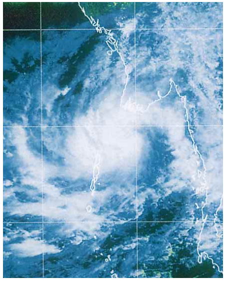


CHAPTER XXIX

ATOMIC ENERGY IN INDIA

India's Atomic Energy programme has been a mission-oriented comprehensive programme with a long-term focus. From its inception the guiding principle of this programme has been self-reliance through the utilization of domestic mineral resources, and building up capability to face possible restrictions in international technology and the exchange of resources. The events of the last 50 years have, in fact, validated this approach.

The Department of Atomic Energy (DAE) in India is today a broad-based multidisciplinary organization incorporating basic and applied research, technology development and their translation into industrial application, as closely linked activities. As a result, India today builds its own thermal reactors and associated nuclear fuel cycle facilities and is well poised to march on to the second and third stages of its planned programme involving fast breeder and thorium utilization technologies respectively. This effort is expected to provide a significant long-term solution to India's crucial electricity needs to support its overall development.

THE ROLE OF NUCLEAR POWER

There is a well established link between per capita electricity consumption and human development. The installed electricity generation capacity in the country is quite impressive and gross electricity generated during the year 2000-2001 was about 500,000 million units. In absolute terms, this is a large figure, but when looked at on a per capita basis, this is far below the world average. To meet our large electricity production needs, we have to tap all energy resources available to us. While coal-fired thermal power plants, apart from hydro, would remain the mainstay for our electricity production for quite some time, we would need to supplement them with sizeable additional resources to assure long-term energy-security as well as environmental protection. In this energy mix, nuclear power has an important role to play in the coming years.

The Indian uranium reserves are modest and cannot make an overly significant contribution to electricity requirements, if this uranium is used once in a nuclear reactor and then disposed of as waste. However, with a carefully planned programme, the available uranium can be used to harness the energy contained in non-fissile thorium, of which India possesses about 30 per cent of the world's reserves. The first stage of this programme involves using the indigenous uranium in Pressurised Heavy Water Reactors (PHWRs), which produce not only energy but also fissile plutonium. In the second stage, by reprocessing the spent nuclear fuel and using the recovered plutonium in Fast Breeder Reactors (FBR), the non-fissile depleted uranium and thorium can breed additional fissile nuclear fuel plutonium and uranium-233 respectively. In the third stage, thorium and uranium-233 based nuclear reactors can meet India's long-term energy requirements. Sustainable development of the country's economy requires nuclear energy, and sustainable development of nuclear energy requires closing the nuclear fuel cycle with thorium utilization.

Indian concerns and priorities are, thus, quite unique. For its long-term energy security India has no option but to deploy nuclear power according to a strategy precisely tuned to its needs and resources.

Evolution of the Indian Nuclear Programme

Homi Jehangir Bhabha formulated this strategy nearly 40 years ago, when India possessed hardly any infrastructure to support the nascent nuclear technology. The first Prime Minister of India, Jawaharlal Nehru, helped Bhabha lay the foundations of the Indian atomic energy programme, with self-reliance as the motto. Accordingly, a large R&D establishment, named Atomic Energy Establishment, Trombay, was progressively set up. This was renamed the Bhabha Atomic Research Centre (BARC), after India tragically lost Bhabha in an air crash in 1966. It incorporates research reactors, basic facilities for nuclear research, supporting infrastructure, and trained humanpower in all disciplines dealing with nuclear energy.

The Indian nuclear power programme commenced in 1969 with the building of the twin reactor units of the Tarapur Atomic Power Station (TAPS), employing Boiling Water Reactors (BWRs), with American assistance. The reasons for this choice lay in favourable performance guarantees for these reactors, and the need to gain experience quickly in running nuclear power plants.

The construction of the first two Indian PHWRs, RAPS-1 and RAPS-2, was a joint venture project with Canada. In parallel, the DAE set up facilities for fabrication of fuel, zirconium alloy components, manufacture of precision reactor components, and for production of heavy water. The import content of RAPS-1 was 45 per cent and half of its first core fuel charge was imported. Commercial operation of RAPS-1 commenced in December, 1973. In the year 1974, India conducted the peaceful nuclear experiment at Pokhran. The Canadian support was summarily withdrawn while RAPS-2 was still under construction. France too, followed suit by refusing to supply fuel for the Fast Breeder Test Reactor (FBTR) which was then under construction with French cooperation. The USA expressed its inability to continue fulfilling its contractual obligations to supply fuel for TAPS. The era of technology control regimes had begun for the Indian nuclear programme.

Coping with the Pokhran-I Fall-out

The abrupt withdrawal of foreign technical co-operation and supplies following the Peaceful Nuclear Explosion Experiment of 1974, could have caused a serious setback to the Indian nuclear programme. This did not happen on account of the nation's determination to face the challenges head-on with the help of the R&D infrastructure already created to develop self-reliance, and the support of Indian industry. India's stakes lay not only in the continuation of the ongoing

FBTR at Kalpakkam.

activities without external help, but also in the pursuit of the originally stipulated long-term strategies.

To cut a long story short, although delays were caused in some ongoing projects, the embargoes spurred the growth of indigenous capability for developing substitutes for the denied products, technologies and knowhow. RAPS-2 started commercial operation in 1981; FBTR went critical in 1985, using indigenously made plutonium-uranium mixed carbide fuel; and India developed a plutonium-uranium mixed oxide fuel, as well as the facilities for its industrial scale production, as an alternative to the enriched uranium based fuel for TAPS. India has not looked back since, and has continued to proceed on its chosen path without depending on external help.

The Present and the Future

The table on the right summarizes the present status of and future plans for nuclear power in India. The designs of new reactors have progressively evolved to incorporate advanced features to further improve safety, reliability and economics. The country has successfully developed technologies for in-service inspection, maintenance and refurbishment of older plants. As India gains experience and masters various aspects of nuclear technology, the performance of its nuclear plants continues to improve. The average capacity factor of Indian plants in 1995-96 was 60 per cent and it has risen to 82.5 per cent during 2000-2001. So far they have produced more than 165 billion units of electricity.

Two 500 MWe PHWRs, fully designed and developed in India, are under construction at Tarapur. In parallel, to further accelerate the growth of nuclear power, plans are being considered to build a few light water reactor based plants as an additionality, with foreign collaboration. The deal with the Russian Federation for setting up two 1,000 MWe units at Kundankulam is a step in this direction. Pre-project activities for setting up these units have commenced and DAE expects to start construction later this year. The two programmes of light water reactor and the indigenous self-reliant three-stage PHWRs, run as parallel programmes.

Nuclear Power Plants: Present Status and Future Plans

	MWe
Plants under operation 14 reactors at 6 sites-- Tarapur, Rawatbhata, Kalpakkam Narora, Kakrapar and Kaiga	2,720
Plants under construction 2x500 PHWR at Tarapur	1,000
Plants likely to commence in the current financial year 2x220 PHWR 2x1000 VVER 1x500 PFBR	2,940
Future plans 2x220 PHWR 4x500 PFBR 10x500 PHWR 6x1000 LWR	13,440
Total:	20,100

The Nuclear Power Corporation of India Limited (NPCIL) has gained considerable experience and confidence in plant life management, after many complex repair and rehabilitation jobs. Its nuclear power reactor maintenance capability is now on par with that of advanced countries. The intricate job of *en masse* replacement of coolant channel assemblies in the RAPS-2 reactor was successfully completed by employing indigenously developed technology well ahead of schedule and with minimum consumption of man-rem. The technology for tackling the OPRD (Over Pressure Relief Device) problem of the RAPS-1 leak was evolved and demonstrated and the repair work carried out successfully. From RAPS-2 onwards, improved coolant channel material and modified channel design have been adopted for longer life of the coolant channel.

Nuclear Fuel Cycle

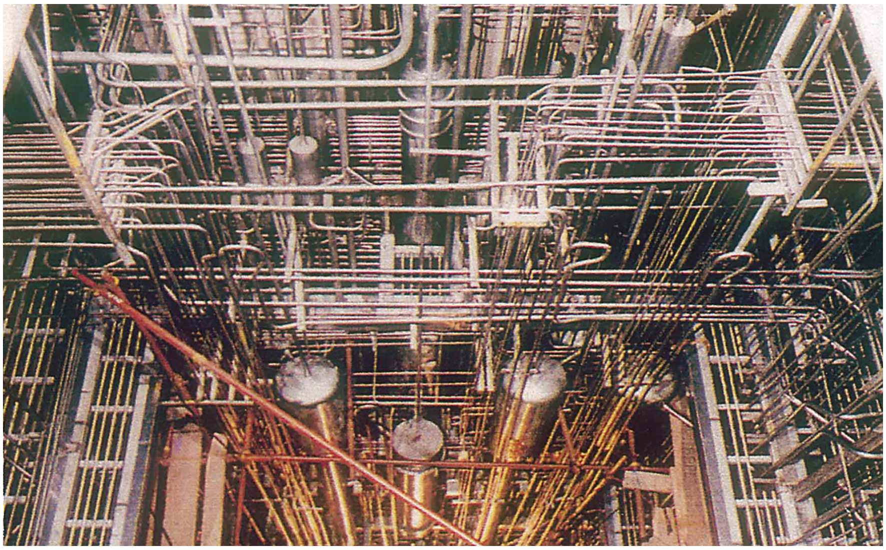
India has acquired a comprehensive capability in design and operation of associated plants/facilities (apart from reactors) covering the entire fuel cycle, starting from mining, milling and concentration of ore, through fabrication of fuel and production of heavy water to reprocessing and management of waste. Today, heavy water plants are operating with high efficiency and with a good safety record in the processes and technologies based on hydrogen sulphide-water exchange and ammonia-hydrogen exchange. This has enabled India to export modest quantities of heavy water after meeting its domestic needs. Full-scale heavy water upgrading plants based on the electrolytic and vacuum distillation process are also operational. The focus at present is on implementing energy conservation measures so as to reduce the cost of production of heavy water.

Ensuring a continuous supply of reliable qualified fuel for the reactors is vital for maintaining a nuclear power programme. Fabrication of fuel for nuclear reactors is a complex technology demanding high level of competence in process engineering and technology, extractive and physical metallurgy, materials and manufacturing technology, modern quality control and inspection based on NDT techniques. During the last four decades, a wide variety of metallic, ceramic and dispersion fuels have been developed and fabricated on an industrial scale at the BARC and at the Nuclear Fuel Complex (NFC). Zircaloy clad, high-density natural uranium oxide 'pellet -pins', is the fuel for the 220 MWe and 500 MWe PHWRs in India and these have been fabricated on an industrial scale at the NFC over the last two decades.

The nuclear energy resource profile of India calls for adoption of a closed cycle that involves reprocessing of spent fuel and the recycle of plutonium and uranium-233. India thus commenced development activities in fuel reprocessing technology from the inception of the nuclear programme and today has plants operating at Trombay, Tarapur and Kalpakkam. The first plant built at Trombay was designed with limited laboratory and pilot plant data, and with hot cell technology. However, the plant at Kalpakkam incorporates various innovations and new concepts based on experience gained from the operation of the Tarapur plant and R&D studies carried out in test facilities. In addition, we have separated uranium-233 from irradiated thorium rods and the radioactive

Top: Rajasthan Atomic Power Station (RAPS 3 & 4).
Bottom: Research Reactors DRUVA and CIRUS.

wastes generated at various stages of the nuclear fuel cycle are categorized as low-, intermediate- and high-level waste. State-of-art technologies have been developed and implemented for all three categories. A plant for immobilizing highly active waste in a glass matrix is operational in Tarapur. Based on this experience, new nuclear waste immobilization plants are being set up at Trombay and Kalpakkam. Vitrified waste is stored in a specially designed solid storage surveillance facility for about 30 years prior to its disposal in a deep geological formation. The first such facility became operational at Tarapur in 1999 and can store waste generated during 40 years of operation of two nuclear reactors of 220 MWe capacity. Plants for managing all types of radioactive wastes have been set up and are operating along with every nuclear facility in the country.



Kalpakkam Reprocessing Plant (KARP) with cell complexity.

Fast Breeder Programme

Studies with regard to the content of the FBR programme and the type of test reactor to be built were undertaken in the early 1960s. The construction of FBTR was started in 1972 and completed in 1984. Critical components of the reactor -- like the reactor vessel, rotating plugs, control rod drive mechanisms, sodium pumps, steam generators, remote fuel handling machines, turbo-alternator and instrumentation and control packages -- were manufactured in India. Foreign input constituted only 20 per cent of the total cost, and it was mainly towards knowhow and cost of raw materials.

An important achievement was the fabrication of mixed carbide fuel at BARC. This indigenously designed and developed fuel was unique, as the mixed carbide fuel core was being used as the driver for the first time anywhere in the world. The fuel burn-up now has crossed 72,000 Mwd/t. As a logical follow-up of FBTR, it was decided to build a prototype fast breeder reactor (PFBR) and the detailed design work was taken up at the Indira Gandhi Centre for Atomic Research (IGCAR). The design work has been completed and technology development for the PFBR is in progress, in collaboration with Indian industry. The construction of PFBR is scheduled to begin in 2001-02.

Evolution of Research and Development

The profile of the R&D programmes being pursued in the research centres of the DAE has kept changing with the evolution of the country's total nuclear programme. To cite an instance from the experience of BARC, in the early years of the evolution of the programme involving setting up of PHWRs, in addition to R&D on reactor systems and components and process development for the fuel cycle and the heavy water plants, BARC provided support to nurture competence in various sectors such as the manufacture of complex equipment, plant construction, acceptance testing and calibration of equipment and components being manufactured for the first time by Indian industry or in-house facilities. Now, when the programme is well developed, many of these activities are being conducted by industry. On the other hand, newer activities involving R&D focused on technologies related to repair and refurbishment had to be taken up at BARC, to take care of the emerging needs of operating power reactors. Plant life management has now become a major programme which requires a lot of specific data to be generated, and this is being done at BARC. Adequate experience has been acquired in this area as well. Having reached a degree of maturity in the PHWR programme, the focus has once again shifted, and BARC is now working on new reactor systems, particularly the Advanced Heavy Water Reactor (AHWR). This reactor aims to utilize vast reserves of thorium available in India and incorporates several passive safety features which are planned to exceed current international expectations. Indian technology in this area expects it to become a forerunner of similar systems, which may be developed here or in other countries. To verify some of the design features, thermosyphon studies have been conducted on specially built experimental facilities in BARC. Further, a low- to medium-pressure experimental facility is being set up at the Indian Institute of Technology, Mumbai. Engineering development of this reactor is progressing well and we hope to begin construction in a few years. Meanwhile, development efforts in the fuel cycle area have to match the needs of the emerging reactor programme. This, in fact, has been the case with all activities at BARC.

> RADIATION FROM RADIO-ISOTOPES AND FROM ACCELERATORS HAS A VARIETY OF APPLICATIONS, INCLUDING HEALTH CARE, AGRICULTURE, FOOD PRESERVATION, INDUSTRY AND RESEARCH.

Safety of Nuclear Power

The DAE has accorded a prime position to safety in all its activities through the entire nuclear fuel cycle, from prospecting and mining of ores to management of waste. This encompasses all aspects of safety concerns -- nuclear, radiological, industrial, and fire, -- as well as environmental protection and occupational health. Safety is also an important subject for research and development in all the units and dedicated groups are involved in continuous monitoring and upgrading of systems based on domestic experience and that gained elsewhere.

The NPCIL has gathered operating experience amounting to over 170 reactor-years with a good record in the safety of operating personnel, the public and the environment. Safety measures (in all activities) are in comformity with the norms stipulated by an independent body, the Atomic Energy Regulatory Board (AERB). These norms are also in line with international standards.

Radiation Technology Applications

Radiation from radio-isotopes and from accelerators has a variety of applications, including health care, agriculture, food preservation, industry and research. Research reactors at Trombay regularly produce a variety of radio-isotopes and meet a major part of the demand in the country. In addition to research reactors, power reactors too have been equipped to produce cobalt-60. Work on the development of accelerators is being pursued at Centre for Advanced Technologies (CAT), Indore, and at BARC. Development of radiation technology applications is a major thrust area in the R&D programme at BARC. These applications are being commercialized by the Board of Radiation and Isotope Technology (BRIT).

Health Care

Investment in R&D health care has resulted in the setting up of a Radiation Medicine Centre (RMC) as part of BARC in Mumbai, which has become the nucleus for

The Variable Energy Cyclotron Centre

The Variable Energy Cyclotron Centre (VECC) at Kolkata has been operating the nation's largest and the first indigenously built Cyclotron in the country, providing charged particle beams of various energies. It has been serving the research needs of a distinguished community of scientists belonging to 36 national laboratories and universities.

The first ever Electron Cyclotron Resonance (ECR) Ion Source, the latest successful heavy ion source, has been designed and commissioned in the Centre. The Heavy lon Acceleration Programme has resulted in the first heavy Ion beams beyond 6MeV/nucleon in the country. VECC has undertaken the project to construct a K500 Superconducting Cyclotron, the seventh of its kind in the world. This will open a new era of frontline experiments in the fields of medium energy heavy ion physics, materials science and biology. As a policy VECC has been using indigenous technology involving reputed Indian manufacturers in the development and construction of the accelerator.

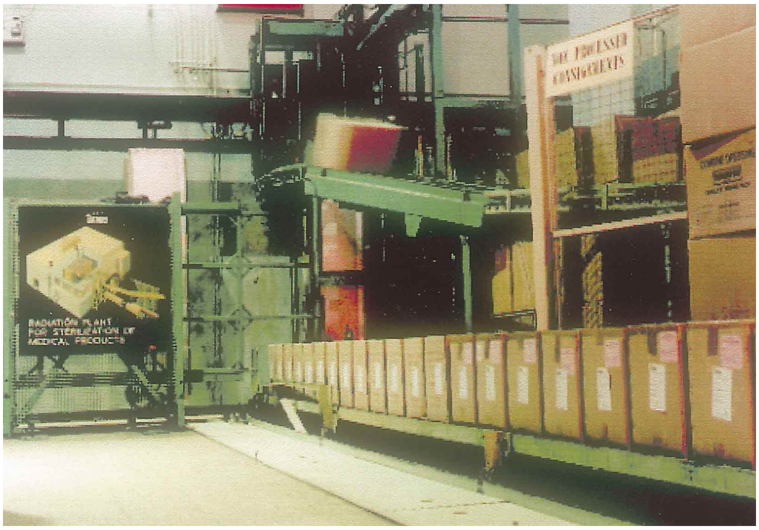
The first Isotope Separator On Line (ISOL) system in the country was indigenously designed and fabricated in the Centre for the study of exotic nuclei. The Regional Radiation Medicine Centre (RRMC) has been set up by the VECC in collaboration with the Thakurpukur Cancer Centre and Welfare Home, to extend the benefit of nuclear diagnostic facilities to the economically weak communities in the eastern region. A laboratory has been set up for collecting helium gas from hot springs at Bakreshwar and Tantloi. Recovery of 99.9 per cent pure has been accomplished.

The Centre has contributed in a substantial way in the CERN-India Collaboration Programme by fabricating a Photon Multiplicity Detector (PMD), which has been successfully used at CERN, Geneva, for the detection of a possible signature of Quark Gluon Plasma. In the next phase of experiments with Large Hadron Collider, the Indian team led by VECC will contribute a totally indigenous PMD to the ALICE experiment. Detector of a similar design has been proposed and approved for STAR experiments at the RHIC, BNL (USA).

the growth of nuclear medicine in the country. Similarly, Tata Memorial Centre (TMC), a fully autonomous institute aided by the DAE, provides comprehensive treatment for cancer and allied diseases and is one of the best internationally. It carries out a vast number of patient investigations every year (about 800,000 pathological investigations in 1999-2000). To cater to the requirements of the eastern region of the country, a regional radiation medicine centre has been set up at Kolkata as a part of the Variable Energy Cyclotron Centre (VECC). The facilities include those for *in vitro* studies like RIA and IRMA, gamma cameras for diagnostic and 4MeV LINAC for therapy. Radio-pharmaceuticals and other preparations for these and several other medical centres in the country are regularly supplied by BRIT, which runs a comprehensive programme for this purpose based on the R&D generated at BARC.

Agriculture and Food

Application of radiation to agriculture has resulted in the release of 22 improved varieties of seeds, which are contributing directly to the increase of GDP in the country. Of these mutant varieties, blackgram (urad) accounts for 95 per cent of the cultivation of this pulse in the State of Maharashtra. At an all-India level, four BARC blackgram varieties account for over 49 per cent of the total national breeder seed indent of all the blackgram varieties taken together. Groundnut variety TAG-24 is very popular and accounts for 11 per cent of the national



ISOMED plant at Trombay.

breeder seed indent. At a conservative estimate, these varieties constitute a GDP of over Rs.10,000 millions per year.

Research done in BARC and other centres in the world, has clearly demonstrated the advantages of food preservation by irradiation, and the Government of India has cleared several items for radiation processing. Setting up of such plants is expected to reduce the percentage of food that is lost due to various causes and provide the means for improving food hygiene and facilitate export.

One spice irradiator is already operating at BRIT in Navi Mumbai, to treat items requiring high doses. A Proton irradiator at Lasalgaon, near Nasik, is being set up by BARC and will be completed in the year 2001 to treat items requiring low doses. Efforts are being made to encourage other agencies to set up such plants in the private sector.

Industry

Applications of radiation technology for industry span a wide range, including radiography, water hydrology, gamma scanning of process equipment, use of tracers to study sediment transport at ports and harbours, flow measurements, pigging of buried pipelines and water hydrology in general. All these applications are in use and have made significant contributions to Indian industry. For example, the country's expertise in gamma scanning has been used by almost all the major petrochemical companies for troubleshooting in process equipment and this has resulted in minimizing downtime and production loss costs, which could be of the order of several crores per day for such big units. BARC has handled about 20 such scannings every year for the past five years. Radiotracers have been utilized to study sediment transport at almost all the major ports and harbours. Such studies have provided guidance for desilting operations, increasing the time intervals between desilting campaigns and thus saving costs. On a conservative estimate, savings to the nation due to isotope application related services like gamma scanning, blockage and leakage detection, RTD studies and sediment transport studies amount to over Rs.20,000 millions per year.

Social Benefits

Over 6,000 technicians have been trained in the use of radiography and they have found employment in India and abroad, where the certification provided by BARC is well recognized. BARC has also developed many applications using electron beam machines, for radiation processing of products such as cross-linking of polyethylene insulation, heat shrinkables, and vulcanization of natural rubber.

BARC has developed desalination technologies based on multi-stage flash (MSF) evaporation, reverse osmosis (RO) and low temperature vacuum evaporation. A 425 cu.m/day MSF desalination plant is in operation at Trombay. Plants based on BARC's RO technology have been set up in rural areas for purification of brackish water. Currently, BARC is setting up a 6,300 cu.m/day capacity desalination plant using MSF-RO technology at Kalpakkam using nuclear heat from the Madras Atomic Power Station.

Technology Development

Research centres of the DAE have been at the forefront of development of advanced and strategic technology and these have had a galvanizing impact on Indian industry. In recent years, areas that are receiving special attention are, lasers and accelerators.

Accelerator Programme: CAT has constructed the Synchrotron Radiation Source (SRS) Indus-1, the first such machine in the country. This consists of three accelerators, a 20 MeV microtron, a 450 MeV booster synchrotron and a 450 MeV storage ring. All three accelerators have been designed, developed, fabricated and commissioned indigenously. Current was stored for the first time in April, 1999, and the machine has been in routine operation since then. Scientists have been able to store 192 mA of current against the design value of 100 mA. Of the five beam lines planned, two have been commissioned. Work for the construction of the second SRS (namely 2.2 GeV Indus-2) is progressing to schedule. All the subsystems have been designed and prototypes built whenever necessary. After successful tests of the prototypes, fabrication has been entrusted to the industries. Indus-2 is expected to start operating by the middle of 2002.

CAT has also developed a 750 keV, 20kW DC accelerator which is in the initial phase of commissioning. It is expected to be fully operational by the end of 2001. This accelerator can be used for radiation processing of paper pulp, surface modifications, paint and resin curing and other industrial applications. A radiotherapy machine based on the microtron is also under development at CAT. In addition, CAT is developing two types of accelerators for radiation processing of agricultural products and sterilization of medical products. At BARC, the 500 keV accelerator is being tested for longer duration at higher power. The accelerator ILU-6, hitherto operating at BARC, Trombay, has been moved to the BRIT campus in Navi Mumbai to provide easy access to industrial users.

VECC has been operating at Kolkata for the past two decades and now construction of a super-conducting cyclotron has been started there.

THE DAE HAS A MAJOR PROGRAMME TO DEVELOP LASERS FOR R&D, INDUSTRIAL AND MEDICAL APPLICATIONS. THE SURGICAL CO_2 LASER SYSTEM DEVELOPED BY CAT HAS BEEN USED FOR A WIDE RANGE OF SURGICAL MODALITIES INCLUDING ENT AND GYNAECOLOGY.

Laser Programme: The DAE has a major programme to develop lasers for R&D, industrial and medical applications. The surgical CO_2 laser system developed by CAT has been used for a wide range of surgical modalities including ENT and gynaecology. About a dozen such systems have been supplied to hospitals around the country. A 4 kW CO_2 laser for industrial applications has been developed at CAT. This laser has been used for several studies on laser cutting, welding, alloying and cladding. A 10 kW CO_2 laser has also been developed at CAT and is already providing 7.5 kW of continuous power. CAT has also designed a high repetition rate pulsed TEA laser which gives peak power of more than 1 MW at 500 Hz repetition rate. This laser has been used for studies on separation of carbon isotopes. CAT has also developed several types of NdYAG lasers suitable for R&D and medical applications and developed and supplied fully automatic four-axis computerized laser welding station, to a manufacturer of cardiac pacemakers in India. A laser engraver based on 100 W Nd:YAG laser has been developed to enable engraving on any material with a high degree of precision; it can be connected to a Personal Computer and programmed. One such unit has been supplied to a company manufacturing solar cells.

Technologies to Other Agencies

While working towards fulfilling its mandate, the DAE has developed capabilities in several hi-tech areas which are of interest to other agencies as well. Whenever a request is received for assistance in a field where it has the expertise, DAE provides the help. To quote a few examples, BARC has completed the development of a finite element based software package specially tailored for rotor dynamic analysis of turbopumps required for indigenous development of cryo-engines. Nickel-titanium shaped memory sleeves for the lightning insulator assembly have been developed in BARC. These components were certified for airworthiness and have been extensively used in the Light Combat Aircraft. BARC has provided consultancy to the Department of Ocean Development for recovery of cobalt and nickel from leach liquor obtained by processing of polymetallic nodules. The DAE is also collaborating with Vikram Sarabai Space Centre for the development, testing and qualification of a 250 kW simulation plasma source called 'constricted arc plasma generator' for testing strategic thermal protection systems for rocket motors and re-entry simulator devices. Expertise acquired by BARC in the development of reactor control systems has been also used for providing antenna controls for a number of strategic projects. Similarly, expertise acquired by BARC in non-destructive testing and digital signal processing techniques has been used for the development of a pipe inspection gauge for monitoring the health of cross-country oil pipelines for the Indian Oil Corporation.

Basic Research

The DAE places high importance on basic research. All disciplines in nuclear sciences and several science disciplines where nuclear techniques play a role, are covered by this programme, which is broad-based enough to enable use of the DAE facilities by scientists from other organizations as well as provide support to nuclear science activities there. Apart from the four R&D centres BARC, Mumbai; CAT, Indore; VECC, Kolkata; and IGCAR, Kalpakam; there are aided institutions such as Tata Institute of Fundamental Research, Saha Institute of Nuclear Physics, Institute of Physics, Harish-Chandra Research Institute, Institute of Mathematical Sciences, Cancer Research Institute and Institute of Plasma Research, which are engaged in basic research activitites spanning a broad range of disciplines.

The DAE also offers several opportunites to scientists from other institutions in India and abroad to interact and collaborate on research activities of mutual interest. The Board of Research in Nuclear Sciences enables such support to Indian scientists, while those from abroad are supported through several bilateral cooperative arrangements or through schemes sponsored by international organizations like the International Atomic Energy Agency in Vienna, the Third World Academy of Sciences in Trieste and others.

In conclusion, it may be stated that the DAE is manned by trained scientists and engineers, who are relentlessly working towards fulfilling the mandate given to them by the nation, by developing technologies having direct and widespread societal benefits. Nuclear power plants are working well; application of radiation technology to health care is benefiting a large number of patients on a regular basis; improved crop varieties are helping to increase the agricultural output; and radio-isotopes and tracer techniques are helping industry in many ways. It has been able to reach this level because of the broad R&D base that has been nurtured over the years. India is happy to share its experience with scientists from the third world countries and collaborate in areas of mutual interest.