt, Myanmar, Nepal, Sri Lanka, Syria and Tanzania.

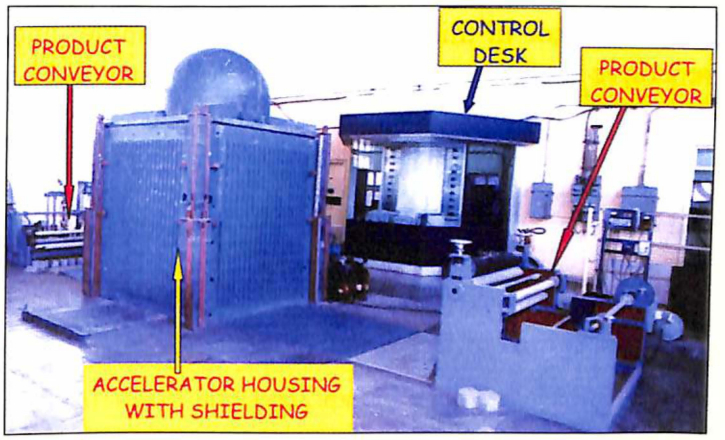
## Beam Technologies

DAE is engaged in the development of radiation technologies and services. Laser systems and Electron Beam Accelerators are the areas where India is one of the front runners.

*RAPPCOF Plant, Kota, Rajasthan. The plant manufactures Cobalt-60*

The DAE's research organisations viz. Centre for Advanced Technology (CAT) in Indore, Madhya Pradesh and Bhabha Atomic Research Centre (BARC) in Mumbai, are engaged in the development of applications in the areas of Laser systems, Electron Beam processes and devices, and Plasma devices.

Currently a number of equipment based on electron beam technologies are being developed. BARC has been working with major cable manufacturers to indigenously develop electron beam crosslinked cables. In collaboration with Sriram Institute of Chemical Research, New Delhi, BARC has developed a special formulation of PVC based material which on radiation cross-linking, leads to a product that can withstand temperature upto 105 Celsius. To induce uniform crosslinking, a rotating multi-spindle conveyor system was designed at Trombay.




*Electron Beam setup at Kharghar, Navi Mumbai.*

The process has been commercialised.

BARC has successfully developed a 500 keV, DC Accelerator, now housed at BRIT Complex, Vashi, Navi Mumbai. The accelerator has been in regular operation for surface modification studies as well as applications. Industries such as M/s Reliance India Ltd. are using it for crosslinking of plastic sheets and granules. M/s Hindustan Lever Ltd. is planning to irradiate its brand of wheat flour by utilising this facility. BARC and IIT-Madras, Chennai are pursuing radiation damage studies of materials by using 500 keV accelerator beams.

In addition, to meet the diverse demands of radiation processing of materials, BARC is designing and developing a 3 MeV, 30 kW DC accelerator and a 10 MeV, 10 kW RF electron LINAC. They are going to be housed at Electron Beam Centre (EBC) Kharghar, Navi Mumbai. 10 MeV, 10 kW RF electron LINAC (Linear Accelerator) has been installed and the components of 3 MeV accelerator are in the advanced stage of fabrication. EBC is planned to serve as a unique and dedicated centre for carrying out research and development in the areas of industrial accelerators and the material processing.

## High Power Pulsed Electron Accelerators

High power pulsed electron accelerators are used for producing Flash X Rays (FXR) and High Power Microwaves (HPM). These accelerators have many applications in the industry, nuclear power sector and the strategic areas. BARC has been developing two types

of accelerator in this category, namely single and repetitive shot types. KALI 200, KALI 1000 and KALI 5000 belong to the single shot & Linear Induction accelerator (LIA) to the repetitive type. Kali 200 has been handed over to Defence Research and Development Organisation (DRDO), and is being used for HPM work. KALI 5000, commissioned recently , is in use at a microwaves power level of about 2 GW. All the subsystems of LIA are in the advanced stage of fabrication.

## High Power Electron Beam Units for Thermal Processing

BARC has developed a number of High Power Electron Beam (EB) machines for evaporation, melting and welding of reactive and refractory metals and their compounds. One 150 kV, 6 kW welder has been supplied to Machine Tool Prototype Factory at Ambernath, Ministry of Defence. This is being used for welding of maraging steel components. At present it is developing one 80 kV, 24 kW welder for welding thick section materials. It has, recently, developed one 30 kV, 80 kW melting unit for melting of reactive and refractory metals. Coating units have been developed for production of hard and corrosion resistant coatings as well as optical coatings on various surfaces.

*KALI 5000, undergoing commissioning trails at Trombay*

## Customer Relations Cell inaugurated at BRIT

To strengthen the customer support services and marketing operations of BRIT, a Customer Relation cell was inaugurated at the Project House, V N Purav Marg, Mumbai on 18 June, 2004.

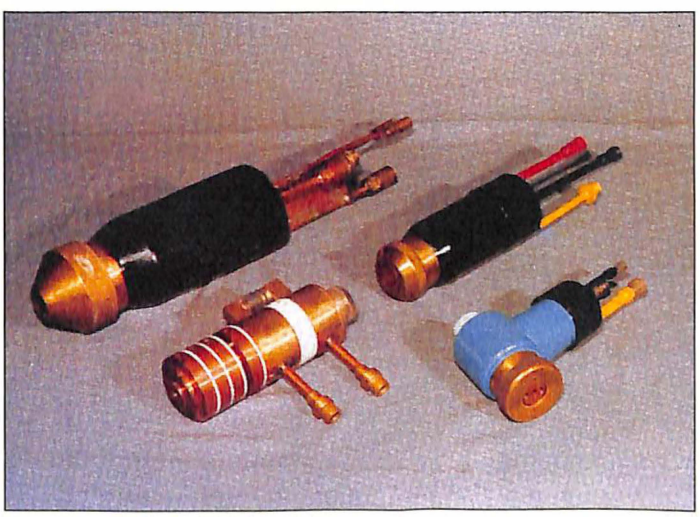
The sales and marketing of radioisotopes is carried out from this building. The day-to-day sales activities like handling initial enquiries, order registration, scheduling, pre-despatch and post-despatch communication are handled by the new Customer Relations Cell which will be part of the Customer Support Services.

## Laser Systems and Applications

BARC has developed many laser based devices which include a laser based projectile speed-measuring instrument commissioned at the Defence Metallurgical Research Laboratory, Hyderabad, and Surface Profilometer for measuring roughness. For measurement of the equation-of-state-of-materials, various shock diagnostics systems are being set up at Trombay.

## Plasma Devices and Systems

BARC has developed a large number of atmospheric plasma torches and processing systems. The high power plasma torches (40 – 300 kW) operating in transferred and non transferred arc mode, have been used for cutting, melting, spraying and other high enthalpy applications. Few notable examples are the joint work with Department of Space culminating in establishment of a plasma jet assisted thermal protection materials testing system at Trivandrum, underwater plasma cutting systems and plasma assisted aerosol generator for BARC. Plasma spray systems have been extensively used to develop special purpose thermal barrier, chemical barrier and bioceramic coatings that have drastically improved system performance. Low pressure surface coatings of 1-2 micron have also been developed using microwave plasma.



*Plasma torches developed at Trombay*

## National Security

On May 18, 1974, India conducted a peaceful underground nuclear experiment at Pokhran in Rajasthan desert. After twenty four years, on May11 and 13, 1998, here India successfully conducted five nuclear tests. These included a thermonuclear device, a fission device and three sub-kiloton nuclear devices. The Department is continuing implementation of necessary research and development as well as manufacturing activities to meet the national policy of credible minimum nuclear deterrence.

## Material Sciences

In the area of material science, R&D efforts at BARC and IGCAR are directed towards the development of materials for pressure vessels, clad and control elements, multiphase alloys and structural inter-metallics, refractory metals and alloys, preparation of radiation sources, ultra high purity metals, and other special applications.

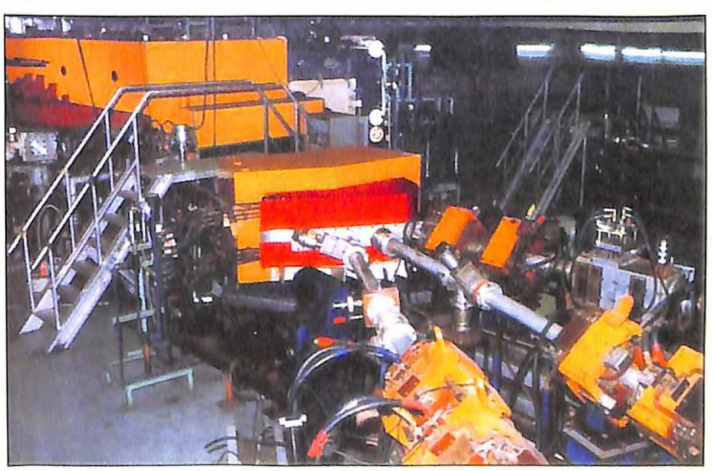
## Accelerators

DAE has established capability in design, construction and operation of accelerators used in nuclear research, isotope production and in radiation processing. The Variable Energy Cyclotron (VEC) at Kolkata, 14MV Pelletron Accelerator in Mumbai, and Synchrotron Radiation Sources (SRS) Indus-I in Indore, Folded Tandem Ion Accelerator (FOTIA) at Trombay, are the major accelerator facilities in the country.

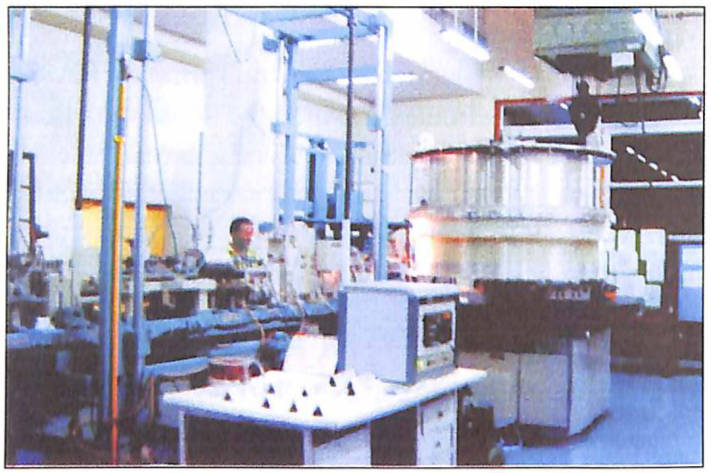
*Cyclotrons & Other Accelerators*

The **Variable Energy Cyclotron Centre** (VECC) at Kolkata is a national centre for accelerator based research. The Variable Energy Cyclotron set up here by BARC in 1977, is used for basic research. It also produces radioisotopes for various applications. The Cyclotron is utilized by over 35 national laboratories and universities.

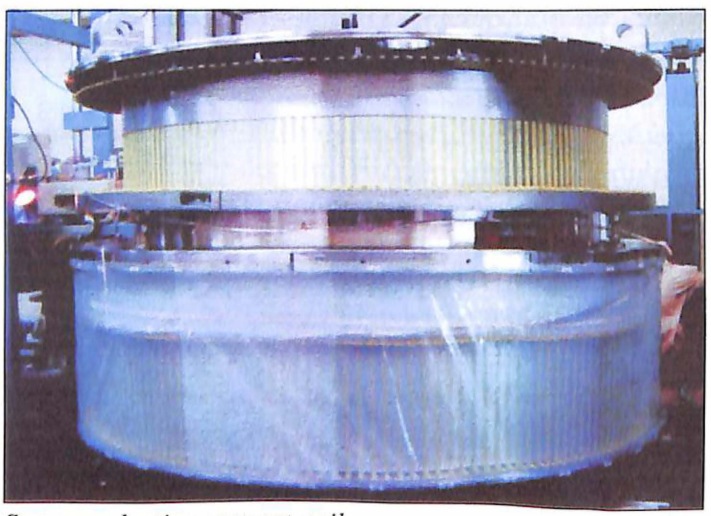
The Electron Cyclotron Resonance (ECR) ion source at VECC is an unique facility for research with heavy ions. An ECR-2 Ion Source is also connected to cyclotron. The heavy ion accelerator programme has



*Variable Energy Cyclotron, Kolkata*



*Coil winding setup for K-500 superconducting cyclotron magnet coil*



*Superconducting magnet coil*

succeeded in providing the heavy ion beams beyond 6 MeV/nucleon. So far oxygen, nitrogen, argon, neon, sulphur ion beams have been accelerated successfully. For the study of exotic nuclei, an indigenously designed and fabricated Isotope Separator-On-Line (ISOL) system is also in operation here.

Currently, VECC is constructing a K500 *Superconducting Cyclotron* and a Radioactive Ion Beam (RIB) facility for accelerating radioactive ions.

*Synchrotron and its Utilization*

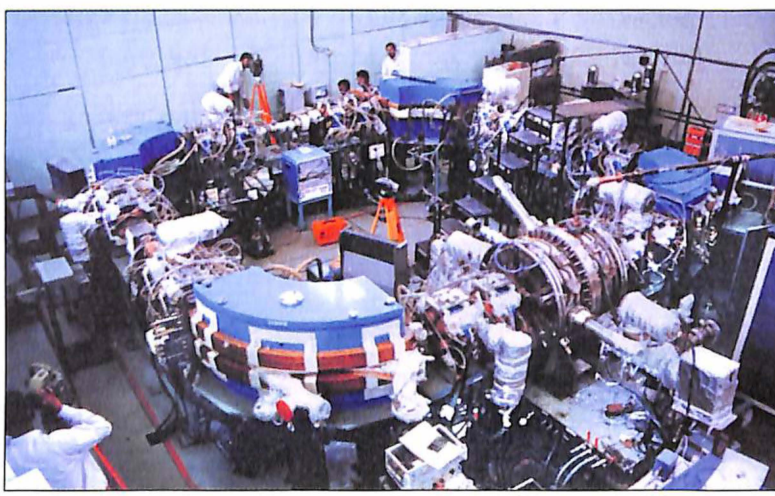
In late eighties, accelerators related R&D in India got a boost with the setting up of a dedicated establishment the Centre for Advanced Technology (CAT). Of the two Synchrotron Radiation Sources (SRS) planned for setting up at this centre, to be used as national research facility, the 450-MeV Indus-1 became operational in 1998. Current was stored in Indus-1, for the first time, in April 1999. This SRS is operating routinely.

The construction of Indus-2 is in progress. Efforts to enlarge the Indus-1 storage ring user community are continuing.

Only a dozen countries have the capability in designing and construction of such complex accelerators.

*FOTIA*

For providing light and heavy ion beams for use in basic and applied research in nuclear, atomic and material



*Synchrotron radiation source Indus-1 at CAT, Indore*

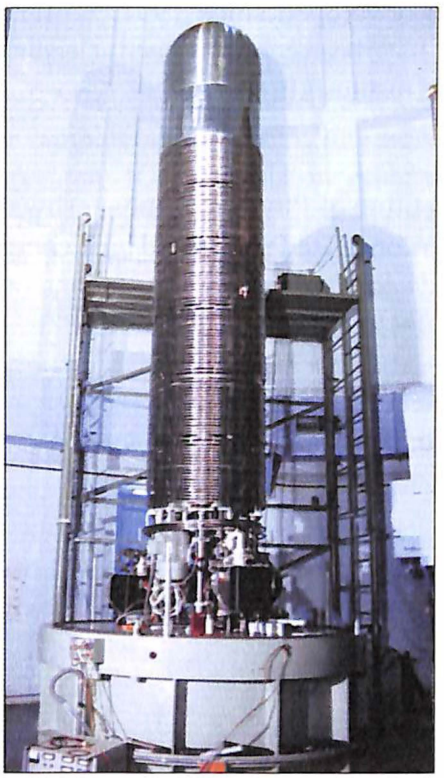
sciences, BARC had commissioned a Folded Tandem Ion Accelerator (FOTIA) in April 2000 at Trombay.

*Pelletron*

The BARC-TIFR *Pelletron Accelerator Facility* at Mumbai, operating for over a decade, has made an impact internationally, in the field of nuclear research. To further increase the beam energy of Pelletron, a superconducting linear accelerator (LINAC) is being set up. The Phase-I of LINAC is operational now.

*Other Accelerators*

Recently, IGCAR has successfully commissioned at Kalpakkam, a 1.7 million-volt Tandetron accelerator,



*Folded tandem ion accelerator (FOTIA) at Trombay*


*Full scale prototype of steadystate superconducting tokamak (SST-1) cryostat and vacuum vessel*

*LINAC*

with high current and heavy ion capability.

The design of a 30 mA, 10 MeV Proton LINAC has been initiated at BARC.

### Fusion & Other Plasma Technologies

The Institute for Plasma Research (IPR), Ahemdabad operates Aditya Tokamak for the studies on high temperature magnetically confined plasmas. Studies conducted on this tokamak have had important implications on the nature of particle transport.

To address physics and technology issues related to advanced Tokamak configurations, SST-1, one of the world's first Superconducting Steady State Tokamaks with elongated diverter plasmas and 1000 second operation capability, is being set up at IPR.

## BASIC RESEARCH

The research centres of DAE are engaged in basic research in the areas relevant to the programmes they are pursuing. In addition, the autonomous research institutes, supported by grant-in-aid by DAE, are the centres of excellence in basic research that ranges from mathematics to computers, physics to astronomy, and biology to cancers.

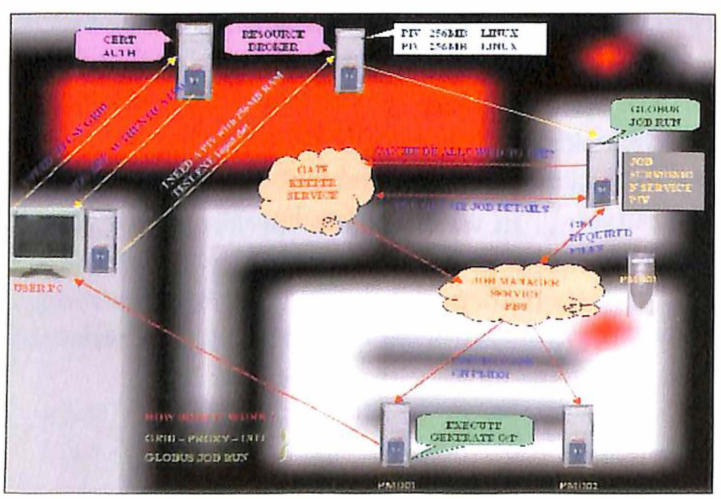
### *Mathematics & Computation*

In the field of mathematics and computation science, TIFR pursues academic programmes in algebra,

algebraic geometry, Lie group, egodic theory, number theory, combinatories and topology at Mumbai and applications of mathematics at Bangalore; the *Harish Chandra Research Institute*, Allahabad, carries out research in advanced fields of mathematics and theoretical physics including astrophysics, high-energy physics, condensed matter physics and mathematical physics, and the *Institute of Mathematical Sciences* at Chennai, Tamil Nadu is engaged in the research in the fields of Theoretical Physics, Mathematics & Computer Science.

In its effort to develop teraflop parallel super-computers with more than 1000 processors, BARC achieved a very significant milestone by commissioning a supercomputer with 128 processors, giving a computational speed of 360 Gigaflops. More than 15 different models of Anupam series of supercomputers have been developed since 1991. So far, 37 super-computers have been commissioned at leading R&D and educational institutes in the country.

*Supercomputer Anupam developed at Trombay*

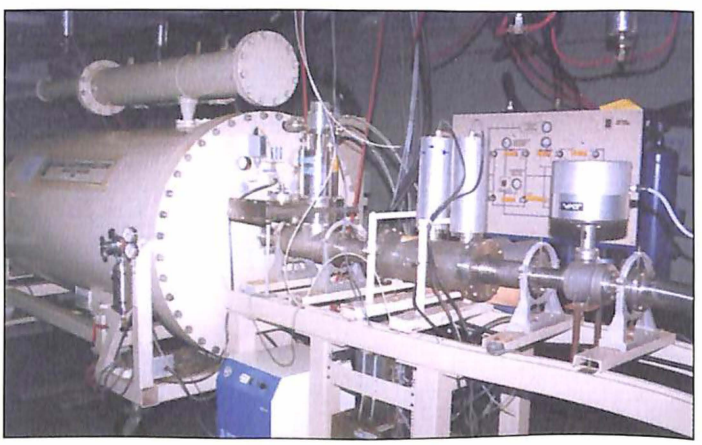



*Execution of sequence of job in grid environment at VECC*

## *Physics*

The Institute of Physics, Bhubaneshwar conducts research in condensed matter and high energy, nuclear, atomic and accelerator based physics and other related subjects. One of the main experimental facilities at the Institute is the Ion Beam Accelerator. The research facilities set up here are used by the researchers from within the Institute as well as from other research institutes and universities in India.

At the Harish-Chandra Research Institute, the research in physics covers the work on understanding the ground state of open string theories, which possess



*Accelerator mass spectomertry tank at the Institute of Physics, Bhubneswar, Orissa*

tachyons. Supergravity solutions with a positive cosmological constant are the other major areas of studies.

The National Facility for High-Field NMR at TIFR provides state-of-the-art services to researchers. Studies have resulted in several advances in the mapping of biomolecules

## *Seismic Studies*

BARC monitors seismic activities at Garibidanur in Karnataka, Delhi and Trombay seismic stations. In addition to routine seismic analysis, research is also carried out in surface wave studies, development of analysis software and in other front line areas.

*Superconductivity*

The field of superconductivity holds big promise for the future. BARC has completed a test facility to characterize samples of superconducting cables at liquid helium temperature. IGCAR is also working towards the development of SQUID based systems for material technology including non-destructive testing.

*Seismic station at Gauribidanur, near Bangalore, Karnataka*

*SQUID fabrication facility at IGCAR*

*DC SQUID sensor with on-chip integrated input coil*

*Astronomy*

In the field of radioastronomy, a *Radiotelescope Array*, set up in the Nilgiri Hills near Ootacamund, Tamil Nadu, has been in use for decades. It is used in the studies of distant extragalactic radio-sources and interplanetary objects.

At Narayangaon, near Pune, Maharashtra, the *Giant Metre Wave Radio-Telescope* (GMRT) with 30 gigantic parabolic dishes, has been in operation, fathoming the universe. Set up by TIFR, the telescope, is a frontline research facility in radioastronomy and is world's most powerful radiotelescope in its range. GMRT is now a full fledged international observational facility for radioastronomy below 1.4 GHz. A number of national and international users carried out research in astronomy, on this telescope.

Another international class astronomy-research facility *GRACE* is being set up by BARC at Mount Abu, Rajasthan. GRACE comprises four radiotelescopes namely the TACTIC, MACE, BEST and MYSTIQUE.

TACTIC (Tera-electron-Volt Atmospheric Cerenkov Telescope with Imaging Camera), the first-ever Indian imaging gamma-ray telescope, has been commissioned at Mt. Abu, Rajasthan. It is used for high-sensitivity observations of cosmic gamma ray sources above 1 TeV energy.

*Giant metrewave radio telescope at Narayangaon, near Pune*

*STEP Zeeman atomic absorption spectrometer at the Centre for Compositional Charactri-zation of Materials, Hyderabad*

*Transgenic mice generated by injecting pK14-EF into single cell embryos to study squamous cell carcinoma*

*Chemistry*

BARC provides state-of-the-art analytical and chemistry related services to nuclear power plants, research reactors and heavy water plants, and carries out research in the frontier areas of chemistry.

It also offers specialised analytical chemistry services to various user organizations within DAE and outside. The type of samples analysed cover a wide spectrum of materials such as metals and alloys, organic and organometallic compounds, inorganic compounds, rocks and minerals, nuclear and strategic materials, high purity materials, environmental and biological materials and others.

BARC's Centre for Compositional Characterization of Materials (CCCM) in Hyderabad provides high quality analytical services to various departmental, governmental and private institutions.

*Biology*

At Trombay, the research in bio-sciences is directed towards evolving high yielding food crops, delaying or preventing post-harvest losses by increasing shelf life, developing modalities for low dose cancer radiotherapy and employing molecular and isotope techniques in basic biology for disease diagnosis and finger printing of individuals and population.

The National Centre for Biological Sciences of TIFR at Bangalore has been working on new research initiatives in the frontline areas of modern biology.

The Saha Institute of Nuclear Physics, Kolkatta is engaged in research elucidating the structure function correlation of biomolecules at the cellular and molecular level.

DAE supports synergistic interaction amongst the national laboratories and the university systems through a number of mechanisms such as utilisation of DAE's research facilities through Inter-University Consortium, funding of extra-mural research, grant-in-aid to institutes of national eminence, and others.

## UGC-DAE Consortium for Scientific Research

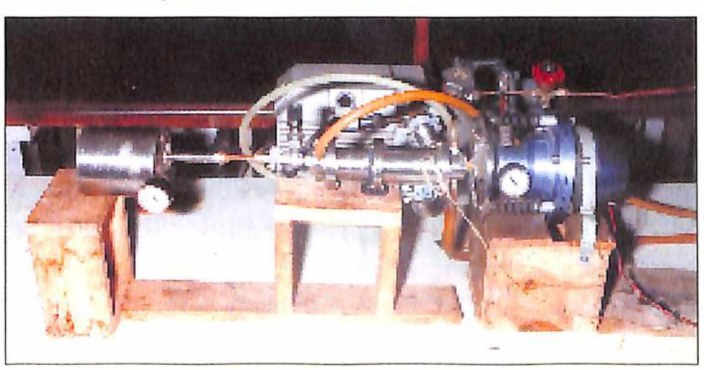
DAE and the University Grants Commission (UGC) had signed a MoU (memorandum of understanding) in 1989 for setting up Inter-University Consortium of DAE Facilities (IUC-DAEF) at Indore. The Consortium, now known as UGC-DAE Consortium for Scientific Research, functions under the control of UGC. The scope of cooperation between UGC and DAE has been broadened to include all programmes pursued by DAE in the area of physical, chemical, life and engineering sciences.

*Academic Programmes*

The research centres of DAE are recognized by the universities of their region, as the centres for research leading to postgraduate degrees. A number of scientists and engineers are recognized as post-graduate teachers by the respective universities. The employees are encouraged to register and obtain research degrees based on the work done in these research centres.

## Funding of Extra-Mural Research

DAE encourages and promotes scientific research in universities, institutes and laboratories in the areas of relevance to the Department. This is done through the **Board of Research in Nuclear Sciences (BRNS)** and the **National Board for Higher Mathematics (NBHM)** both at Mumbai.



*Experimental set up of the Linear Compressor developed by IIT-Bombay for liquefaction of nitrogen.The project was sponsored by BRNS*

*The Test Specimen (beam-column joint of turbine building of 500 MW TAPP 3&4) being tested on the 500 Ton Test Frame built under the BRNS Project, "Experimental and Analytical Evaluation of Nonlinear Behavior of RCC Frame Structures and Joints" at SERC, Chennai*

BRNS is an advisory body of the DAE to recommend financial assistance to universities, academic institutions and national laboratories. It supports high quality R&D projects and lays emphasis on collaborative programmes amongst DAE organisations and the organisations outside the Department, and provides financial assistance to organize symposia/conferences/ workshops on topics of relevance to DAE programmes.

To motivate young scientists to adopt a career of research, BRNS awards projects to them. It has initiated DAE Graduate Fellowship Scheme also. The Board awards Dr. K.S. Krishnan Research Associateships to attract highly talented young scientist and technologists. Its DAE-BRNS Senior Scientist Scheme aims at utilizing the expertise of active retired scientists/engineers who were involved in high quality research in the units of DAE or any National Laboratory or Universities/Institute, and who after retirement, are keen to carry out R & D in the field of their choice and of interest to DAE. It offers Homi Bhabha Chair to honour distinguished scientists. BRNS also encourages visiting scientist programmes for promoting active interaction with senior level scientists.

BRNS has also introduced "DAE Science Research Council (DAE-SRC) Award" that aims to setup frontier area research units around individuals.

During the year 2003-04, the Board approved 134 new research projects at a total financial assistance of Rs.12 crore. Financial sanctions involving an expenditure of Rs. 9.79 crore were also committed for various ongoing research projects.

DAE, through the National Board for Higher Mathematics (NBHM) is enganged in promoting excellence in higher mathematics, education and research in the country. The Board implements programmes which include development of mathematical centres, scholarships to research fellows at doctoral and post-doctoral levels, travel assistance to young mathematicians for attending conferences/seminars etc., support to mathematics libraries, assistance to conferences, monitoring mathematics Olympiads, and others.

In collaboration with the International Mathematical Union, NBHM has also initiated schemes for making mathematical literature accessible through electronic-communication.

NBHM operates schemes such as helping the development of mathematical centres, giving scholarships to research fellows at doctoral and postdoctoral levels, travel assistance to young mathematicians for attending conferences/seminars etc., visiting professorship, assistance for research project/schemes, support to libraries, assistance to conferences, monitoring mathematics Olympiads, and others. In collaboration with the international mathematical union, NBHM initiated schemes for making mathematical literature accessible through electronic-communication. During the year 2003-04, an annual budget of Rs.7.47 crore was allocated to the Board.

### *Grant-in-Aid to institutions and cancer hospitals*

DAE provides grant-in-aid to seven institutes of national eminence engaged in basic and applied research ranging from natural sciences, mathematics and astronomy to fusion research. The Department also supports a society which manages education for the children of DAE employees.

There has been a growing synergy between these research institutions and the Research and Development Units of DAE. Several joint projects were undertaken between the DAE units and the aided Institutions.

During the financial year 2003-2004, the grant-in-aid of over Rs. 318.46 crore was provided by DAE to these institutions.

DAE also provides funds to cancer hospitals in the country to support small projects and purchase of radiation related equipment for cancer treatment. The financial support provided in this regard during the year 2003-2004 was to the tune of Rs. 5.86 crore. The Department, under a Tripartite Agreement with the North-Eastern Council and the Government of Assam, is revitalizing Dr. B. Barooah Cancer Institute (BBCI), Guwahati.

DAE has also initiated out-reach efforts in cancer care programme that include, creation of better network between cancer institutions in the country focussing on research and development, training and preparation of protocols for treatment as well as incentive for indigenisation of radiation related equipment for cancer treatment.

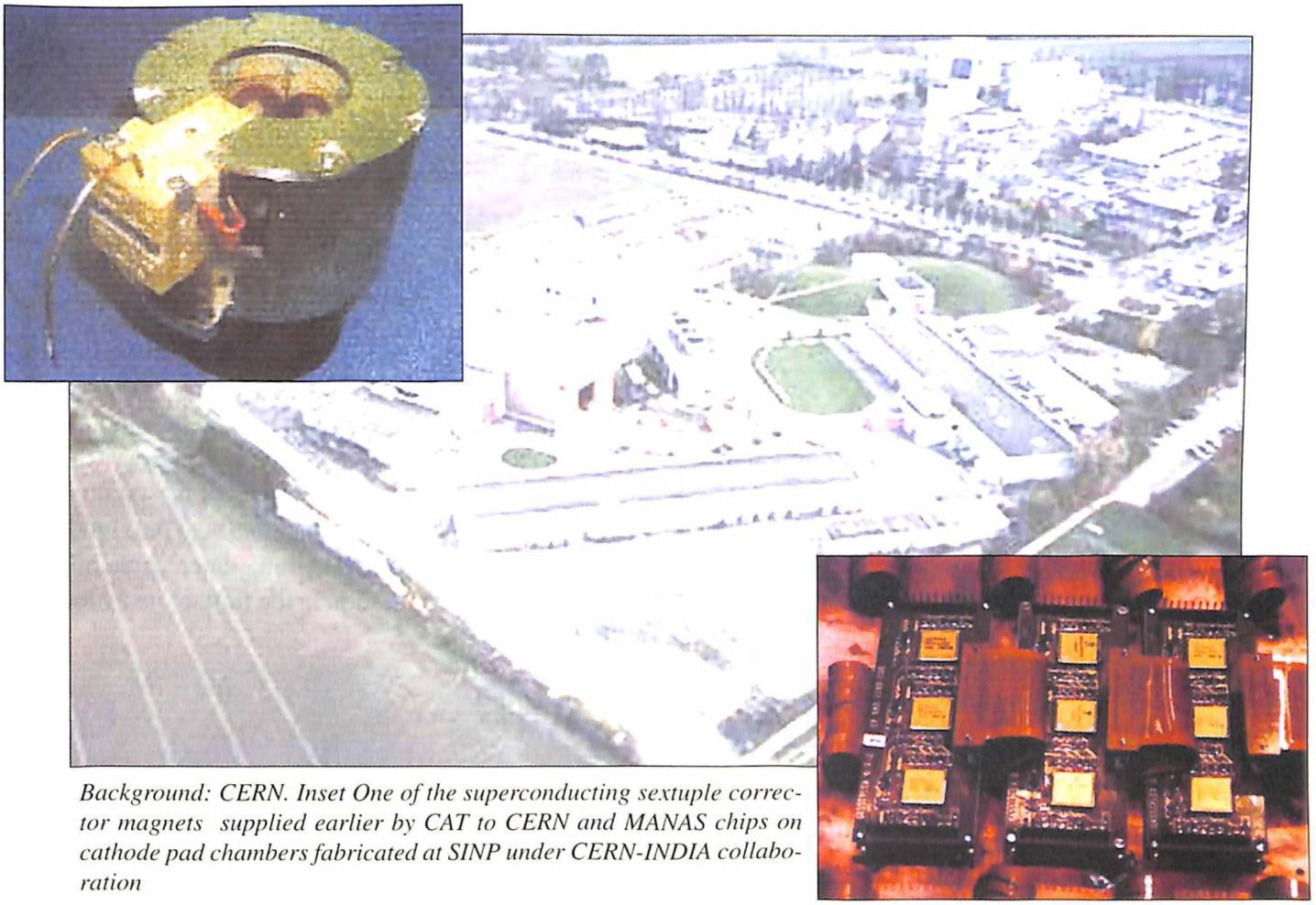
## International Research Collaboration

Under a cooperation agreement, signed in March 1996, DAE, through its units, is required to develop and supply some of the sophisticated components of Large Hadron Collider (LHC), a particle accelerator under construction by European Centre for Nuclear Research (CERN) at Geneva, Switzerland.

Under the collaboration, the first shipment of 190 precision magnet positioning system jacks and the 1000th superconducting correction magnet made by CAT for the LHC was also sent to CERN in 2003.

At CERN, BARC has a strong collaborative participation with international mega project which includes supply of 100 numbers of large area silicon strip detectors for use in CMS facility at CERN.

Contributions of DAE and other organisations in India to the activities of CERN have earned the "Observer" status for India at CERN.



*Background: CERN. Inset One of the superconducting sextuple corrector magnets supplied earlier by CAT to CERN and MANAS chips on cathode pad chambers fabricated at SINP under CERN-INDIA collaboration*

BARC's participation in the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) in the Brookhaven National Laboratory of United States, the Large Hadron Collider and its experiments CMS and ALICE under construction at CERN, participation of Indian scientists in several synchrotron and other facilities in several laboratories abroad has earned considerable respect for Indian capabilities.

BARC participated in an IAEA sponsored international effort for searching of Sr-90 "orphan sources" at Georgia. Aerial Gamma Spectrometry System (AGSS), developed by BARC, was deployed in the search operations. The technical superiority of this system in detecting the orphan sources and the expertise of BARC staff in locating the same and training of the staff of Nuclear Radiation and Safety Services (NRSS), Ministry of Environment, Georgia in the operation of the AGSS system, were highly appreciated by both the Government of Georgia and IAEA.

## Technology Transfer

The multi-disciplinary research carried out in DAE research centres has been generating, several spin-off technologies that are transferred to industry. These centres also provide various technical services that benefit industry. Several technologies developed at BARC have been transferred for commercial production. Recent ones transferred to industry are on-line domestic water purifier, electrolyzing of reactor channel sealing plug jaws, foldable solar dryer, and improved lascan dia guage. The technology of Nisargruna, a biogas plant based on biodegradable waste, was transferred to seven parties. The instrumented pipe inspection gauge is now commercially available to inspect 12-inch oil pipe lines.

The Technical Services offered by DAE research centres to industry are related to non-destructive testing, stress measurements, acoustic topography, material characterisation and others.

BARC offers complete range of conventional fabrication and machining capacity to various units of DAE. It also offers specialized design and development expertise, backed by state-of-the-art facilities and co-ordinate machining facilities, for developing sophisticated equipment for various applications.

The Centre has provided analytical services for determining the radioactivity content, in packed drinking water samples & samples from pharmaceutical companies.

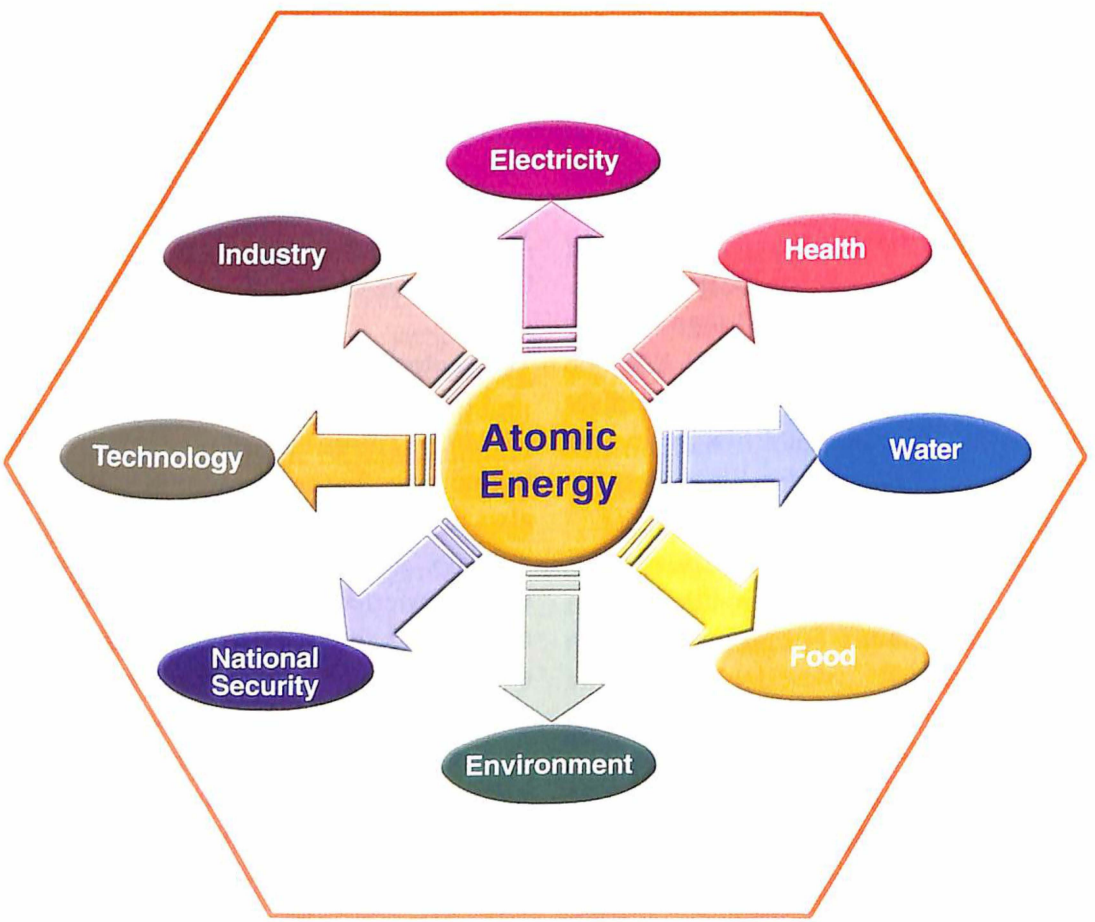
## Intellectual Property Protection

To protect the intellectual property created during the process of research and development in the R&D organisations of DAE, an Intellectual Property Rights Cell of DAE works as a nodal agency for all the IPR related matters including filing of patents within India and abroad.

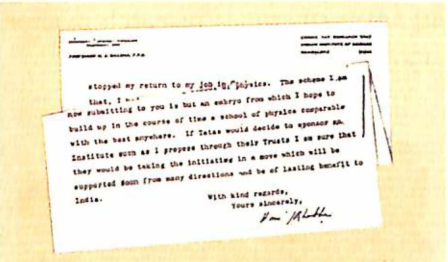
So far, DAE has filed 137 patent applications out of which 50 have been granted and of which 33 have been in force.

## International Relations

A designated member of the Board of Governors of the International Atomic Energy Agency (IAEA) since its inception, India has been taking active part in policy management and programme of the Agency. India offers training facilities, fellowships, scientific visits, etc. to foreign scientists and provides the services of its scientists for expert assignments to other countries both through IAEA and to countries with which we have entered into bilateral agreements for cooperation in the field of peaceful uses of atomic energy.



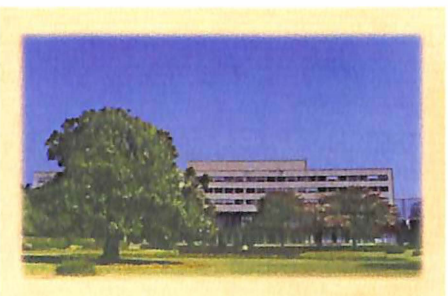
• March. 12, 1944 : Dr. Homi Jehangir Bhabha writes to Sir Dorabji Tata Trust for starting nuclear research in India.



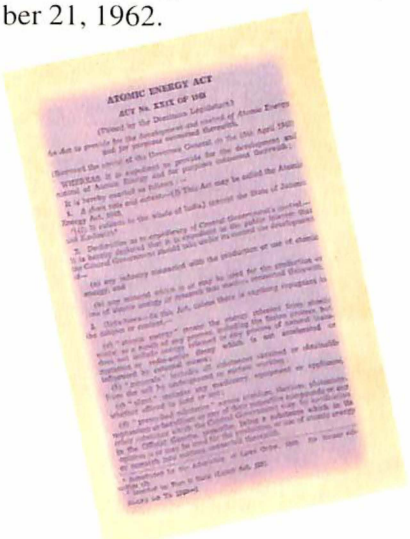
stopped my return to my job in physics. The scheme I am
now submitting to you is but an embryo from which I hope to
build up in the course of time a school of physics comparable
with the best anywhere. If Tatas would decide to sponsor an
Institute such as I propose through their Trusts I am sure that
they would be taking the initiative in a move which will be
supported soon from many directions and be of lasting benefit to
India.

With kind regards,
Yours sincerely,

• June 1, 1945: Tata Institute of Fundamental Research (TIFR) was set up at Mumbai as a result of initiative taken by Dr. Homi Bhabha. The Institute is inaugurated on December 19, 1945.



• April 15, 1948 : Atomic Energy Act is passed. This is replaced by the Atomic Energy Act 1962 on September 21, 1962.



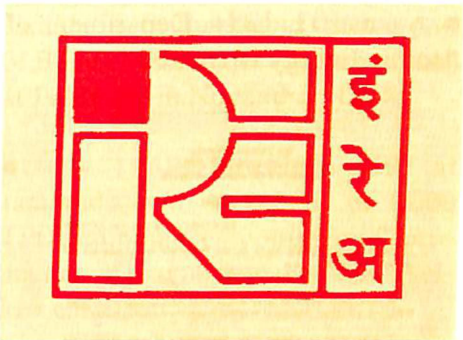
ATOMIC ENERGY ACT

ACT No. XXIX OF 1948

• August 10, 1948 : Atomic Energy Commission is constituted.

• July 29,1949 : Rare Minerals Survey Unit brought under Atomic Energy Commission and named as 'Raw Materials Division' (RMD), with Headquarters in New Delhi. In 1958, this unit becomes the Atomic Minerals Division (AMD), and later shifts to Hyderabad in 1974. On July 29, 1998 it is renamed as Atomic Minerals Directorate for Exploration and Research (AMD).

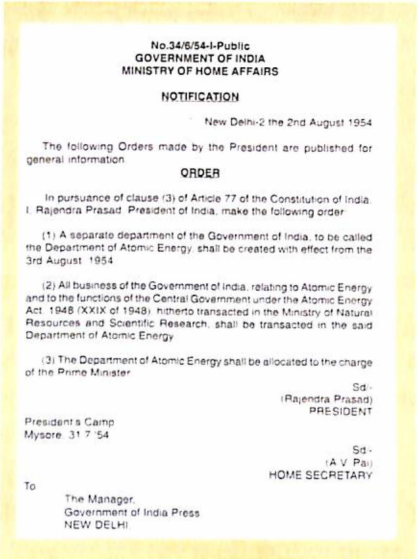
• August 18, 1950 : Indian Rare Earths Limited (IREL), owned by the Government of India and Government of Travancore, Cochin, is set up for recovering minerals, processing of rare earths compounds and Thorium - Uranium concentrates. In 1963, IREL becomes a full-fledged government undertaking under the Department of Atomic Energy (DAE).




• April 1951: Uranium Deposit at Jaduguda is discovered by AMD. Drilling operations commence in December 1951.

• December 24, 1952 : Rare Earths Plant of IREL at Alwaye, Kerala, is dedicated to the nation and production of Rare Earths & Thorium - Uranium concentrate commences.

• August 03, 1954 :Department of Atomic Energy is created.



No.34/6/54-I-Public
GOVERNMENT OF INDIA
MINISTRY OF HOME AFFAIRS

NOTIFICATION

New Delhi-2 the 2nd August 1954

The following Orders made by the President are published for general information

ORDER

In pursuance of clause (3) of Article 77 of the Constitution of India, I, Rajendra Prasad, President of India, make the following order

(1) A separate department of the Government of India, to be called the Department of Atomic Energy, shall be created with effect from the 3rd August, 1954

(2) All business of the Government of India, relating to Atomic Energy and to the functions of the Central Government under the Atomic Energy Act, 1948 (XXIX of 1948), hitherto transacted in the Ministry of Natural Resources and Scientific Research, shall be transacted in the said Department of Atomic Energy

(3) The Department of Atomic Energy shall be allocated to the charge of the Prime Minister

Sd/-
(Rajendra Prasad)
PRESIDENT

President's Camp
Mysore, 31.7.'54

Sd/-
(A.V. Pai)
HOME SECRETARY

To
The Manager,
Government of India Press
NEW DELHI

• 1955: Saha Institute of Nuclear Physics (SINP), Kolkata, becomes the grant-in-aid institute of DAE.

• August 01, 1955 : Thorium Plant at Trombay goes into production. (Plant is now closed).

• 1956 : AMD discovers uranium mineralisation at Umra, Rajasthan.

• August 04, 1956 :APSARA - the first research reactor in Asia, attains criticality at Trombay, Mumbai.

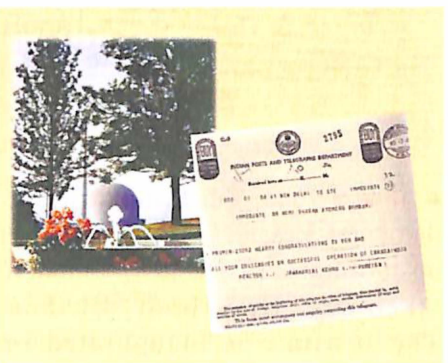
• January 20, 1957 : Atomic Energy Establishment, Trombay (AEET) is inaugurated. It is named as Bhabha Atomic Research Centre (BARC) on January 22, 1967 after its founder Dr. Homi Jehangir Bhabha.

• August 19, 1957 : AEET Training School starts functioning at Trombay. It is shifted to its present location at Trombay in 1970.

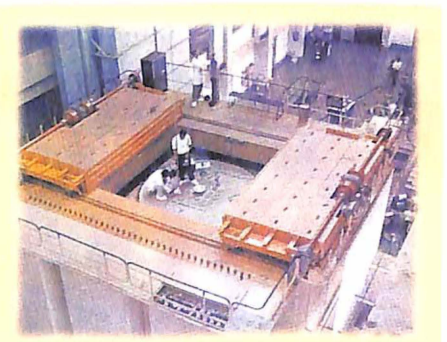
• January 30, 1959 :Uranium Metal Plant at Trombay produces first ingot of Uranium.

• February 19, 1960 : First lot of 10 Fuel Elements for CIRUS reactor, is fabricated at Trombay.

• July 10, 1960 : CIRUS – the 40 MWt (thermal) research reactor, attains criticality at Trombay.



• January 14, 1961 : Research Reactor ZERLINA attains criticality. (Decommissioned in 1983).

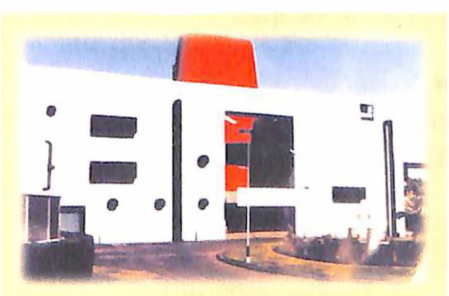


• 1962 : Tata Memorial Centre comprising Tata Memorial Hospital and Cancer Research Institute, becomes a grant-in-aid institute of DAE.

• 1965: Indian Rare Earths Ltd. (IREL) takes over operation of Mineral Processing Unit at Manavalakurichi in Tamil Nadu and at Chavara in Kerala.

- Seismic station is set up at Gauribidanur, near Bangalore, Karnataka .

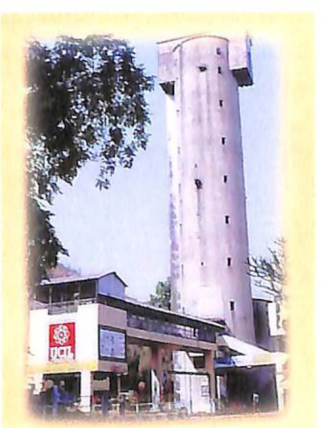
• January 22, 1965 : Plutonium Plant is inaugurated at Trombay.



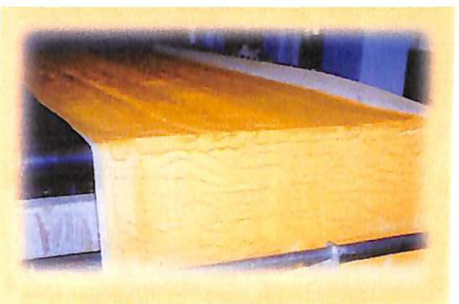
• April 11, 1967 : Electronics Corporation of India Limited (ECIL) is set up at Hyderabad for producing electronic systems, instruments and components.

• June 1, 1967 : Power Projects Engineering Division (PPED), Mumbai is formed. The Division becomes Nuclear Power Board on August 17, 1984. The Board is incorporated as Nuclear Power Corporation of India Limited (NPCIL) on September 17, 1987.

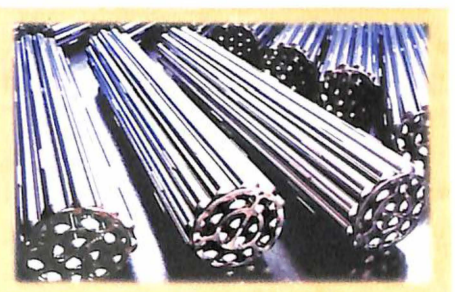
• October 4, 1967: Uranium Corporation of India Limited (UCIL) is established with head quarters at Jaduguda in Jharkhand (then a part of Bihar).Mine shaft is commissioned at Jaduguda in November, 1968.



• May 1968: Uranium Mill at Jaduguda, with a capacity of 1,000 TPD, commences commercial production of magnesium diuranate (yellow cake).



• December 31, 1968 : Nuclear Fuel Complex is set up at Hyderabad, Andhra Pradesh.



• March 12,1969 : Reactor Research Centre starts at Kalpakkam, Tamil Nadu. The Centre is named as the Indira Gandhi Centre for Atomic Research (IGCAR) on December 18, 1985.

• May 01, 1969 : Heavy Water Projects is constituted at Mumbai. Later, this becomes the Heavy Water Board on Feburary 17, 1989.

• October 02, 1969 : Tarapur Atomic Power Station commences commercial operation.

• 1970 : AMD hands over Uranium Deposits at Narwapahar (Jharkhand) to UCIL.

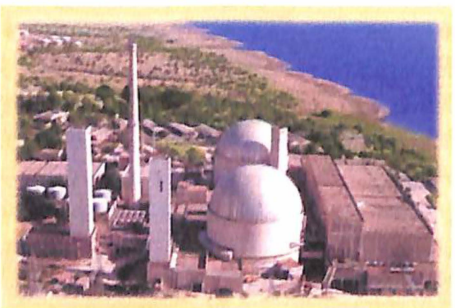
• September 06, 1970 : Uranium-233 is separated from irradiated Thorium.

• February 18, 1971 : Plutonium fuel for Research Reactor PURNIMA-I is fabricated at Trombay. It attains criticality on May 18, 1972.

• 1972 : AMD hands over beach sand heavy mineral deposits of Chhatrapur, Orissa and Neendakara-Kayankulam, Kerala to IRE.

• February 3, 1972 : DAE Safety Review Committee is formed.

• November 30, 1972 : Unit-1 of Rajasthan Atomic Power Station at Rawatbhatta, Rajasthan, begins commercial operation. Unit II goes commercial on November 1, 1980.



• May 18, 1974 : Peaceful underground Nuclear Experiment is conducted at Pokhran, Rajasthan.

• June 16, 1977 : Variable Energy Cyclotron (VEC) becomes operational at Kolkata.

• July 1977 : Heavy Water Plant, Baroda, Gujarat is commissioned.

• July 1978 : Heavy Water Plant, Tuticorin, Tamil Nadu is commissioned.

• 1979 : AMD hands over uranium deposits, Bhatin and Turamdih (East), Jharkhand, to UCIL.

• November 18, 1979 : Plutonium-Uranium Mixed Oxide (MoX) fuel is fabricated at Trombay, Mumbai.

• November 19, 1982 : Power Reactor Fuel Reprocessing Plant (PREFRE) of BARC is commissioned at Tarapur .

• November 15, 1983 : Atomic Energy Regulatory Board (AERB) in Mumbai is constituted.

• 1984 : Sandstone-type uranium deposit at Domiasiat, Meghalaya is discovered.

• January 27, 1984 : Unit I of Madras Atomic Power Station at Kalpakkam starts commercial operation. Unit II goes commercial on March 21, 1986.

• February 19, 1984 : Centre for Advanced Technology (CAT) at Indore (Madhya Pradesh) is inaugurated.

• March 08, 1984 : Plutonium - Uranium mixed Carbide Fuel for Fast Breeder Test Reactor (FBTR) is fabricated at Trombay.

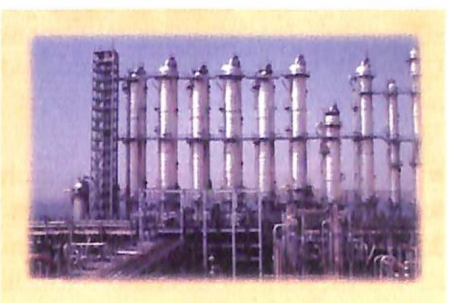
• May 10, 1984 : Research Reactor PURNIMA-II, a Uranium-233 fuelled homogenous reactor, attains criticality at Trombay.

• 1985 : AMD hands over the Bodal uranium deposit to UCIL.

• March 05, 1985 : Waste Immobilisation Plant (WIP) at Tarapur is commissioned.

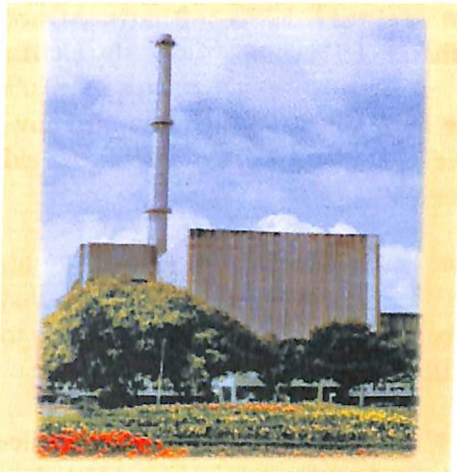
• March 25, 1985 : The Institute of Physics, Bhubaneswar, Orissa, becomes a grant-in-aid institute of DAE. The Institute was earlier established in 1974 by the Government of Orissa as an all-India institute of research and advanced studies.

• March 31, 1985 : Heavy Water Plant, at Talcher, Orissa is commissioned.

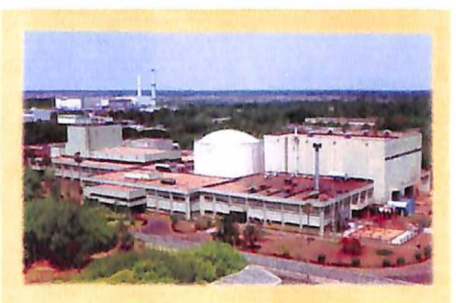


• April 1, 1985 : Heavy Water Plant, at Kota, Rajasthan is commissioned.

• August 08, 1985 : Research Reactor DHRUVA (100 MWt) attains criticality. It attains full power on January 17, 1988.



• October 18, 1985 : Fast Breeder Test Reactor (FBTR) of IGCAR attains criticality at Kalpakkam. FBTR fuel attains burn up of 10,000 MWd/T in the year 2001



• 1986: Institute of Mathematical Sciences, Chennai, Tamil Nadu, becomes a grant-in-aid institute of DAE. The Institute was earlier founded in 1962, as a national institution for higher learning for promotion of fundamental research in frontier disciplines of mathematical sciences.

- Dredge Mining, Mineral Separation and Synthetic Rutile Plant at OSCOM, Chhatrapur, Orissa is commissioned by IRE.

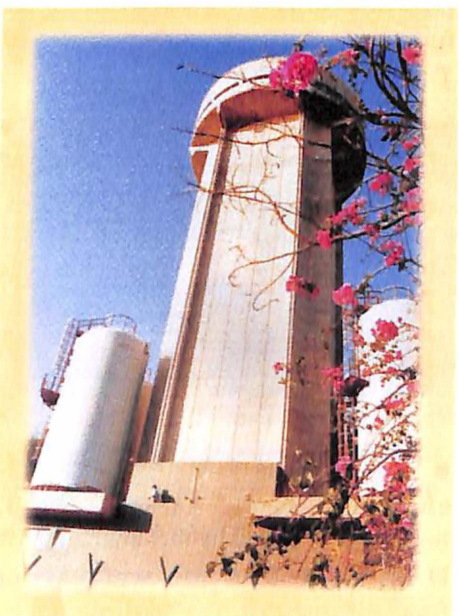
- HERO Project for production of heavy rare earths oxide is commissioned at Alwaye, Kerala.

• October 1986 : Bhatin Mine, Jharkhand is commissioned by UCIL.

• December 1986 :Uranium Recovery Plant of UCIL is commissioned at Mosaboni, Jharkhand.

• 1987 : AMD hands over Turamdih (West) uranium deposits to UCIL, and beach sand deposits in Tamil Nadu to IREL.

• December 30, 1988 : 14 MV Pelletron Accelerator is inaugurated in Mumbai. The accelerator is a joint endeavour of BARC & TIFR.



• 1989 : AMD Training School is inaugurated.

- Board of Radiation and Isotope Technology (BRIT) is constituted.

• January 3, 1989 : Regional Radiation Medicine Centre (RRMC) at Kolkata is inaugurated.

• March 12, 1989 : Unit I of Narora Atomic Power Station, Uttar Pradesh attains criticality. Its Unit II attains criticality on October 24, 1991.

• 1990 : Dolostone-hosted unique type of uranium mineralisation is discovered in the South-Western margin of Cuddapah basin.

- Mineral Research Development Centre (MRDC) of IREL is launched at Kollam.

• November 09, 1990 : Research Reactor PURNIMA-III, a Uranium-233 fuelled reactor, attains criticality.

• 1991: AMD discovers uranium mineralisation at Lambapur, Nalgonda district, Andhra Pradesh. Produces upgraded xenotime concentrate at 'Pre-concentrate Upgradation Plant' at Kunkuri.

• February 1, 1991 : Heavy Water Plant, at Hazira, Gujarat is commissioned.

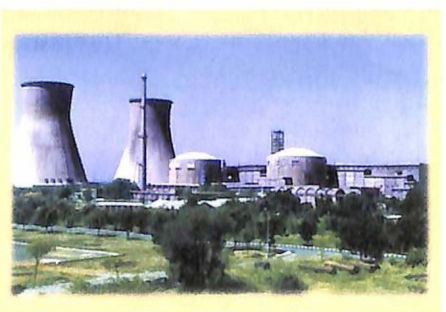
• May 16, 1991: First Electron Cyclotron Resonance (ECR) heavy ion source of the country becomes operational at the Variable Energy Cyclotron Centre, Kolkata.

• 1992: Mehta Institute of Mathematics and Mathematical Physics, Allahabad, Uttar Pradesh, (now Harish Chandra Institute of Mathematics and Mathematical Physics), comes under the DAE umbrella, as a grant-in-aid institute.

- Significant heavy mineral concentration along the East Coast, Andhra Pradesh, is identified.

- New Thorium Plant at OSCOM, Chhattrapur, Orissa is commissioned by IRE.

• September 03, 1992 : Unit-1 of Kakrapar Atomic Power Station attains criticality. Unit II attains criticality on January 08, 1995



• December 1992 : Heavy Water Plant, Manuguru, Andhra Pradesh is commissioned.

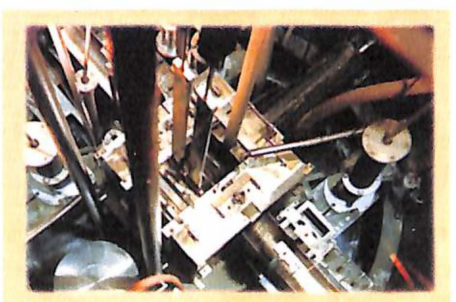
• 1995 : Research Irradiator Gamma Chamber 5000 is launched by BRIT.

• January 1995 : Narwapahar mine of UCIL is inaugurated.

• March 27, 1996 : Kalpakkam Reprocessing Plant (KARP) is cold commissioned. KARP is dedicated to the nation on September 15,1998.

• October 1, 1996: Institute for Plasma Research, Ahemdabad, Gujarat, becomes an autonomous institute of DAE.

• October 20, 1996 : Kalpakkam Mini Reactor (KAMINI), with Uranium-233 fuel, attains criticality at Kalpakkam, Tamilnadu.

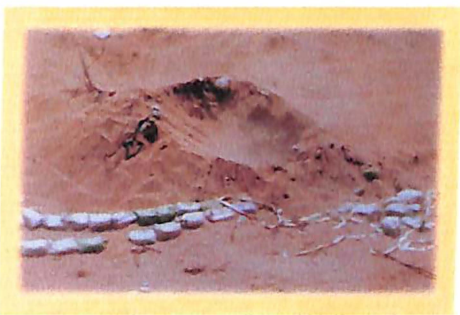


• 1997 : AMD discovers uranium mineralisation in brecciated limestone at Gogi, Gulbarga district, Karnataka in the Bhima basin.

- Microzir Plant of IRE is commissioned in Chavara, Kerala.

• December 1997: PRYNCE (95% Neodymium Oxide) Plant is commissioned at Rare Earths Division of IREL.

• May 11 & 13, 1998 : Five underground nuclear tests are conducted at Pokhran Range, Rajasthan.

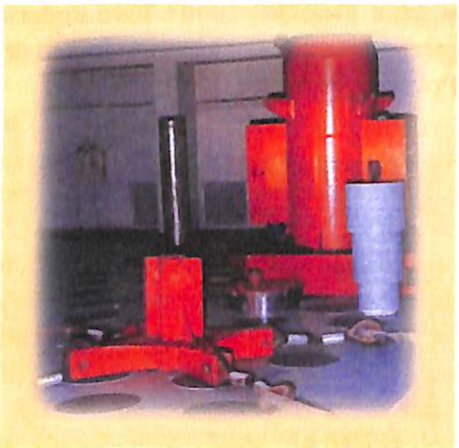


• August 10, 1998 : The 500 keV industrial electron accelerator developed indigenously by BARC is commissioned for its first phase of operation.

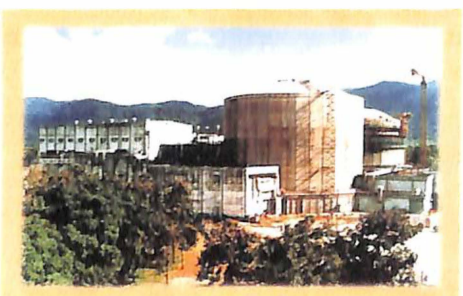
- Ammonium diuranate production commences at Rare Earths Division of IRE, at Alwaye, Kerala.

• April 22, 1999 : 450 MeV Synchrotron Radiation Source Indus-1 achieves electron beam current of 113 milli-ampere superceding the design value of 100 milli-ampere.

• July 1999 : Solid Storage and Surveillance Facility (S3F) is commissioned at Tarapur.



• September 24, 1999 : Unit-2 of Kaiga Generating Station, Karnataka attains criticality and dedicated to nation on March 05,2000. It is synchronised to the grid on December 02, 1999, and becomes commercial on March 16, 2000. Unit-1 of Station attains criticality on September 26, 2000. It synchronises to the grid on October 12, 2000 and becomes commercial on November16, 2000.

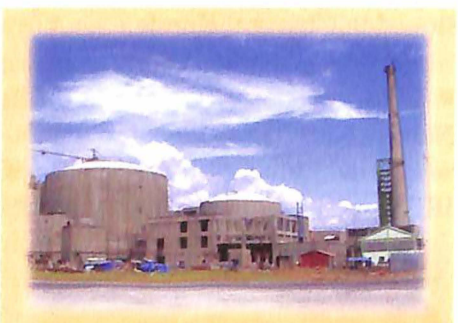


• December 24, 1999 : Unit-3 of Rajasthan Atomic Power Station attains criticality. It is synchronised to the grid on March 10, 2000, and becomes commercial on June 2, 2000. Unit-4 of the station attains criticality on November 03, 2000. It creates history by synchronising with the grid within a period of 14 days on November 17, 2000. The unit becomes commercial on December 23, 2000. The station is dedicated to the nation on March 18, 2001

• January 1, 2000 : BRIT's Radiation Processing Plant at Vashi, Navi Mumbai is commissioned.

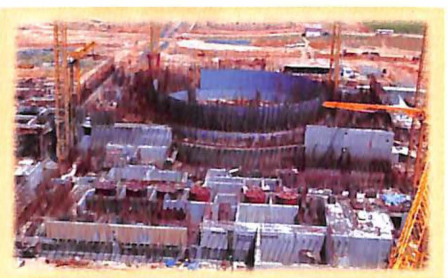
• 2000 : Boron Enrichment Plant is commissioned at IGCAR, Kalpakkam.

• March, 2000 & May 2000 : First concrete pour of Unit-3 and Unit-4 of 2 x 540 MWe PHWR Tarapur Atomic Power Project-3 & 4.



• April 21, 2000 : Folded Tandem Ion Accelerator (FOTIA) at Trombay delivers first beam on target.

• February 12, 2002 : India signs the contract with the Russian Federation for setting up 2 x 1000 MWe VVER type light water reactors at Kudankulam, Tamil Nadu. First pour of concrete of Units 1&2 of Kudankulam Atomic Power Project, Tamil Nadu is carried out on March 31,2002.



• March 30 & May 10, 2002 : First pours of concrete of Unit-3 and Unit-4 of Kaiga Generating Station-3 & 4(Karnataka).

• September 18, 2002 : First pour of concrete of Unit-5 of Rajasthan Atomic Power Project 5 & 6 (Rajasthan).

• October 31, 2002 : Radiation Processing Plant , Krushi Utpadan Sanrakshan Kendra (KRUSHAK) at Lasalgaon, district Nasik, Maharashtra, is dedicated to the Nation.

• October 31, 2002 : Waste Immobilisation Plant and Uranium-Thorium Separation Plant at Trombay are dedicated to the Nation.

• November 2002 : UCIL's Turamdih Mine, Jharkhand is inaugurated.

• 2003 : 1.7 MeV Tandetron Accelerator becomes operational and the Lead Mini Cell (LMC), for reprocessing of FBTR carbide fuel on lab scale, are commissioned at IGCAR.

• October 22, 2003 : Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) is set up at Kalpakkam, Tamil Nadu.

• October 23, 2004 : Construction of 500 MWe Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is launched by the Prime Minister Dr. Manmohan Singh.