

Radiation – Sources, Technologies and Applications for Societal Development



Government of India
Department of Atomic Energy

RADIATION –SOURCES, TECHNOLOGIES AND APPLICATIONS FOR SOCIETAL DEVELOPMENT

Introduction

The field of nuclear science came into existence towards the end of 19th century, when many discoveries were made in a short span of time. These included discovery of X-rays by Wilhelm Roentgen in 1895, radioactivity emitted by uranium salt by Henri Becquerel in 1896 and electron by J. J. Thompson in 1897. Both natural radiation and X-rays have been used for a variety of applications. Use of radiation grew manifold after artificial radioactive materials were produced and the first such artificial radioactive material was Phosphorus-30 produced in 1934. Since then many such radioactive substances have been produced and utilized for the benefit of society and their applications have spanned many fields such as research, health care, industry, food and agriculture. The Department of Atomic Energy (DAE), in India, has been engaged in developing technologies for the use of radiation in all possible fields. The purpose of this booklet is to provide a comprehensive summary of the programmes of the department aimed at the use of radiation for the benefit of society.

Radiation occurs in many forms, but the most important types are those which are able to pass through matter such as X-rays and gamma rays; or have high energies which can be used for some sort of processing, say melting of metals using high power lasers or cross-linking of cables using electron beams. Sources of radiation can be radioisotopes, research reactors, machines such as accelerators, X-ray generators and lasers etc..

Activities involved in this area include production and supply of sources of radiation such as radioisotopes and accelerators, use of radiation for known applications and research & development aimed at acquiring new applications, design and manufacture of equipment and plants to facilitate the use of radiation technologies and deployment of such technologies in the country. Research reactors to produce radioisotopes, accelerators to produce certain radioisotopes or for direct use of their beams for processing, and hot cell facilities to process the radioisotopes, have been set up as part of various research centres. An industrial unit called, “Board of Radiation and Isotope Technology (BRIT)”

has been set up exclusively to canalise the radiation technologies to the market place.

The properties taken advantage of for the applications of radiation can be broadly described as follows¹.

i. Attenuation of the radiation when it passes through an object. Attenuation occurs due to absorption and scattering. The extent of attenuation depends on the composition and the geometry of the object as well as energy and type of radiation.

ii. Physical or chemical changes brought out in the target matter by the deposition of radiation energy. Mechanism of change depends on the type and energy of radiation. It could be production of reactive free radicals or ions and consequential physical and chemical changes in the irradiated material. It also could be simple thermal effects such as heating and melting and consequent changes.

iii. The ease of detection of radioisotopes in extremely small quantities enables their use as tracers to investigate biological, industrial and environmental processes.

iv. In case of lasers, their directionality, monochromaticity, tunability, amenability to modulation and capability to produce ultra short pulses.

Based on the above properties, a wide spectrum of applications has been developed. For example, common X-ray images of patients taken for diagnostics in hospitals and radiography of welded joints are based on the first property. Teletherapy for the treatment of cancer wherein the radiation energy deposited onto the target cells brings about their destruction; radiation vulcanization of natural rubber and the use of high power laser beams for welding are based on the second property. Leakage detection in buried pipelines using radiotracers and diagnostics using radiopharmaceuticals make use of the third property. Laser communicator is based on the fourth property. The first requirement, therefore, is to have sources to produce radiation of the type required for the usage and this is described in the next section.

Sources of Radiation

The most common sources of radiation are radioisotopes² and they

1 D.D.Sood, "Changing Scenarios in Isotope Production and Utilisation", *IANCAS Bulletin*, Vol 14, No 1, 1998.

2 S Ramakrishna Iyer, "Gamma Radiation Sources", *IANCAS Bulletin*, Vol 15, No 4, 1999.

are produced by nuclear reactors either by utilizing available excess neutrons for activation of stable elements or by separating useful fission products from the spent fuel. In India, the production of radioisotopes started in the late fifties with the commissioning of the Apsara reactor in 1956. The production capability was augmented in 1963 when the CIRUS reactor attained its full rated capacity of 40 MWt. There was a major increase in the production capacity when the 100 MWt reactor, Dhruva, attained criticality in 1985. Dhruva is one of the large research reactors in the world and it caters to the production of a wide spectrum of radioisotopes for use in medicine, industry, agriculture and research. All these reactors are located in Bhabha Atomic Research Centre (BARC) at Trombay. A major part of Cobalt-60, an isotope that is used for several applications including radiation processing, is produced in the power reactors of the Nuclear Power Corporation of India Ltd. (NPCIL).

A major challenge in the production of radioisotopes is to prepare them with the appropriate specific activity and radionuclidic purity conforming to the specifications for different applications for which they are used. For example, the low specific activity (~60 Ci/g) Cobalt-60 would suffice for radiation processing applications, whereas very high specific activity (>250 Ci/g), is needed for teletherapy applications. Appropriate irradiation conditions at high flux irradiation position in suitable reactors are essential to get high specific activity radionuclides. Well-equipped processing facilities with hot cells are needed for handling the large quantities of activity involved. The hot cell facilities at the Radiological laboratories and at the High Intensity Radiation Utilization Project (HIRUP) at Trombay; and at the cobalt handling facility at Rajasthan (RAPCOF) are used for processing the irradiated Cobalt-60 and for fabrication of the radiation sources as per the designs approved by regulatory agencies. Board of Radiation and Isotope Technology (BRIT) operates processing facilities for radioisotopes.

Standardisation of appropriate radiochemical separation techniques for preparation of the isotopes in adequate radiochemical and radionuclide purity is of paramount importance in the production of radioisotopes for several applications especially for medical use. Radiochemical processing facilities set up at the Radiological Laboratories, Trombay is used for the radiochemical separation of several isotopes (Molybdenum-99, Iodine-131, Phosphorus-32, Sulphur-35 etc.).

Particle accelerators are machines, which are capable of producing beams of electrically charged particles of kinetic energy ranging from

several hundreds of keV to thousands of MeV. Depending upon the type of particles and their beam energy and current, several types of particle accelerators are now available³. Accelerators can be electrostatic type such as Cascade Generators, Van de Graaff or Pelletron or of electromagnetic type with resonant cavities and wave-guides such as linear accelerators (linac) and cyclotrons or synchrotrons. Electromagnetic accelerators can also be of non-resonant type such as linear induction accelerators or Betatrons. Earlier, the accelerators were primarily conceived and built for nuclear physics research. Over the years, these have been increasingly utilized for the production of radioisotopes for medical applications, for medical science studies and for processing of materials. Work on the design and development of accelerators is being done at Centre for Advanced Technology (CAT), Indore, BARC and VECC.

X-rays are produced when high velocity electrons strike the target material of high atomic number and lose their kinetic energy to the target material⁴. DAE is also working in the area of synchrotron sources, which offer the advantage of wavelength tunability and very high brightness and have wide ranging industrial and research applications. The first synchrotron source, Indus-1 has already been commissioned at CAT and beam lines are being set up.

Lasers are stable sources of nearly monochromatic optical frequency waves i.e., they are highly coherent sources. Therefore, their output radiation can be collimated to form a sharply directed beam or may be focused to form a small spot. Consequently, high power density irradiations can be obtained and this forms the basis of many of the applications of lasers. Laser based equipment are manufactured at CAT, Indore, while applications of lasers are being developed at CAT as well as BARC.

Health Care

The Radiation Medicine Centre (RMC) of Bhabha Atomic Research Centre (BARC) in Mumbai, has become the nucleus for the growth of nuclear medicine in the country. Similarly Tata Memorial Centre (TMC), a fully autonomous aided institution of DAE, provides comprehensive treatment for cancer and allied diseases and is one of the best radiation

³ Amit Roy, "Accelerators and their Applications", *Physics in the 20th Century and Emerging Trends for the New Millennium*, IPA Seminar, November 1999, Mumbai.

⁴ K D Singh, "X-ray Sources and their Application", *IANCAS Bulletin*, Vol 15, No 4, 1999.

oncology centres in the country. RMC carries out a large number of patient investigations every year (about 8.5 lakhs pathological investigations in 2000-2001). To cater to the requirements of the Eastern region, a regional radiation medicine centre is located at Kolkata as a part of Variable Energy Cyclotron Centre (VECC). BRIT supplies radiopharmaceuticals and allied products to nearly 120 Nuclear Medicine Centres in the country. Technetium-99m (Tc-99m) is the main workhorse of diagnostic nuclear medicine practice. Iodine-131, as sodium iodide, is used for diagnosis and treatment of thyroid disorders.

Radioimmunoassay (RIA) is an important medical application of radioisotopes. It is an in vitro technique for accurate, sensitive and specific estimation of vital substances present in minute quantities (nanomole to picomole) in complex biological matrices such as blood and serum⁵. This is a very simple and very affordable technique for diagnosis. There are nearly 650 RIA laboratories in India offering RIA services. BRIT regularly provides RIA kits to these centres. Another related technique is immunoradiometric assay (IRMA), which is more sensitive than RIA.

Radiopharmaceuticals are a special class of radiochemical formulations of high purity and safety, suitable for administration to humans orally or intravenously to carry out organ investigations in vivo (or by bringing about a therapeutic effect). The introduction of gamma camera, which enables simultaneous mapping of the radiotracer distribution over a large area (30-40 cm²) covering one or more organs, was a major turning point in the development and use of radiopharmaceuticals.

Radiotherapy is practised in two modes: teletherapy and brachytherapy. In teletherapy, the radiation source is placed in a shielded housing and a well-defined beam of radiation emanating from the source is directed towards the tumour for treatment, while application of small sealed radiation source in close proximity to the tumour for treatment is called brachytherapy. Intense Cobalt-60 sources ranging from 9000 to 12000 curies encapsulated and supplied by BRIT are being used in most of the 225 teletherapy units set up in 62 cities in India for cancer treatment. BRIT supplies Brachytherapy sources like Iridium-192 and Cesium-137 for cancer treatment. BRIT also supplies sodium phosphate (Phosphorus-32 based) injection for pain palliation in severe bone cancer cases. Another important radiopharmaceutical, Samarium-153-

5 A.M.Samuel, "Radionuclides in the Treatment of Benign and Malignant Diseases", Annual Conference of Indian Nuclear Society, Mumbai, 1998.

EDTMP for treatment of cancer patients, is also supplied by BRIT. This radiopharmaceutical is effective in pain relief of terminally sick cancer patients. Demand for nuclear medicine facilities and cancer hospitals is very large and a lot more needs to be done. It also has potential for export to other developing countries.

DAE also provides training in this area. The RMC of BARC, Mumbai has been conducting a one-year Diploma Course in Radiation Medicine (DRM) to provide trained manpower to other similar centres in the country. A four week course on RIA is also conducted by the Radio-Pharmaceuticals Division of BARC. In addition, BARC also conducts a one year post-graduate diploma course in Medical Physics.

Continuous efforts are being made for finding new applications of radioisotopes in medicine. Towards the same, coronary stents coated with Phosphorus-32 supplied to hospitals for clinical trials on cardiovascular radiation therapy are yielding good results. Liquid filled balloon approach for endovascular beta irradiation to prevent restenosis after angioplasty is fast gaining popularity among cardiologists. Considering this, a method for the preparation of $^{188-186}\text{Re-DTPA}$ complex has been optimized. Method has been developed to prepare Iodine-125 source for treatment of ocular tumors and prostate cancer. Similarly, special radioactive sources of Iodine-125 are being developed for the treatment of eye cancer. Holium-166 and Samarium-153 labelled hydroxyapatite particles have been developed at BARC for treating arthritis of large and medium-size joints respectively and tried on a number of patients. The Radiopharmaceutical Division, BARC has developed a new radiopharmaceutical namely, Holium-166 labeled hydroxyapatite for treating rheumatoid arthritis. The modality of treating arthritis, radiosynovectomy, using the above radiopharmaceutical was evaluated at Ruby Hall Clinic, Pune. Several patients treated with this pharmaceutical have shown excellent result with respect to pain relief.

A new Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) at Navi Mumbai is being set up. This centre is being established to keep abreast with the advances in cancer research and train its scientists in upcoming technologies. Basic research at ACTREC will focus on frontline areas such as vector development, gene therapy, basic immunology, immunotherapy, molecular genetics, molecular epidemiology, and drug development. At this centre, there would be close interaction between clinical and basic research. Education program in cancer prevention will also be an important activity of this centre.

Radiation medicine Centre, BARC located in Parel, Mumbai is also getting ready for the installation of a medical cyclotron and PET (Positron Emission Tomography) scanner. This 16.5 MeV cyclotron will be used for the production of radioisotopes and will be the first such facility in India. PET scanner is a kind of detecting system and utilizes the principles of the tracer kinetic method and tomographic image reconstruction.

Over the years, various units of the DAE have developed several low cost equipment for health care and some of these technologies have been transferred to interested private entrepreneurs. Examples include Impedance Plethysmograph, Impedance Cardio Vasograph, Cardiac Output Monitor and Bilirubin Strip developed by BARC. Hospital Management Information System developed by BARC has been installed in a few hospitals after customization. CAT has developed lasers for medical applications. The surgical CO₂ laser system developed by CAT is useful for a range of surgical modalities such as ENT, Gynaecology, General surgery, Dermatology, Plastic surgery, etc. This laser cuts tissues with minimum loss of blood. Its other advantages include lesser oedema and pain, lesser chances of infection and faster recovery. Fourteen such systems have been supplied by CAT to various hospitals within the country including All India Institute of Medical Sciences (AIIMS), New Delhi, Choithram Hospital & Research Centre, Indore, Cancer Care Trust, Indore, Shri Vivekanand Medical College, Kolkata, Shri Chitra Tirunal Institute, Thiruvananthapuram and Bio-Medical Engineering Group, IIT-Delhi, New Delhi.

A patient suffering from tuberculosis develops cavities in lungs. Exposure of these cavities to nitrogen laser radiation helps in drug penetration. It has also been observed that exposure of burn wounds to nitrogen laser radiation helps in faster healing. Three units of nitrogen laser with fibre optic beam delivery systems have been given to Choithram Hospital and Research Centre, Indore; Maharaja Yashwant Hospital, Indore and Sen Medical Research Centre, Patna for treatment of tuberculosis.

BRIT has developed a gamma irradiator known as blood irradiator for hygienisation of blood in hospitals and blood banks. Hydrogel for the treatment of burn-injuries has been developed and has been advertised for technology transfer. Certain products such as Cobalt-60 based teletherapy machine, electron beam accelerators are under development and it should be possible to manufacture them at a cost much lower than

imported equivalents. Cobalt-60 based teletherapy machine is being developed by BARC and the prototype machine will be ready for field trials by March 2002. The development involves material selection, heavy fabrication, precision component manufacturing, calibration, programmable controls and implementation of safety interlocks. The machine can deliver a dose of 200 Roentgen per minute at one metre from the source. Apart from Fixed therapy and Rotation therapy, the machine can also be programmed for Arc therapy and Skin therapy.

Now-a-days, electron accelerators are being widely used for radiotherapy. The advantage of electron beam therapy lies in the precision with which it can irradiate and destroy tumours. CAT is developing electron accelerator based teletherapy machine. In this machine, a microtron, a type of electron accelerator, accelerates electrons to an energy, which depending on the depth of the tumour varies from 6MeV to 12 MeV. For very deep tumours, the electron beam can be converted to X-rays, which then are equivalent to gamma rays from Cobalt-60 source. The machine is in final stages of assembly and is expected to be commissioned for by mid-2002.

Laboratory scale experiments have been carried out to develop charged-coupled device (CCD) based X-ray machine for imaging to be used in hospitals and at present BARC is having an exploratory discussion with Bharat Electricals to develop a prototype for clinical trials.

The DAE proposes to accelerate its programme to manufacture health care equipment at a low cost and supply them to health care centres in the country till an entrepreneur comes forward to take up the technology for production.

Radiation Sterilisation

Another important application of radioisotopes towards health care is by way of Radiation Sterilisation Services offered on commercial basis to the Indian medical industry. The ability of gamma radiation to kill micro-organism is effectively made use of in radiation sterilisation of various medical products. A number of products such as disposable syringes, surgical sutures, cotton dressing, drugs and related products etc. are sterilised by irradiation. The advantage of radiation sterilisation over conventional techniques is that the sterilisation is effected in the final packing so that the product remains sterile up to the point of use. Moreover, as it is a cold process, heat sensitive materials like plastics

Production of Radioisotopes



At BARC: Hot Cell facility for production of radioisotopes

Accelerator at CAT



Synchrotron Radiation Source: INDUS 1



Photo-electron Spectroscopy Beamline on INDUS-1

Lasers development at CAT



Dye-Laser Pumped Copper Vapour Laser. Both these lasers were developed and fabricated inhouse



Carbon dioxide surgical laser

Laser equipment developed for treatment of oral cancer



Nuclear Facilities for Health Care



ISOPHARM : Radiopharmaceutical Laboratory of BRIT at Vashi, Navi Mumbai

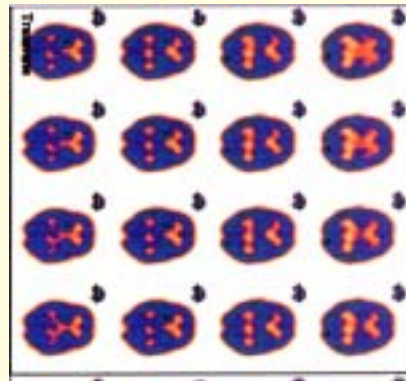


At Radiation Medicine Centre: Gamma Camera in action for diagnosis

**Radiation Imaging
Services of RMC**



Technetium-99m Generator

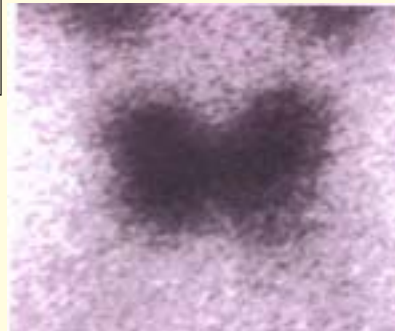


Brain scan taken at RMC



Thyroid scanning

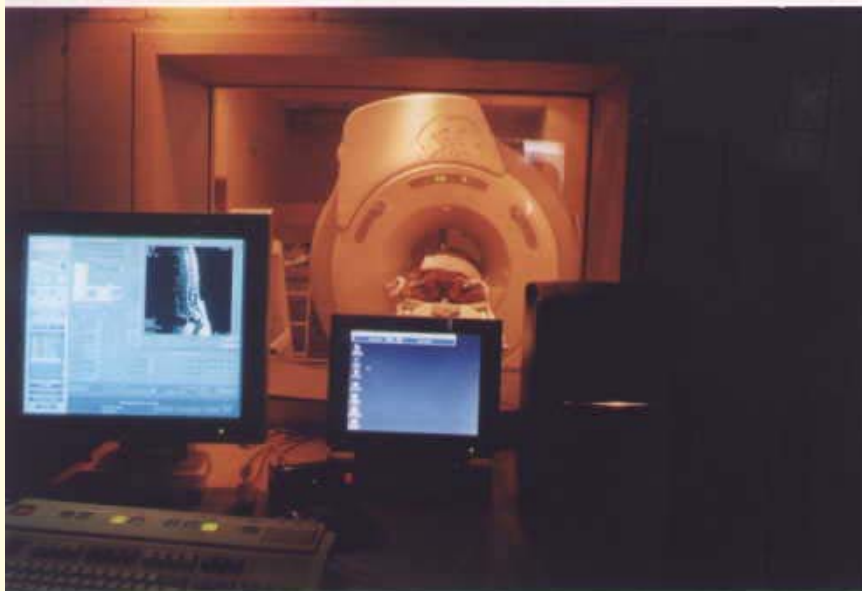
Thyroid scan



**Cancer diagnosis and treatment facilities at
Tata Memorial Centre**



Linear Accelerator Clinac-2100c



Magnetic Resonance Imaging facility



*Advanced Centre for Treatment, Research and Education in Cancer
(ACTREC) at Owe Village, Navi Mumbai*

Radiation Sterilization



ISOMED plant at Trombay










*Radiation sterilised
medical products*

*Dai Kit : Over a million radiation
sterilised kits and delivery packs,
for use in rural areas for preventing
infection of mothers and helping to
minimize infant mortality rate, have
been distributed through rural
health programmes funded by WHO.*



Nuclear Agriculture: Improved seed varieties

CROP VARIETIES DEVELOPED AT BARC USING MUTATION BREEDING

	CROP	NO.	CHARACTERISTICS
	GROUNDNUT	9*	High yielding, improved quality
	PIGEON PEA	2	High yielding, disease resistant, early maturing Improved quality
	BLACKGRAM	4	High yielding, disease resistant
	MUNG BEAN	4	High yielding, disease resistant
	RICE	1	High yielding, improved quality
	MUSTARD	2	High yielding, improved quality
	JUTE	1	High yielding, fibre yielding

* Latest updated data

Nuclear Agriculture: Tissue Culture



Pineapple and Banana varieties developed at BARC using tissue culture technique.



Sesbania rostrata plant for green manure

Radiation Processing Plants



Spice Plant at Vashi, Navi Mumbai

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



Radiation Technology for Food Preservation



Radiation processing has been established as a simple and very effective technique for preservation of various food items. Shown on the left in the pictures are radiation processed potatoes, onions, turmeric, sooji, and banana.

Some of the food items which have been approved by the Government of India for radiation processing.

**Radiation Technology for Industry
developed at Trombay**

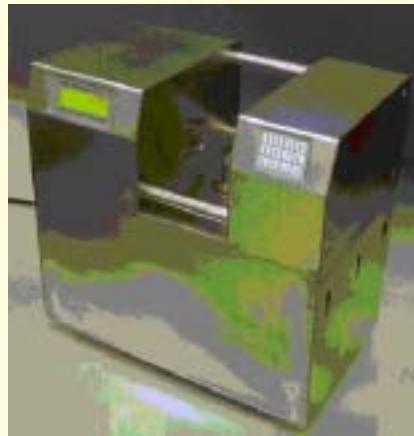


*500 keV Electron Beam Industrial Accelerator of BARC installed at Vashi,
Navi Mumbai for various radiation processing applications.
(Left) Radiotracer studies at a trickle bed reactor in a factory*

Laser Technology for Industry



Laser cutting mild steel plate developed at CAT



Density Measurement Station



Radiotracer studies being conducted in Hoogly river to study silt movement. Below: Radioisotopes being used to determine mercury inventory in electrolytic cells



BRNS Sponsored Research



*New mutant Winged Bean developed by Dr Babasaheb Ambedkar
Marathwada University under a BRNS project*



*Weevil Resistant Sweet Potato developed by the Central
Tuber Crop Research Institute, Thiruvananthapuram*

used in medical products are not adversely affected. The Irradiation Sterilisation of Medical Products (ISOMED) Plant at Trombay was the first unit to be pressed into this service by the DAE for this purpose. The second radiation sterilisation plant has been established in Bangalore and the third one at New Delhi. In the year 2000 - 2001, about 13,000 cu. metres of medical products have been processed with over 90% plant availability factor at ISOMED. Its services obtained ISO 9002 accreditation in July 2000 thus enabling better acceptance of ISOMED services internationally. Over a million radiation sterilised DAI (midwifery) kits and delivery packs, to be used in rural areas for preventing infection of mothers and helping to minimize infant mortality rate, have been distributed through rural health programmes funded by WHO and this has decreased infant mortality rate in the areas⁶ where these kits were supplied. BRIT has the experience and the expertise to provide consultancy for setting up gamma sterilization plants.

Agriculture and Food preservation

In order to promote sustainable development of agriculture, the national agricultural policy document lays major thrust on higher productivity based on technically sound, economically viable, environmentally non-degrading and socially acceptable use of natural resources – land, water and genetic endowment. The DAE, through its research and development activities in nuclear science and technology, has been making active contributions towards enhancing agricultural production and food preservation. BARC has a broad-based research programme in nuclear agriculture involving genetic improvement of crops by mutation breeding and biotechnological approaches, isotope-aided studies on soils, fertilizers uptake and pesticide residues analysis, and integrated pest management including the use of sterile insect technique, pheromones and biopesticides.

Genetic mutation of crop plants resulting in improved yield, better characteristics or disease resistance is a continuous endeavour of scientists at BARC⁷. Heritable variations occur spontaneously in all living

⁶ *Studies conducted by Indian Institute of Population Studies, Govandi, Mumbai and published in Mid-day, 2nd April 2001, Mumbai.*

⁷ *K Raghu, "Nuclear Energy for Sustainable Development", Annual Conference of Indian Nuclear Society on "Public Perception on Benefits of Nuclear Energy in Health Care, Industry & Agriculture", INSAC-98, Mumbai.*

organisms and are largely due to mutations of genes. Radiation induced mutations enhance the range of variability, from which plant breeders can select and combine desired characteristics to produce better crop plants. Using induced mutations and cross breeding, 22 crop varieties have so far been developed and released for commercial cultivation by Government of India. Among them are 8 groundnut, 10 pulses and 2 mustard varieties and one variety each of jute and rice. These improved varieties have high yield and they are resistant to diseases. They are contributing directly to the increase of GDP in the country. Of these mutant varieties, black gram (urid) accounts for 95% of the cultivation of this pulse in the State of Maharashtra. At all India level, 4 BARC black gram varieties account for over 50% of the total national breeder seed indent of all the black gram varieties taken together. Groundnut variety TAG-24 is very popular and accounts for 11% of the national breeder seed indent. This variety has been adopted for cultivation in Maharashtra, W.Bengal, Rajasthan, Karnataka, Orissa, Andhra Pradesh, Madhya Pradesh, Punjab and Tamil Nadu.

Fertilizers are expensive and therefore, it is necessary to ensure that fertilizers are applied efficiently and with minimum loss. The use of isotopes help in obtaining information on relative merits of different fertilizer practices such as method of fertilizer placement, time of application and types of fertilizers needed. Studies initiated at BARC have resulted in recommendation of a new binutrient fertilizer ammonium polyphosphate (APP) for rice, pulse and plantation crops based on several field studies conducted over a number of years. The advantage of APP is that cost of production is low and is a good source of phosphorous and serves as carrier of micronutrients.

One of the major achievements in radiation-induced mutation is the development of a photoperiod insensitive green manure crop – *Sesbania rostrata*. This West African legume harbours nitrogen fixing nodules both in the root and the stem. The mutant TSR-1 (Trombay *Sesbania Rostrata*) is photoperiod insensitive and can be grown throughout the year with higher biomass. Studies have revealed that 120-160 kg. of nitrogen, from a biomass of 10 tons per hectare, can be added to the soil by ploughing in the plants grown for 55-60 days. The decomposition takes around 15 days after which the soil is ready for sowing. Growth parameters and yield of rice crop following TSR-1 as a green manure were similar to that grown with 60-kg nitrogen per hectare of chemical fertilizer.

The use of chemicals to control insects that damage crops results in the problems of development of resistance to insecticides, environmental pollution and undesirable chemical residues in food. The Sterile Insect Technique (SIT) is one of the brilliant achievements of applied entomology during the century. The method consists essentially of rearing vast number of insects in the laboratory, sexually sterilizing them by exposing them to ionizing radiation and releasing sterile adults into wild population. The sterile males outnumber the native males and mate with females which in turn produces only infertile eggs. BARC has developed SIT for red palm weevil and potato tuber moth. SIT is being field tested at 3 locations covering three states, Maharashtra, Karnataka and Kerala in collaboration with the State Agricultural Universities under programme of the Board of Research in Nuclear Sciences (BRNS) of the DAE.

Based on the research done in BARC and other research centres in the world, advantages of food preservation by gamma radiation from radioisotopes have been clearly demonstrated and Government of India has cleared certain items for radiation treatment. Setting up of such plants is expected to reduce the percentage of food that is lost by various causes and provide a method for improving food hygiene and facilitate export. The process of food preservation by radiation offers several advantages over conventional techniques of food preservation such as fumigation and heat. It is a cold process, which preserves the freshness of food and can be applied to prepacked commodities. It does not leave harmful residues in food and is safe for workers and environment. The shelf-life of fruits including mango, banana, papaya, chickoo (sapota) and pineapple could also be extended by the application of gamma radiation. Gamma radiation can also be used to extend shelf life of meat, poultry and seafood and also to destroy pathogen and parasites present in them. Irradiation facilities licensed to process food items include R&D facilities at BARC and Defence Laboratory, Jodhpur and commercial facilities at Sriram Institute for Industrial Research, Delhi and Spice Irradiator at BRIT, Navi Mumbai.

The spice irradiator with a maximum throughput of 30 tonnes/day treats items requiring high doses. Poton irradiator at Lasalgaon, near Nasik is being set up by BARC and will be completed by the end of 2001 and will be used to treat items requiring low doses. Efforts are being made to encourage other agencies to set up more such plants. BRIT is also exploring possibilities for exporting radiation processing

plants and has recently executed a project for installation of a 50 kCi radiation plant for R&D at Atomic Energy Research Establishment, Dhaka, Bangla Desh.

In addition to gamma radiation from radioisotopes, electron accelerators can also be used for radiation processing of food products⁸. This can be done either by direct electron beam or by X-rays generated by the electron beam. The direct use of electron beam provides very good utilization of the beam power and is well suited to food products requiring high dose. However, low penetrability of the electron beam restricts its application to food items in small packing. For food products in large packing, electron beam is converted into X-rays by impinging the electron beam onto a high Z target material and X-rays are then used for radiation treatment. Experiments to gain experience with this technique are in progress using the 2MeV Russian accelerator ILU-6 located at BRIT, Navi Mumbai and CAT, Indore is working to develop indigenous accelerator for this purpose.

BARC has developed a tissue culture based protocol for rapid multiplication of 12 commercial cultivars of banana. This technology has been transferred to Maharashtra State Seeds Corporation, Akola. They have established a commercial tissue culture laboratory and are distributing plants to farmers. This technology has also been transferred to Pondicherry State Government. Similarly, a large-scale multiplication of pineapple by micro-propagation has been standardized. From a single bud of a crown over 95 plants are produced within six months compared to only one in the conventional procedure practiced by the farmers. The Government of Tripura has shown interest in this technique. *Accasia Victoriae* is a plant suitable for desert area and can withstand salinity. We have made good progress in developing hardened plants for this variety using micro propagation. Now we will proceed further and carry out field trials in collaboration with Rajasthan Agricultural University. Success in this area will help in greening the desert.

We have several effective linkages with several State Agricultural Universities and National Research Institutes. So far, 9 State Agricultural Universities and one State Seeds Corporation and 7 Research Institutes are involved with us in this effort, which have been very successful

⁸ H.C.Soni, "Radiation Processing of Food Items by Accelerators", Seminar on Radiation Processing of Food Products, Indian National Academy of Engineering, Mumbai, 2000.

in taking these research efforts to the farmers.

Hydrology and Industry

Applications of radiation technology to industry span a wide range including radiography, gamma scanning of process equipment, use of tracers to study sediment transport at ports and harbours, flow measurements, pigging of buried pipelines isotope hydrology and water resource management, radiation processing and nucleonic gauging.

Use of isotope sources for radiography testing is one of the earliest applications of isotopes in industry. It has grown steadily as isotope sources have many advantages over X-ray machines such as portability, freedom from electric power requirements and the possibility of use of tiny isotope sources in otherwise inaccessible areas of industrial system. Over and above this, radiography testing is a mandatory requirement in the inspection of welds and castings in many areas of industrial activity. Because of the importance of radiography, BRIT regularly supplies industrial radioactive sources, exposure devices (cameras) and BARC conducts training programmes. Training courses at Levels 1, 2 and 3 are provided to radiography personnel at regular intervals as per the procedure prescribed by the International Standards Organisation (ISO-9712) and the Bureau of Indian Standards (BIS-IS-13805). In case of certain materials, neutron radiography is used in place of gamma radiography. Sometime it is the only alternative for testing of materials containing light elements which offer little attenuation for X-rays as well as samples with components of similar atomic number which show little contrast in X or gamma radiographs⁹. Research reactors like KAMINI at Indira Gandhi Centre for Atomic Research (IGCAR) are useful neutron sources for many of these applications.

Gamma scanning¹⁰ of industrial columns is a very important application of radiation technology. The chemical and petro-chemical industries operate a variety of process columns (both tray type and packed bed type). Any malfunction such as collapsed trays or flooding or maldistribution etc. adversely affects column efficiency. Shutting down and stripping a column for diagnosis is a time consuming process and can

⁹ G K Gubbi, "Neutron Sources and their Applications", *IANCAS Bulletin*, Vol 15, No 4, 1999.

¹⁰ Gursharan Singh, "Sealed Sources Applications for Column Scanning and Tomography" *Annual Conference of Indian Nuclear Society, Mumbai, 1998.*

involve long downtime leading to loss of production and revenue. Gamma scanning at different elevations along the column is an elegant on-line diagnostic procedure. BARC, in collaboration with Engineers India Ltd. has developed the technique and has been providing the services to the industry for about half a decade and has conducted more than 100 such investigations covering columns ranging in diameter from 1 to 11 metres and height from 20 to 75 metres.

Indian industry has been using nucleonic gauges for over three decades for noncontact measurements and control of levels of liquids and solids in industrial vessels, thickness of foils and sheets in plastic and metal industries, basic weight of paper in paper mills densities of fluids flowing through pipelines, moisture in coke in steel plants, coal ash monitoring in coal handling plants and for mineral analysis of effluent streams in mineral processing. In most nucleonic control systems, small isotopic sources like Cesium-137, Cobalt-60, Americium-241 and Krypton-85 are used. The Electronics Corporation of India Limited (ECIL), Hyderabad, a public sector undertaking under the DAE, is the main manufacturer of nucleonic gauges in India. In most cases, BRIT provides necessary isotopic sources.

Isotope tracer methods are available to locate leaks in pipelines and are very convenient to use. If a buried gas or liquid pipeline springs a leak in a say 10 km section, it is not necessary to dig open the entire stretch to locate the leak. Radiotracers have been used since the late 70's to locate leaks in buried pipelines, such as the 120 km long Viramgram-Koyali crude oil line, the Mumbai-Pune petroleum product line and many others. Similarly it is a common practice to use an isotope source loaded gadget called "pig" (pipe inspection gauge)¹¹ to locate blockages in pipelines¹².

In recent years, tracer technology has been used to analyse more complex problems in industrial process vessels and in environmental control. Some examples follow.

- Determination of the dead volume in a bauxite digester in an aluminium plant (Dead volume is the volume not available for the process either due to deposits or because of faulty flow patterns in the vessel.)

11. Isotope pig is different from the instrumented pig developed by BARC for the Indian Oil Corporation. The latter is an electronic device to determine the health of cross-country pipelines.

12. Gursharan Singh, "Radioisotope Sealed Source Applications in Industry" IANCAS Bulletin, Vol 16, No 4, 2001.

- Determination of the cause of poor heat transfer in an aniline production reactor (Cause: large scale fouling on the shell side of the heat exchanger.)
- Identification of the cause of malfunctioning of an oxidation reactor in a petrochemical complex (Cause: poor design of an impeller leading to less than desired level of circulation.)
- Investigation of flow dynamics in trickle bed reactors (for scale up.)
- Investigation of flow dynamics in different continuous pans in sugar industry (for investigating poor quality and low efficiency).

Radioisotopes were also used to study the dilution and dispersion of sewage disposed off into sea at the Colaba outfall in Mumbai. The information is vital for designing new outfalls and to ensure safety of coastal waters for a variety of uses. Radiotracers have been used to study sediment transport at almost all the major ports and harbors and such studies have provided guidance for dredging operations and have saved cost of these operations. As part of an ongoing programme of service to port and harbour development in our country, radiotracer investigations have been carried out to study the direction of bed load transport at Kolkata and Mumbai ports to help in their expansion programmes.

An isotope study was conducted to determine the origin of salinity and evaluate groundwater recharge conditions in the Delang-Puri sector of coastal Orissa. Isotopes techniques were used to date ground water along the ancient course of the legendary 'Saraswati' river in Western Rajasthan. Isotopes were also used to determine the origin of thermal waters in the geothermal areas in Madhya Pradesh, Uttar Pradesh and Himalayas. In arsenic infested aquifers of West Bengal, isotope techniques were used to study ground water dynamics

Radiotracers also find application in oil fields, where they are used to provide a rapid, generally quantitative and economically feasible means of providing information on fluid movements in and adjacent to well bore and subsurface fluid movement¹³. Tracer information is a small but important part of the information used in building up the oil reservoir model.

The unique capability of high energy radiation to bring about physical and chemical changes has formed the basis of a new technology

13 Prabuddha Jain, "Radiotracer Applications in Oil Fields", IANCAS Bulletin, Vol 16, No 4, 2001.

known as radiation processing – the term used to describe large scale modification of materials by the application of radiation. In the field of polymers, this technique has led to the development of polymeric products having improved thermal, chemical, wear and other properties without the use of additives. For example, radiation processing has been used to produce rubber latex products free from toxic nitrosamines and has also been used to enhance the performance of simple thermoplastics, which would otherwise have required high cost engineering materials. Over the years, DAE has developed technology for the fabrication of high intensity sources and for the design, construction and operation of gamma irradiators for a variety of purposes. Radiation vulcanization of natural rubber is one such application and DAE has designed and built a gamma irradiator for radiation vulcanization of the natural rubber latex for the Rubber Board, Kottayam.

In recent years, Electron Beam (EB) processing has emerged as a preferred mode for polymer processing as these machines can be easily equipped with a variety of material handling systems, have a very high throughput, and do not require periodic source replacement. In view of this, DAE has an ongoing programme for building of industrial accelerators as well as developing their applications. The 2MeV Russian accelerator ILU-6 was installed in 1988 to get hands on experience on this technology and has been used for establishing radiation processing protocols for a number of new applications in collaboration with industry and research institutes. These include: cross-linked polyethylene ‘O’ rings that possess dimensional stability up to 220 degrees centigrade and are used as gaskets in caps for drums for the export market; degraded Teflon scrap for use in lubricants at high temperatures and non-stick kitchenware; fast acting hydrogels for concentration of slurries; cross-linked wire and cable insulation that are thinner than conventionally cross-linked products and as specified by Indian railways; and coloration of precious stones¹⁴. The accelerator ILU-6 has been shifted to a larger campus in Navi Mumbai to make it easily available to industrial users.

Realising that the future of radiation processing will depend largely on electron accelerators, CAT and BARC have taken up programmes to build industrial electron beam machines and related facilities to help

14 K S S Sarma and A B Majli, “Electron Accelerators and their Applications”, IANCAS Bulletin, Vol 15, No 4, 1999.

Indian industry to keep pace with technology development elsewhere in the world. BARC is setting up an Electron Beam (EB) Centre at Navi Mumbai and it will have a 3 MeV accelerator and a 10 MeV accelerator. These accelerators are being built in collaboration with Society for Applied Microwave Electronics Engineering and Research (SAMEER) and will be made available to industrial users. BARC is also collaborating with a private cable manufacturer to help them set up an electron beam accelerator for cable radiation. CAT has developed a 750 keV, 20 kW DC accelerator and it is being commissioned. This accelerator will find wide ranging applications where the required depth of irradiation does not exceed 1-2 mm. CAT is also developing a 10 MeV, 10 kW electron linac (linear accelerator) and it will be commissioned in early 2002. This accelerator can also be used for sterilization of medical products and processing of agricultural produce in addition to conventional industrial applications.

CAT and BARC are developing a wide variety of applications based on unique properties of lasers. Development of laser based health care equipment has already been described. CAT has also developed industrial lasers which could be used for welding, drilling, cutting metal sheets up to 1 cm, heat treatment and cladding. An industrial YAG laser developed at CAT can give power up to 300 W and can cut stainless sheets of 6mm thickness. This laser beam can be transmitted through a flexible optical fibre up to 100 m for remote cutting or welding. CAT has also developed several models of industrial CO₂ laser. These models have different power, highest being 10 kW, which is sufficient to cut more than 1 cm thick steel with great precision. This laser can also be used for cladding, alloying and surface treatments. A laser engraver developed at CAT can engrave with great precision on the hardest substances without any physical contact.

Many laser based instruments have also been developed. These include laser fluorimeter to detect trace quantities (0.2 ppb) of uranium in water samples; laser based non-contact dimension measuring instruments; projectile speed monitor and free space laser voice communicator. Units of DAE have already made a beginning for collaboration with Bharat Electronics to produce some of the laser based developments on a commercial scale. Technology for the dimension measuring instrument has already been licensed to a private entrepreneur.

Concluding Remarks

Applications of radiation technology to health care, industry, food and agriculture are of direct benefit to society and the DAE is working on all aspects, viz. production and supply of sources of radiation, use of radiation for known applications and research & development aimed at acquiring new applications, design and manufacture of equipment and plants to facilitate use of radiation technologies and deployment of such technologies in the country. We are now trying to reach production as well as user agencies for wider deployment of such technologies, so as to provide larger benefit to society and to make higher contribution to the health and prosperity of our people.

Front Cover: Research reactors Dhruva and Cirus at Trombay