Industrial Applications of Radioisotopes and Radiation

Chapter-3

Ensuring Wealth for the Nation

Radioisotopes and radiation processing techniques are increasingly being used in industry to enhance productivity, produce better materials and for elucidating information that is not possible to be obtained by any other means. The applications include gamma radiography, radioisotope gauging, use of radioisotopes as tracers, sterilization of medical products and processing of polymeric materials. At DAE, the programme on use of radioisotopes for industrial applications was initiated with the commissioning of APSARA in 1956 and the programme was firmly established with the availability of radioisotopes from CIRUS. The use of gamma radiography during the construction phase of CIRUS provided an opportunity to the technologists to understand intricacies of the technology for examining critical components for internal defects without damaging the object. The use of radioisotopes as tracers was demonstrated as early as 1958 to provide information to Bombay Port Authority regarding movement of the silt after dredging operations in the Bombay Harbour. Over the years, radioisotopes have also emerged as valuable tools for locating leaks in dams, heat exchangers and oil pipelines. High-energy radiation has the unique ability to generate highly reactive radicals or ions in the irradiated substrate in any phase, at any temperature. These highly reactive species could later induce chemical or biological changes in the material. This formed the basis of another area of application of radioisotopes, namely radiation processing. Setting up of the ISOMED, the first large-scale irradiator in South-east Asia, in 1974 heralded a new era in the country for gamma sterilization of medical products. The establishment of electron beam accelerator for processing of polymeric materials opened new avenues for Indian industries to gain hands-on experience of crosslinking of wire and cables, heat-shrinkable materials and developing polymers for high temperature applications.

Fluid Catalyst Cracking Unit investigated using radiotracers

INDUSTRIAL APPLICATIONS OF RADIOISOTOPES AND RADIATION
Ensuring Wealth for the Nation

Introduction

The progress of human civilization since ancient times has been markedly dependent on finding new tools and developing new technologies. Towards the end of the nineteenth century, discoveries such as X-rays and radioactivity empowered mankind with yet another tool in the new form of energy. It was immediately recognized that both natural radioactivity and X-rays could be utilized for a variety of applications in industry. With the availability of artificial radioactive materials in the1930's, utilisation of radiation and radioisotopes grew manifolds. For industrial applications, advantage was generally taken of one of the following unique properties of radiation:

1. Attenuation of radiation when it passes through an object due to absorption and scattering. The extent of attenuation depends on the composition and geometry of the object as well as energy and type of radiation.
2. Ease of detection of radioisotopes in extremely small quantities makes them useful as tracers for investigation of biological, industrial and environmental processes.
3. Physical or chemical changes induced in the target material by deposition of radiation energy.

These properties have formed the basis of a number of industrial applications. For example, attenuation of radiation emitted by sealed radiation sources can be made use of in non-destructive testing, the ease of detection of radioisotopes makes them ideal tracers for studying chemical processes and the physical or chemical changes produced by radiation can be used to modify properties of materials like polymers. Over the years, many such applications have been developed at BARC.

The Early Years

Work on utilization of radiations and radioisotopes for industrial applications began in the early years of Indian atomic energy programme. Use of radioisotopes, *inter alia,* allowed carrying out non-destructive testing of flaws in welds and castings. Following the concept that "charity begins at home", the DAE itself was the first beneficiary in India of employing isotope radiography technique on a large scale for inspection of welds and assemblies during construction of CIRUS early in 1957. All the equipment, accessories and radiation sources required for inspection were then imported from Canada. The importance of the technique and the advantages of its application were quickly realized and the Department drew up a comprehensive programme of indigenous development of the technology. As a result of this, an integrated approach for technology development was initiated at Isotope Division in 1959. Production of radiography sources was started in 1959. on a limited scale in the APSARA reactor. By 1962, production of radiography sources of iridium – 192 and cobalt – 60 was taken up on a larger scale in CIRUS reactor. Simultaneously, work was initiated on the production of equipment needed for radiography testing. Radiography camera capable of containing 10 Curies of iridium-192 was developed at Trombay in 1962 and made available to industrial users. These cameras were useful for field testing of objects such as storage tanks and structural welds. Later, in 1965, another camera housing 10 Curie of cobalt-60 and weighing 350 kg was developed and made available for industrial radiography. As the use of this technology grew, besides supplying cameras, sources and other accessories required in radiography, DAE also started providing training facilities and radiography services. Such services in early years were provided to the fertilizesr plants at Sindri, Jharkhand; heavy water plant at Nangal; Tata thermal power station, Mumbai (then Bombay); Patratu thermal power station, Bihar and Oil refineries in Gujarat and Mumbai. Over the years, gamma radiography has been well established in the country. Presently there are over 475 industrial users in the country and radiography inspection is now a mandatory requirement for vessels and welded specimen.

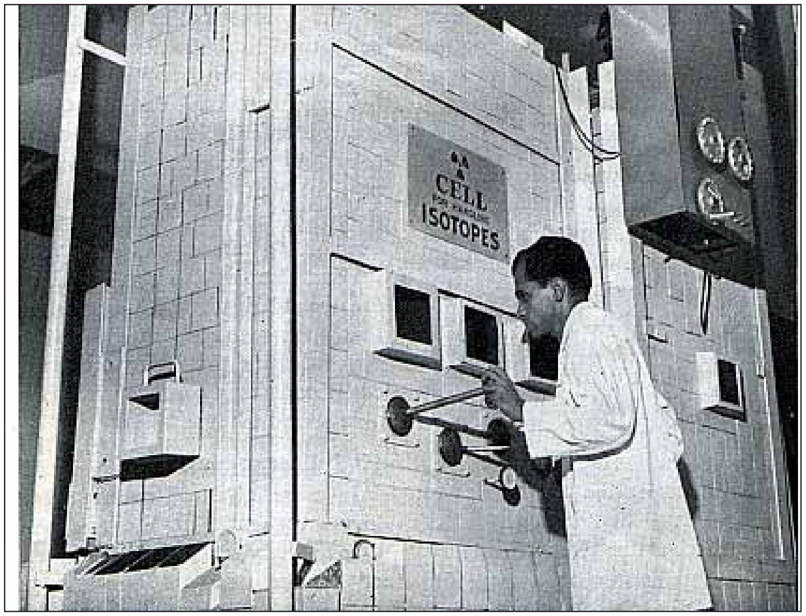
Another important industrial application of radioisotopes and radiation technology emerging in the early years was based on the second property, that is, the use of radioisotopes as tracers. The first ever radiotracer experiment in India was carried out in 1959 to investigate movement of sediment on sea bed in Bombay Harbour. With the construction of the oil terminal at Butcher Island, oil tankers needed 10.2 metre water depth in the channel to enter the harbour. The existing channel was not deep enough and the oil tankers had to wait for favourable tide. The Mumbai Port Trust proposed a programme to dredge a channel to a depth of 10.5 metre right up to Butcher Island. Model studies were carried out by Central Water and Power Research Station, Pune, to select a suitable site for dumping of dredged material. A team of scientists of Isotope division of BARC in collaboration with Bombay Port Trust, carried out the tracer investigation mainly to confirm suitability of the proposed dumping site. Artificial silt was prepared by grinding and sizing glass powder containing 1% scandium to match the particle size distribution of the natural sediment in the area. This ensured that movement of the artificial silt was similar to that of the natural silt. The artificial silt was irradiated in Atomic Energy Research Establishment (AERE), Harwell, UK to produce scandium-46 which was deposited on the sea bed by a remote controlled injector. The direction of movement of the radioactive tracer on the sea bed was followed by a special water proof GM detector for a period of about three months. The results provided vital information for large scale development of the harbour. In subsequent sediment transport investigations, carried out during the early sixties in the Kolkata (then Calcutta), Cochin, Karwar, Mangalore and Marmagoa ports, indigenously produced scandium-46 and gold-198 radiotracers were used. During 1965-1970 radiotracer experiments were carried out in Sethusamudram canal project and harbours of Vishakapatnam, Marmagoa, Mangalore, Kakinada and Cochin. Further experiments were carried out in different locations near Sagar Island for Kolkata port during 1985, 1987, 1991, 2000 and 2003, in Chennai port during 1988, off Karwar coast (Project Sea Bird) during 1991, and Kandla port in 2002. Over 70 investigations have been carried out so far at major ports and harbours in the country. These have provided valuable data and economic benefits to the port authorities. This is perhaps the largest number of tracer studies carried out by any country for harbour development and dredging programmes.

In another experiment in 1966, a radioisotope technique was employed to detect and locate leaks in the coaxial trunk telephone cables which were buried one metre deep between Bangalore and Pune. The isotope employed for the purpose was in the form of a radioactive gas (methyl bromide) containing 50 milli Curies of bromine-82. The gas was prepared in the

Radiotracer being removed from the lead shield for the first tracer experiment conducted on 14th March 1959 for sediment movement of Bombay Harbour

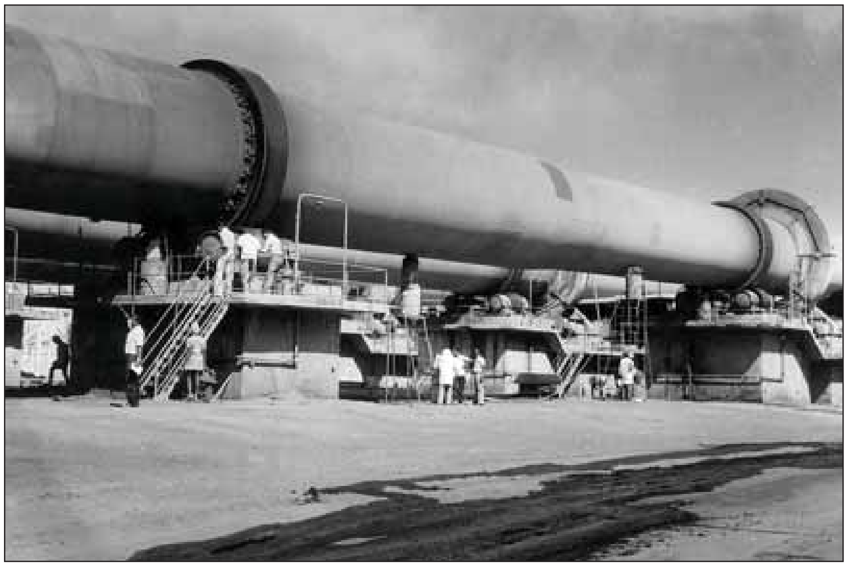
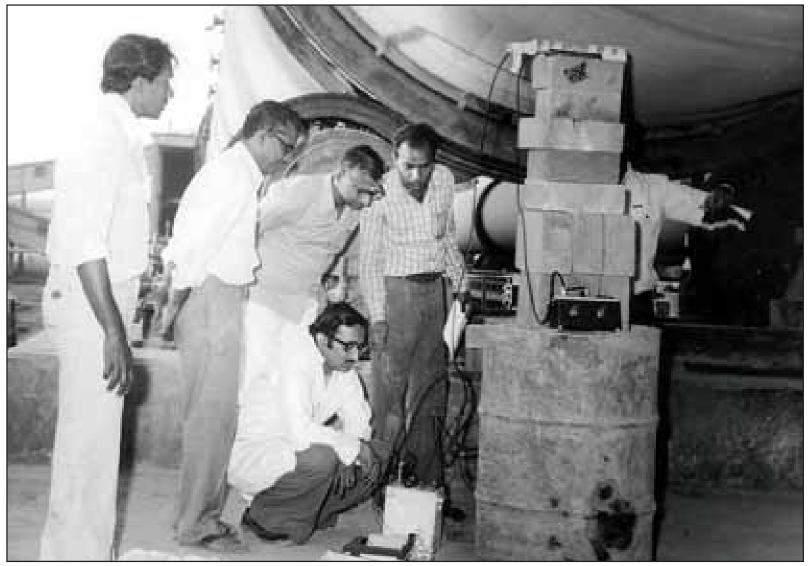
laboratory at Trombay, filled into a specially designed stainless steel container and transported to the site near Bangalore. This was the first time in India a radiotracer technique was used in an underground cable.

With the availability of ingeniously produced radioisotopes, radiotracers have been used for numerous applications such as monitoring the wear of refractory lining in blast furnaces in steel plants, wear rate monitoring of automobile components, leak and blockage location studies in underground pipelines, mercury inventory in electrolyte cells in caustic soda plants, residence time distribution investigations in chemical reactors in various industries, effluent dispersion in water bodies and flow rate measurement in industrial pipelines.



First radiobromine sample employed for detection and location of leaks being processed after irradiation at APSARA research reactor in 1966


The radiosotope being injected for sediment transport studies at Hooghly river, West Bengal



Radiotracer experiment being conducted at one of the cement factories near Coimbatore, for residence time distribution in the rotary kiln


Dr. Iya and Eapen with colleagues taking tea after a hectic day of work at the site

Emergence of fast computing techniques was revolutionizing data processing in the late 1980's and computerised methods were being applied for a variety of applications the world over. For advancement of radiography, development of computerised tomography was the next logical step for meeting the more demanding requirements of some of the advanced applications. Exploratory work on industrial applications of transmission-type computerised tomography was initiated in 1993. Initial experimental work was carried out on a cesium-137 gamma ray based translate-rotate system designed and developed with locally available nuclear counting instruments in the laboratory. A three-axis mechanical manipulator developed by the Central Workshops of BARC, was tested for industrial CT imaging in Isotope Division.

Cesium-137 gamma ray based industrial tomography system

Sewage Sludge Hygienisation Research Irradiator (SHRI)Facility at Vadodara, Gujarat

Chimanbhai Patel, then Chief Minister of Gujarat with Dr.P.K.Iyenger, then Chairman, AEC and Dr.R.Chidambram, then Director, BARC at the inauguration of Sewage Sludge Hygienisation Facility, Vadodara

Work on the use of radiation for causing chemical and biological changes, based on the third important property of radiation listed above, commenced at BARC with the studies related to radiation polymerization and radiation effects on microrganisms. The early research work on radiation polymerization focused on upgrading various low quality wood abundantly available in the country by in-situ polymerization of various organic monomers such as methyl methacrylate, vinyl acetate and styrene to produce wood-polymer composites possessing characteristics of high quality woods. A number of Indian woods such as vellapine, silver oak, Haldu and Tendoo which were available in large quantities were studied. The work was later continued at Isotope Division to upgrade the process for commercial exploitation. The work on the effect of radiation on microorganisms was focused on developing radiation sterilization technology. The success for the applications of radiation and radioisotopes for non-destructive testing was achieved almost immediately, because these techniques were essentially for industrial troubleshooting requiring low activity radiation sources and low initial capital. Establishing new technology for radiation processing was altogether a different proposition. That demanded use of gamma radiation sources in the kilo to mega-curie range and the technology had to compete and replace conventional high capital cost technology. Therefore, with a view to bring radiation technology in India, a proposal was formulated sometime in 1970 to set up an irradiation facility with the help of United Nations Development Programme (UNDP). The facility was set up in 1972 with financial contribution from UNDP, IAEA and the Indian Government. ISOMED, the first large radiation plant for sterilization of medical products, was formally commissioned on January 1, 1974. The setting up of this facility ushered in a new era of radiation processing in the country. One of the challenges in establishing this technology was to develop the dosimetry protocol as the sole process for validation of the sterilization process. The experience gained in the commissioning and operating this facility helped in setting up similar indigenously developed facilities in various parts of the country. In order to further extend the applications of radiation hygienization concept, a Sludge Hygienization Research Irradiator (SHRI) was set up by BARC at Vadodara (then Baroda), Gujarat in collaboration with Gujarat government and Baroda Municipal Corporation.

The programme of radiation processing was further strengthened in 1988 with the commissioning of 2-MeV electron beam (EB) accelerator. This accelerator has formed the backbone of developing industrial applications of electron beam processing in the country.

Radiotracers in Industry

The use of radioisotopes for tracer studies in a number of applications offers many advantages over conventional methods such as dyes and chemicals. The most important advantage being the ease and certainity of detecting radiation as sensitive instruments can detect very low levels of radioactivity and that radiation coming out is unique to the tracer isotope. These applications have been developed since early 1960's and have been deployed for solving a number of challenging problems. Some of the notable ones are the following.

Radiotracers for troubleshooting and process optimization in industry

Radiotracers have been frequently used in the Indian industry for troubleshooting and process optimization. Tritiated water and carbon-14 labeled compounds are being used for tracing the water and oil for effective management of oil fields.

Some of the important applications of tracer technology resulting in huge economic benefits are presented below:

Commonly used Radiotracers in Industry

Isotope	Radiation Energy (MeV)	Half- Life	Chemical Form	Tracing Application
Argon -41	1.37	110 minute	Argon	Gases
Sodium -24	1.37 and 2.45	15 hours	Sodium Carbonate	Aqueous solutions
Bromine -82	0.55 and 1.32	36 hours	Ammonium BromideMethyl BromideP-Dibromobenzene	Aqueous Solutions Gases Petroleum and other organic fluids
Lanthanum -140	0.33 to 2.54	1.68 days	Lanthanum Chloride	Solids as adsorbed tracer
Mercury -197	0.08 to 0.28	1.7 days	Mercury metal	Mercury inventory
Gold -198	0.41	2.7 days	Chloroauric acid	Solids as adsorbed tracer
Iodine -131	0.36 and 0.64	8.04 days	Potassium iodide Iodobenzene	Aqueous solutions Petroleum and other organic fluids
Mercury -203	0.28	46.6 days	Mercury metal	Mercury inventory
Scandium -46	O.89 and 1.48	84 days	Scandium oxide	Solid particles
Krypton -85*	0.7 and 0.54	10.6 years	Krypton	Gases
Tritium*	0.0156	12.43 years	Tritiated water	Aqueous solutions

** Beta emitters, all others are gamma emitters*

Examples of cost savings/benefits accrued to Indian Industry due to Radioisotope Applications

S.No.	Application	Savings / Benefits
1.	Gamma scanning of industrial process columns	- About Rs 6 crore for a typical small column - Reduced shut-down time - Pinpointing of the problem area
2.	Leak location in underground pipelines	- About Rs.18 crore for a typical 50 km long petroleum product pipeline - No need to dig open the suspected section of the pipeline - Pinpointing the leak location
3.	Blockage location in underground pipelines	- Rs. 80 lakh for a typical 50 km long pipeline - Reduced down time of the pipeline - Accuracy in locating
4.	Studies for dead volume estimation in chemical reactors 3 m diameter reactor	- Rs. 105 crore per year for a typical - Reduction in shut-down period
5.	Mercury inventory in caustic soda cells	- Rs. 75 lakh per month for a plant having about 50 electrolytic cells. - No plant shutdown is required - Handling of mercury for inventory is completely avoided.

Many new investigations of complex industrial processes using radioisotopes have been recently carried out for the first time in India. These include investigation of Fluidized Catalytic Cracking Units (FCCU) and Coal gasifier and validation of Computational Fluid Dynamics [CFD] models. Radiotracer investigations have been carried in "Fluid Catalyst Cracking Unit" to investigate dynamics of three different sub-systems of the FCCU i.e. riser, stripper and regenerator. Lanthanum-140 labelled catalyst was used for tracing solid phase, while krypton-79 was used for tracing gas phase. The tracer injected at the inlet of the system was monitored simultaneously at fifteen different locations. The tracer data obtained was treated and analysed. Axial dispersion model was used to simulate the experimentally measured residence time distribution data. The mean residence times of 1.5-20 seconds were measured.

This was the first radiotracer investigation carried out in India in FCCU and was carried out under an MOU with Bharat Petroleum Corporation Limited (BPCL), Engineers India Limited (EIL) and BARC with the help of French experts. The necessary indigenous capability to conduct radiotracer investigations in FCCU has been acquired.

Radiotracer experiment for leak location in heat exchangers

Radiotracer experiment for residence time distribution estimation in Sugar Industry.

Oxidizer investigated using radiotracers

Leak location in underground pipelines using radiotracers

Over the years, BARC has gained considerable expertise in industrial troubleshooting and optimization of industrial processes such as leak and blockage location in underground buried pipelines, material inventory, characterization of reactor kinetics like mean residence time and residence time distribution [RTD]. using radioactive tracers. The Isotope group has carried out over two hundred investigations using tracers in industry. In addition, large steel and oil industries have strong in-house tracer groups for applications within their industries. ONGC extensively uses radiotracers for inter-well studies to plan secondary recovery operations.

Non-destructive Techniques

In a wide range of industrial applications of sealed sources, ranging from laboratory investigations to routine applications of economic significance, radiography testing enjoys a unique position. It is perhaps the simplest widely practiced non-destructive evaluation technique. It costs little but pays more in routine inspection and quality assurance programme. The range of application of the technique is far and wide. This includes inspection of materials, components and assemblies of those ranging from nuclear reactors, boilers, pressure vessels and piping to common industrial products reaching the consumer. Isotope radiography enjoys the unique advantage in terms of inspecting objects located in intricate positions as the equipment required is portable and cheap.

Isotope radiography testing of an aircraft engine

Realizing the importance of radiography testing in industrial development, BARC and BRIT, have an integrated programme of development, production and supply of a range of gamma radiographic equipment along with the production of radiography sources useful to inspect specimens from 10 - 200 mm thick steel or equivalent material. Its use has grown very rapidly and is a mandatory requirement for testing of pressure vessels, turbines, space vehicles, aircrafts, ships, bridges, offshore rigs and platforms, transport pipe lines and a host of other industrial components. There has been a phenomenal growth in the number of X-ray and gamma ray installations in India. Today, in India there are over 1050 gamma radiography cameras, 350 industrial X-ray machines and 750 radiography sites in about 450 institutions. Almost every segment of Indian industry uses this technology.

Human Resource Development in Radiography Testing

BARC has played a pivotal role since 1960 in human resource development to meet growing needs of the industry. Till 1978, adhoc training courses based on individual requirement were conducted. Certification courses on Radiography Testing were started in 1978. Snice January 1994, training courses based on ISO 9712 scheme have been conducted with a three level system. The syllabus for the course is as per the Bureau of Indian Standards document IS 13805, 1993

" General Standard for Qualification and Certification of NDT Personnel", and examination is based on the guidelines of ISO - 9712. Training courses on Industrial Radiography Testing at levels 1, 2 & 3 as per ISO-9712 and IS –13805 are regularly organized for various cadres of radiography personnel; operators to managers (RT-1 to RT-3). Nearly 7000 people have so far been trained in about 15 centres in the country and licensed to practice isotope radiography.

Today, Indian industry is in a very comfortable position due to availability of indigenously produced radiography equipment and availability of trained NDT personnel. Availability of indigenous reliable, safe and low cost radiography cameras has helped to propagate this technology in India, towards achieving self-reliance in this important branch of non-destructive testing.

Gamma Scanning of Industrial Process Columns

This technique was initiated in India in 1995 under a MoU with the Engineers India Ltd [EIL]. At present, BARC and EIL, jointly as well as independently, offer service to industry for on-line troubleshooting and process optimization of industrial process columns. BARC alone has investigated over 180 columns of different types including tray and packed beds upto 9.5 diameters resulting in savings of several hundred crore of rupees to Indian Industry.

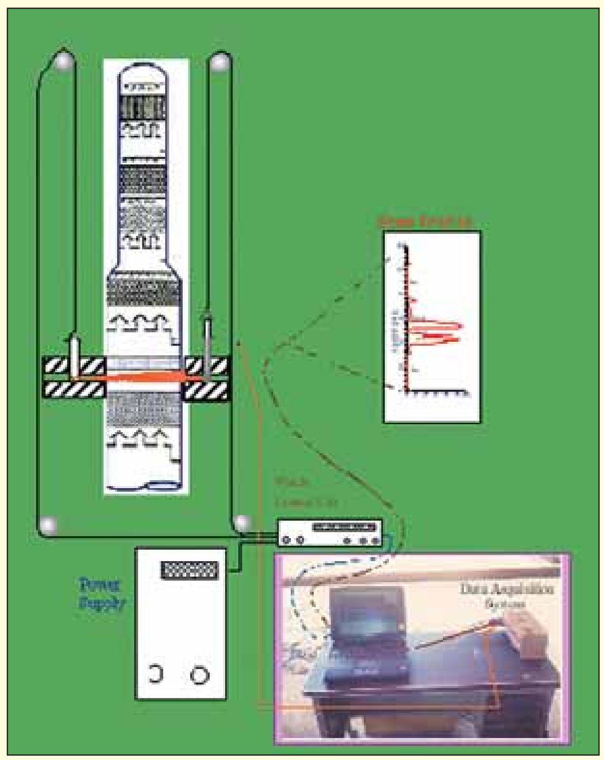
Recent advancement in this technology being carried out jointly by BARC and University Institute of Chemical Technology (UICT), is the use of grid tomography scanning technique for determining axial and radial maldistribution of liquid and vapour phases in petroleum refineries. About 30 major petroleum, petrochemical and chemical process industries, including Heavy Water Board, have benefitted from the gamma scanning technology.

Gamma scanning

Gamma scanning techniques enable on-line assessment of internal condition of the column. It is a non-destructive and non-invasive technique which can be used for troubleshooting of distillation columns and other related systems. This technique can also be employed for removing bottlenecks of processes involving multiphase systems. Being very effective, it is frequently used even for predictive maintenance of column hardware. The technique depends upon absorption of gamma rays emitted from radioisotopes by process fluids consisting of vapours and liquids. In chemical, petrochemical and petroleum refining industries, proper working of process columns such as distillation, extraction, stripper and related systems is very important as it affects production efficiency and product quality. Any malfunctioning could result in huge revenue losses. During the operational life of these systems, many problems can develop, which can lead to mechanical damage to their internals or to a problem in the process itself. Malfunctioning of columns may also lead to fire hazards and atmospheric pollution. Conventional techniques fail to pin-point the exact location of the problem. Gamma scanning can provide information about the following column processes:

- Presence or absence of trays and other internals,
- Identification, location and extent of flooding,
- Liquid levels on trays and liquid distribution in packed bed columns,
- Location and severity of entrainment,
- Presence of weeping and foaming,
- Integrity of mist eliminators,
- Extent of vapour-liquid mal-distribution in packed beds, and
- Presence of liquid level in reboilers and reflux drums.

Schematic of Gamma Scanning Setup



Examples of Economic Benefits due to Gamma Scanning Investigations

Type of column and diameter	Nature of findings	Duration of scanning and cost saving Rs. (Estimated)	Remedial action
Depropaniser Column (2.0 metres)	Flooding observed on 4 trays in the middle portion of the column	4 days 3 crore	Operating parameters optimised
Quench Tower (8. 0 metres)	Flooding and vapour liquid maldistribution observed	5 days 3 - 4 crore	Addition of anti-foaming agents helped in improving the column performance
Vacuum Column (9.5 metres)	- Damage of the trays leading to leakage, - Damage to demister pad	4 days Shut down period reduced from 30 days to 7 days Saving more than 50 crore	Repairs of damaged trays and demister pad
Purification Reactor (3.3 metres)	Level gauge calibration with dip source	2 days 1-2 crore	Recalibration of installed gauge
Vacuum Distillation Column (3.3 metres)	Partial blockage on all the beds Heavy blockage on bed - 2	3 days 20 lakh	Cleaning of packed beds
Sponge Gas Amine Absorber Column (2.2 metres)	Unequal liquid level on trays	4 days 50 lakh	Process parameters adjusted
Distillation Tower (2.4 metres)	Very low liquid level Channeling of vapours Few valves missing or damaged	3 days 50 lakh	Damaged valves replaced
Distillation Tower (2.5 metres)	Unequal liquid level on top section Very low liquid on few trays in the bottom section Localised chocking on trays	4 days 50 lakh	Trays cleaned

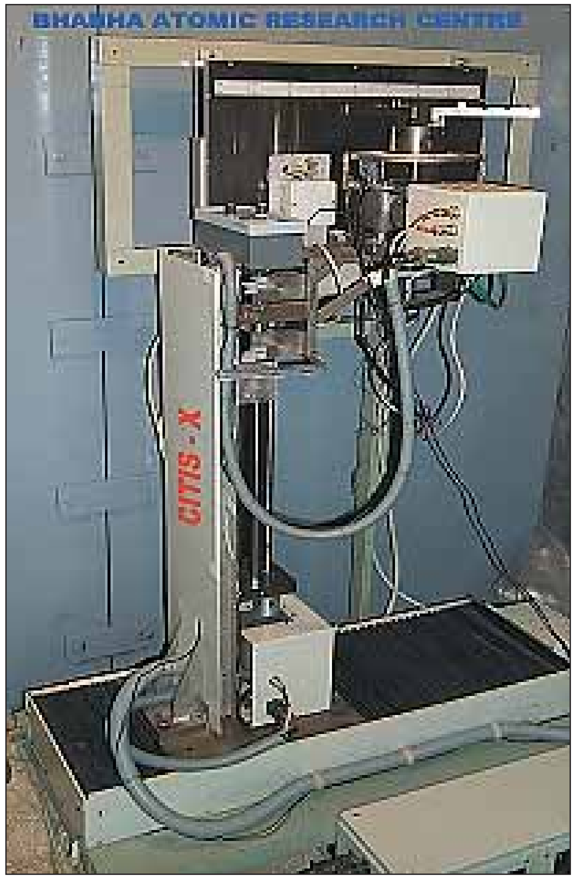
Industrial Computerised Tomography Imaging

As mentioned earlier, work on industrial applications of transmission-type computerisd tomography was initiated in 1993 using a cesium-137 gamma ray based system. This was probably the first of its kind in India, which created keen interest and excitement. A number of organizations, were interested in developing and adapting this new industrial imaging technique for specific requirements. Among them was the Defence Research and Development Laboratory (DRDL) of Defence Research and Development Organisation (DRDO) and Rocket

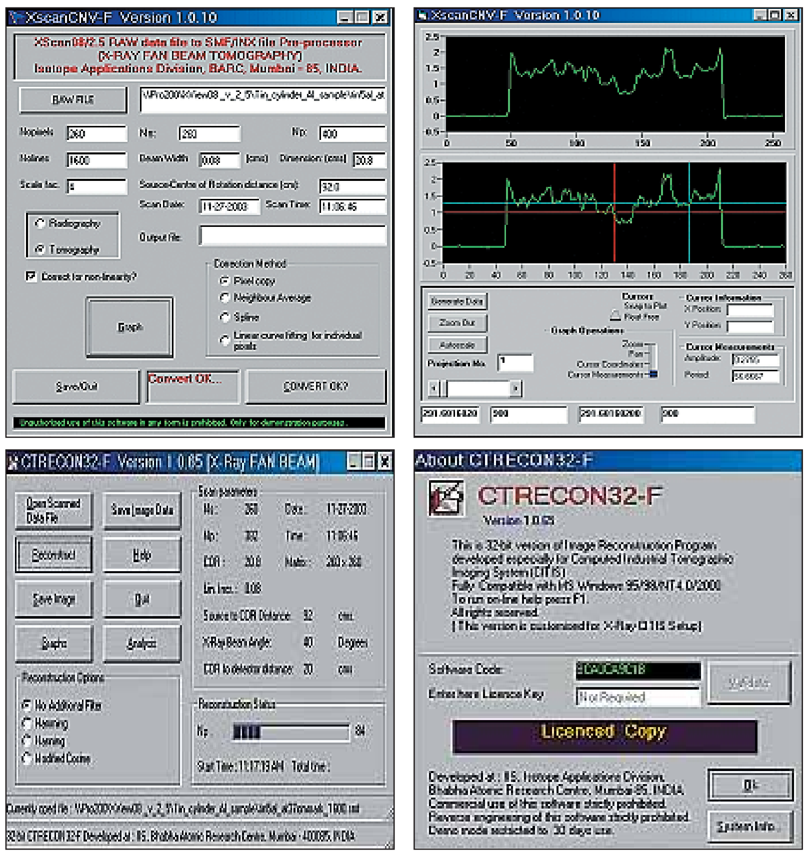
Propellant Plant at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram. However, as this system was slow in acquiring the image due to limited intensity of 7 curie cesium-137 source, it was felt that it should be upgraded with a X-ray machine. DAE acted as the nodal centre for initial research and development work on a prototype using 420/450 kV constant potential X-rays and a linear detector array. DRDO and VSSC contributed by providing on loan basis, some industrial X-ray equipment and test phantoms.

This research project planned to carry out studies in beam-energy and parameter calibrations, cupping effects, also known as beam hardening effects, and associated problems in system alignments and related artifacts. The project intended to make use of (i) a high precision six-axis Controller based on Numeric Control (CNC) based mechanical manipulator, (ii) a 420 kV CP X-ray equipment, (iii) a high dynamic range solid-state linear detector array comprising mainly of $CdWO_4$ (scintillator) and PIN photodiode integral assembly and (iv) software for data acquisition system, system control, image reconstruction, display and analysis. It was also planned that after the system is developed and installed, other studies can be carried out. An MoU was signed between BARC and Hindustan Machine Tools (HMT) for manufacture, installation and commissioning of the six-axis CNC based system in collaboration with Centre for Design and Manufacturing (CDM), and Isotope Applications Division, BARC. The non-availability of a suitable detector for 420 kV machanical array system necessitated use of 160 kV X-ray machine and detector array system.

At present, a 160 kV linear detector array (LDA) meant for low-energy digital radiography designed and developed on the similar data transfer protocols enables carrying out research and development work on the associated problems. BARC has been successful in the code development for tomography image reconstruction, display and defect visualisation, 2D and 3D digital radiographic and computerised tomographic imaging simulation, tomographic image analysis and hardware specific data acquisition system for single detector as well as multi-detector configuration.

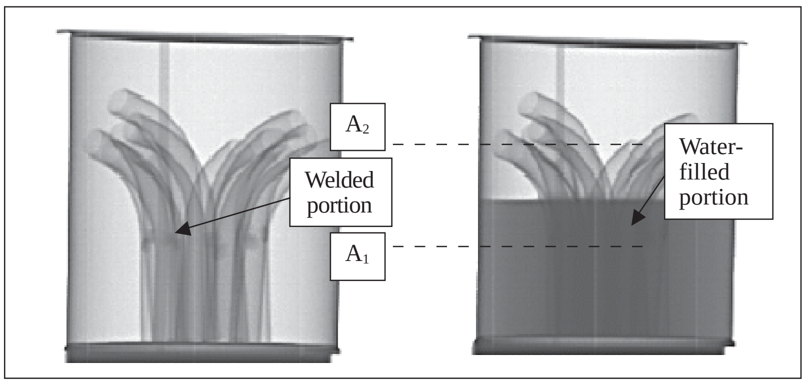


160 kV X-ray based experimental tomography system for industrial applications

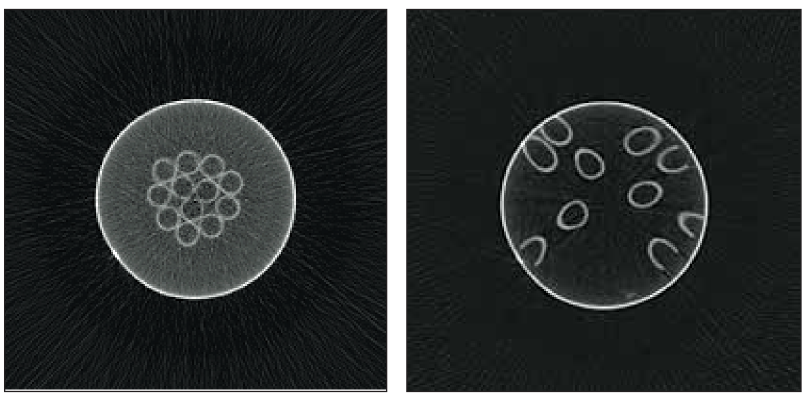


Graphical user interface of the image reconstruction and analysis software for the X-ray based industrial tomography system developed at BARC

A thin metallic container partially filled with water [100mm(H) x 100mm(OD)] housing a section of welded aluminium curved tubes



Radiographic view of the container assembly without water and with partially filled water using 100 kV X-rays



Tomographic images of the container-assembly cross-sections with 100 kV X-rays

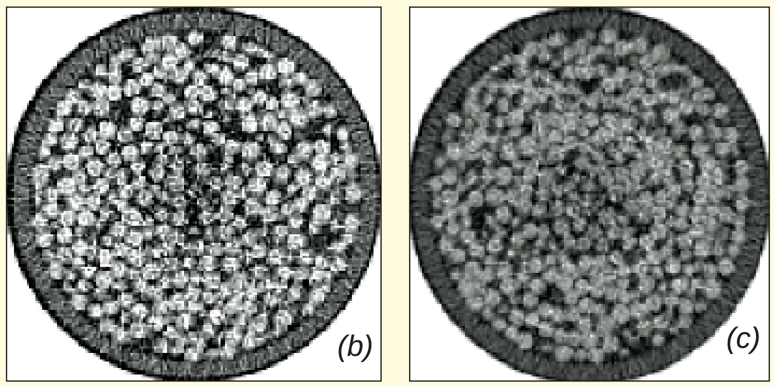
Initial studies on the feasibility of applying computerised tomography imaging to industrial process columns were also carried out using this system. The test specimen was a small trickle bed reactor column made of perspex filled with alumina granules. In the initial test runs, cross-sectional CT images were obtained showing the dry and completely flooded bed with relative geometrical shapes.

(a) Small test trickle bed reactor used in the experiment.

(b) Dry alumina packing in 5mm thick perspex container

(c) Alumina packing in 5mm thick perspex container under trickle flow

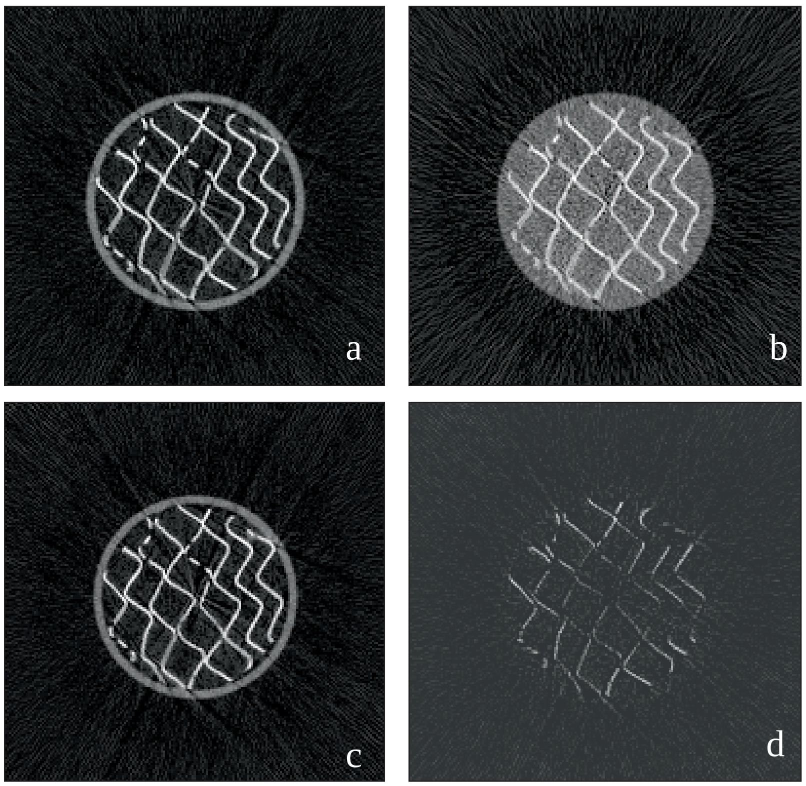
(a)



CT Scanning of Industrial Process Column

Initial feasibility studies on the use of X-ray based industrial tomography imaging for visualising internal details and process parameters were carried out in collaboration with Heavy Water Board and University Institute of Chemical Technology (UICT), Mumbai on a simulated and scaled-down process column specimen. The design of the column was provided by HWB and the same was fabricated in consultation with UICT. The experiment was planned and carried out with active feedback from UICT under the DAE-UICT knowledge base project. The experimental data is being analysed to see its viability for process imaging applications.

A test specimen column designed and fabricated for the X-ray based process tomography visualisation. The specimen is mounted on the experimental 160 kV X-ray ICT System



A typical cross-section of the test specimen (a) No water flow, internal stainless steel packing seen with acrylic container (b) Column completely flooded (c) with liquid flow along the packing (d) Difference image (c-a). On initial examination, the image in figure (c) does not distinguish any liquid film formation from the image in figure (a). However, the difference image shows some liquid distribution along the packing sheets

The major stress during these studies has been on technology development including all the necessary softwares followed by a prototype 160 kV X-Ray based ICT system development. With the procurement of detector systems compatible with 420 kV X-rays, the advanced industrial tomography imaging system would be made operational for test scans and calibration studies.

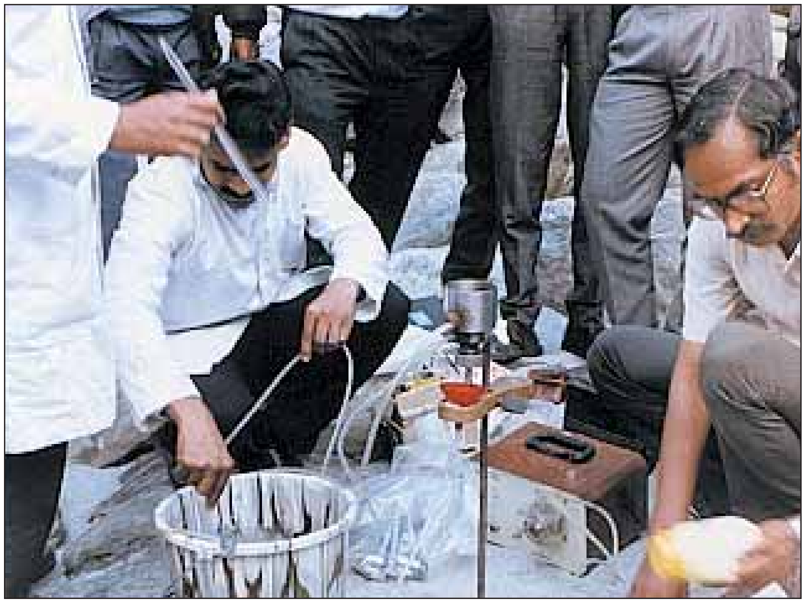
Isotope Techniques for Water Resources Development and Management

Applications of Artificial Radioisotope Tracers in Hydrology

Determination of flow and direction of water bodies

Water is an important natural national resource that is becoming increasingly vital day by day. An important application of using radiotracers for determination of flow rate of water in the rivers was successfully carried out in 1962 in the river Mutha at Pune in collaboration with Central Water and Power Research Station, Pune. It involved injection of bromine-82 as tracer into the river. The flow rate of water was calculated by comparing the amount of radioactivity at a point downstream, where the tracer is well mixed, with radioactivity at the injection point. The major difficulty in application of the tracer method was the requirement of complete mixing of the tracer. Many empirical methods were used to estimate the mixing length. The usefulness of this technique to measure high discharges upto1250 m^3/s was demonstrated in Tapi river near Surat in Gujarat during 1963. The technique was more efficient and accurate than the conventional method of measuring water flow by a current meter. Similar flow measurements were also carried out in Ganga canal in Uttar Pradesh (1967), Tons river (1969), Bhira power station, Maharashtra (1973), Beas river in Himachal Pradesh (1979) and Teesta river in Sikkim (1992). Flow measurements by tracer method have been found to be specially useful for mountainous rivers where conventional techniques are not practicle.

Determination of groundwater velocity and direction of underground water movement is a difficult subject to study by using conventional methods especially for localized ground water flow. Radiotracers, because of their ease of detection *in*



Isotope injection preparation in progress for studying discharge of Teesta River, Sikkim

situ in the field, can be of great help in such measurements. Therefore, a point dilution probe for measurement of groundwater velocity using bromine-82 radiotracer was developed. The probe used for the experiment comprised a tracer injection and mixing device, inflatable rubber packers to isolate portion of the borehole and a built-in scintillation detector assembly. The probe could be lowered to a desired depth in a borehole, the packers inflated to isolate a portion of the borehole (to define the dilution volume and to avoid vertical currents). A suitable short lived radiotracer such as bromine-82 was injected and well mixed in the dilution volume. From the dilution of the radiotracer as measured by the detector the groundwater velocity could be computed. The method has been used to study a variety of seepage and pollution problems. *In-situ* measurement of permeability of seepage flow using the point dilution method in the banks of unlined canals was used to estimate seepage losses. The method was developed for Ganga canal in collaboration with UP Irrigation Research Institute, Roorkee. Later, in a sea water intrusion investigation in Minjur aquifer, in Tamil Nadu, the rate of intrusion of salt water inland was determined by measurement of groundwater velocities in a few selected piezometers. The information was of particular interest in controlling the aquifer exploitation.

The single well method was also used for determination of vertical velocities at different depths in boreholes. The probe developed for the purpose consisted of a tracer injector and scintillation detector placed above or below the injector at specific distances. By recording the times of arrival of the tracer peak it was possible to calculate the upward or downward vertical velocity in the borehole. The technique was applied in seepage investigation in Poip dam in Maharashtra and intrusion of salt water inland in the coastal Minjur aquifer in Tamil Nadu.

For determining the direction of groundwater flow, a technique consisting of instantaneous addition of tracer into a water column in a well and its detection at the wells downstream was developed that allowed spatial and temporal distribution of the tracer.The technique was applied in Manikaran geothermal area in Himachal Pradesh. Manikaran is located at an elevation of 1700 m in the Parvati valley in the Kullu district of Himachal Pradesh. Geological Survey of India undertook detailed hydrogeological and geophysical survey to evaluate the geothermal energy potential. Several exploratory borewells were drilled including 2 deep geothermal wells DGW1 and DGW2. Evaluation of the data gave rise to divergent views on the direction of flow. Hence radiotracer studies were carried out to resolve this issue. Bromine-82 and tritium were used as tracers. First 400 mCi of bromine-82 was injected in DGW-1 at a depth of 70 m below ground level. The bromine-82 activity was monitored in all other borewells and hot springs for a period of 3 days. No bromine-82 activity was detected in any of the monitoring points. Subsequently 25 millicuries of tritium was injected and the activity monitored. From the tritium results it was concluded that the geothermal waters mainly flow from north to south across the Parvati valley.

Application of Environmental Isotopes in Hydrology

In the early years of the programme, the focus was on the development of applications of radioisotopes for water resources management. However, it was clear that naturally occuring isotopes like tritium and carbon-14 could also be utilized beneficially for many other applications. Of course, this required setting up of special facilities like mass spectrometry for analysis of the samples. During 1981-84, an environmental isotope laboratory was built and a space of 400 m^2 was arranged in HIRUP. Facilities such as a mass spectrometer for estimating deuterium and oxygen-18 as well as liquid scintillation counter for Tritium and Carbon-14 measurements were established under UNDP.

Groundwater salinisation in coastal and inland aquifers

Salinity of water resources in coastal areas is a well known problem. Isotopic techniques were used for investigating the source of salinity and delineate the fresh water aquifers. First such investigation was carried out at coastal Minjur aquifer (north of Chennai) during 1983–85. Progressive increase in the salinity of the aquifer was causing concern to the city water supply authorities and to industries in the region. Detailed studies carried out by Public Works Department, Tamil Nadu, indicated sea water intrusion into the aquifer. However, the existence of pockets of hypersaline groundwater in the area indicated other sources of salinity such as marine connate waters. Environmental isotopes deuterium, oxygen-18, sulphur-34, and tritium were used to study the salinisation process. It showed that the pocket of hypersaline water was not of any connate origin but was attributable to past salt pan activity. Similar investigations were conducted in coastal Midnapore in W.Bengal, and in Delang-Puri sector in coastal Orissa. In these areas it was found that the groundwater salinity was due to sea water transgression which had occurred in the past.

Groundwater salinity problems in inland areas were also investigated in parts of Haryana and Purna basin in Maharastra. The deep saline and some shallow saline groundwater in Haryana was found to originate from evaporation of surface waters during interpluvial dry phases in the holocene period. Amelioration of climatic conditions helped to flush out saline waters. However, a few shallow aquifers and most of the deeper aquifers have still retained former saline waters.

Interconnection between surface water and groundwater

During the construction of Salal hydroelectric project in Jammu in 1984, several seepages were encountered during the construction of a tail race tunnel through a dolomite hillock. The 2.5 km long tunnel was to carry tail waters from the power station back to the river channel. When a particular high seepage occurred at about 800 m from the outlet, the tunneling work had to be stopped. The source of seepage had to be found out as any such future seepage could endanger the lives of workers. An environmental isotope investigation was carried out. The deuterium and oxygen-18 of the seepages from the tunnel were distinctly different from those of river Chenab (Himalayan river) and other surface waters in the area. Hence local surface waters were not contributing to the springs. The tritium values of the seepage were higher than river Chenab which represented recent precipitation. By comparing the tritium values of New Delhi and Kabul precipitation, (which were on the IAEA/WMO network) and using a suitable model, it was shown that the seeping waters were 10 to 15 years old rain water trapped in the dolomite which were released whenever a sheer zone was pierced during the tunneling.

Regeneration of river Ganga between Hardwar and Narora

Planning for irrigation and power projects in a river basin is based on the assessment of available water potential and its seasonal variability. This assessment has to take into consideration groundwater contribution to the river. Groundwater contribution to the river Ganga between Hardwar and Narora was studied using environmental oxygen-18 (1985-86). Oxygen-18 of the river water and also groundwater close to the river course was monitored at 8 stations along the 220 km stretch for a period of 10 months. The oxygen-18 of the river was constant during the monsoon months. However during the dry periods from October to April, the oxygen-18 was enriched progressively from Hardwar to Narora. This indicated groundwater contribution to the river during the monsoon months which reached a maximum of about 60% in April.

Percolation tanks in Maharashtra

Construction of percolation tanks is a common practice in several parts of India for artificial replenishment of groundwater for lift irrigation in small agricultural tracts. Many such tanks have been constructed in the semi-arid regions of Maharastra and it was reported that some of them have brought increased benefits to the farmers while others have made no contribution to the wells. Groundwater Survey and Development Agency, Maharashtra, during 1986-88, had undertaken detailed study of the behaviour of some percolation tanks in order to make suitable recommendations on the location of future tanks. BARC was requested to assist through isotope studies to assess the effectiveness of such tanks for artificial recharge of local shallow groundwater bodies. One such tank investigated was Hinganigada tank in Dhond taluk in Pune district of Maharashtra. The tank was shallow with an average depth of ~ 4 m and impounded ~10^6 m^3 of water during the monsoon season. The dug wells in the command area penetrated soft rock over burden and fissured hard rock, which was exposed to the tank bed. The seepage medium consisted of fissured hard rock with jointed planes and fractures. The isotopic study using oxygen-18 showed that the wells near the tank received as much as 50% contribution from the tank. This study showed that the effectiveness of recharge to groundwater body depended on the fractures in the bed of the tank and seepage medium.

Jhamar Kotra phosphate mine, Udaipur

Jhamar Kotra phosphate mine, situated about 25 km south-east of Udaipur city in Rajasthan, is a mechanized open cast mine. The rock phophate in the area occurs in dolomitic lime-stone. As the mining at Jhamar Kotra reached the groundwater table, it needed to be dewatered. Intense dewatering through a battery of tubewells resulted in only a marginal fall in the water level leading to suspicion of water ingress from man made reservoirs located within a radius of about 9 km from the mine. Environmental isotopes deuterium and oxygen-18 showed that the reservoir waters were not connected to the mine waters. The pumped mine waters appeared to be recycled to the groundwater due to poor drainage. This helped authorities to take up necessary remedial measures.

Interconnection of aquifers in the Cauvery delta area, Tanjavur

Vagaries of monsoon and consequent problems in inter-state river water transfer often pose problems of water availability. Artificial recharge of the local groundwater bodies was considered one possibility to partially overcome this problem. To ensure feasibility of such artificial recharge, interconnection between shallow and deep groundwater bodies needed to be confirmed at Tanjavur, Tamil Nadu in Cauvery delta area. Water samples from shallow and deep zone groundwater were collected during January and May 1985 and analysed for deuterium and oxygen-18. The results of January samples showed that the deuterium and oxygen-18 of the shallow zone samples were more enriched compared to the deep zone samples. Comparison of these data with that obtained during May for shallow zone showed further enrichment in deuterium and oxygen-18, while the deep zone samples did not show any change. It was, therefore, concluded that the two zones were not interconnected except at isolated places where clay layers between the zones were either absent or very thin.

Groundwater recharge investigations in arid western Rajasthan

In arid areas precipitation is generally low and the problem is to know whether a given groundwater is being actively re-charged. Environmental deuterium, oxygen-18, tritium and carbon-14 were used to investigate this processes in the Jalore area of Western Rajasthan. The results showed that shallow

Isotopes for Arsenic Pollution Studies

Arsenic polluted drinking water is being consumed by about a million people living over an area of about 37,000 sq km in six districts of West Bengal and many are suffering from arsenic related diseases. The arsenic infested areas lie in the Indo-Gangetic plains. The source of arsenic here is mainly geogenic, i.e. leaching from arsenic bearing sediments. Interaction of arsenic bearing sediment with groundwater under different subsurface conditions play an important role in controlling retention and mobility of arsenic in the aquifer. Isotopic investigations were carried out during 1996-99 in collaboration with Central Groundwater Board, Kolkata, in Murshidabad and 24 Parganas, West Bengal to understand the groundwater dynamics and arsenic release from sediment to the groundwater. This would help to take up suitable remedial action. Groundwater samples from different depths and a few surface water samples were collected and analysed for environmental isotopes as well as arsenic content. Results indicate high arsenic content (up to 1.3 mg/L at Murshidabad and 3.0 mg/L at 24 Parganas) at depths of ~20 to 100 m.The deeper aquifers were free from arsenic. In the arsenic affected aquifers in these areas tritium and carbon-14 indicated that they receive modern recharge. The deeper aquifers, particularly in 24 Paraganas, consisted of old waters. Some interconnection between shallow arsenic-contaminated aquifer and deep arsenic-free aquifer is possible in Murshidabad. In these areas the arsenic is possibly released from the sediment into the aquifer under anoxic conditions.

groundwater near the Sukri river course was enriched in deuterium and oxygen-18 compared to that away from the river course indicating that they are possibly recharged from river channels during flash floods. The deep groundwater (>50 m) near the river course also showed some component of recent recharge indicating probable interconnection of shallow and deep aquifers. The other deep groundwater away from the river course, on the other hand, have negligible tritium and depleted deuterium and oxygen–18 indicating recharge during more humid periods in the past. Similar techniques were applied in Barmer (1986- 87), Bikaner (1987-88), Bilara (1991-92) and Jaisalmer (1995-97). The studies showed that most of the deep aquifers in these areas were old water and not replenished in modern times.

Fluoride contamination in groundwaters of Bagalkot district, Karnataka

Fluoride contamination is one of the acute public health problems that the country faces today. Environmental isotope technique (deuterium, oxygen-18 and tritium) was used to find out sources of fluoride in groundwater of Ilkal area, Bagalk ot district during 2001-03. Water samples were collected from borewells, dug wells, surface water bodies and analysed. Fluoride concentration in groundwater showed positive correlation with bicarbonates. The fluoride concentrations were found to be high in groundwater on either side of the Ilkal stream. Enrichment in deuterium and oxygen-18 was observed in fluoride contaminated groundwater compared to fluoride free groundwater. Tritium values of polluted groundwater indicated modern recharge. The study showed that significant fluoride was contributed by surface water bodies contaminated by man made activities, in addition to leaching of fluoride from fluoride bearing rocks like granite, gneisses and pegmatites.

Groundwater recharge and source of salinity of coastal aquifers in southern part of Chennai metropolitan area, Tamil Nadu

Recently, during 2000-03, isotope hydrological investigations were carried out to assess the ground water quality, source of recharge and ground water salinity in Tiruvanmiyur aquifer in Tamil Nadu in collaboration with Central Groundwater Board, Chennai. Hydrogeochemical and isotope data showed that precipitation is the main source of recharge to this aquifer and the water quality is mostly fresh, except at Mettukuppam, Nilangarai and Shilanagar. Stable isotope (deuterium and oxygen-18) data indicated that the salinity and brackishness of

Mythological River Saraswati : Did it flow through Rajasthan ?

A number of paleochannels had been identified in Western Rajasthan using remote sensing techniques and field observations. One of these channels had been traced to Western Jaisalmer in the North East-South West direction. In spite of the highly arid condition of the region, comparatively good quality groundwater was available along the course below 30m depths. A few dug wells in the study area did not dry up even in summer and tube wells did not show reduction in water table, even after extensive utilization for human as well as livestock consumption. Groundwater away from this course was saline. The above course was thought to belong to the legendary river Saraswati of Himalayan origin, mentioned in many early literary works and known to have existed 3000 years ago. This course was thought to maintain its head water connection with the Himalayan sources and form potential sources of groundwater.

An environmental isotope study was carried out in collaboration with Groundwater Department Jodhpur during 1999-2002 to study the origin and age of groundwater along the paleochannel. The stable isotope, tritium and radiocarbon values indicated that the shallow (<50 m) and deep (50 to 170 m) wells were palaeo waters with negligible modern recharge component. The stable isotopes (^{2}H and ^{18}O) of the shallow groundwater showed that they have undergone evaporation before recharge. ^{14}C model age of shallow wells was < 5000 year BP while that of the deep wells range from ~5000 to ~15000 years BP. Deep and shallow groundwater were generally not interconnected. From isotope results recharge to the shallow and deep groundwater possibly occurred during humid periods in the past. Due to the onset of low rainfall and dry conditions for the last 3000 years, the water in the river possibly dwindled and got buried in the paleochannels.

ground water in these places is not due to present seawater intrusion. The characteristic ion ratios (Ca+Mg)/(Na+K), Mg/Ca & Na/Cl were then computed. These were in good agreement with the environmental isotope as well as other hydrochemical results. The observed groundwater salinity at Mettukuppam was due to dissolution of evaporites of marine origin, while brackishness found in Nilangarai and Shilanagar deep zones could be due to leaching of salts from formation as indicated by their long residence time.

Location of seepage in dams

The use of radioisotopes to locate seepage in dams is another interesting application. Its development was initiated in 1966 to locate zones of seepage and to delineate the seepage path at Srisailam dam in Andhra Pradesh and Aliyar dam in Tamil Nadu. A masonry-concrete dam was proposed to be built across the Krishna river in the valley near Srisailam. Two rock filled coffer dams were built across the river and the river water was diverted through a diversion channel constructed on the right bank of the river. The ponded water in between the coffer dams was to be emptied for the construction of the main dam. Even after continuous pumping for several weeks there was no appreciable reduction in the water in the pond. It was suspected that water might be entering the pond through the downstream coffer dam. Some remedial measures such as grouting of the dam were undertaken. For the grouting operation a large number of boreholes were prepared. A radiotracer study was carried out to find the actual path of seepage through the coffer dam, so that remedial measures to arrest the seepage could be taken up. Bromine-82 was used as tracer. The points of entry of the seepage water into the dam and the seepage path could be traced. At Aliyar dam the tracer study was intended to locate seepage paths in the masonary spillway of the dam. Bromine-82 was injected into a cavity of the reservoir below the main entry point of seepage. Water was injected into the cavity before and after the tracer injection in order to establish steady flow conditions. Gamma logs were made of a series of gauge holes available in the body of the dam. Interconnected fissures were located by tracer detection and the radiation intensity was assumed to indicate the relative amount of seepage. The holes were successfully grouted on the basis of the tracer information and the seepage was arrested.

Similar experiments were carried out in the Bhadra dam in Karnataka during 1968. Bromine-82 was released into the reservoir so that its movement could be followed with a scintillation probe lowered from a boat, and then the boreholes drilled along suspected seepage paths were logged. The actual path of seepage was delineated by the radiotracer tests. Other notable seepage studies carried out included Supa dam in Karnataka during 1968, seepage in a tunnel for Beas-Sutlaj link project, Hazaribaug in 1970, and Kadana dam in Gujarat 1973.

The nature of a large fissure noticed at the Lakya dam site of Kudremukh Iron ore project was investigated using tracer technique during 1980. The aim of the study was to investigate possibility of any hydraulic connection between the 'future' reservoir (now complete and operating) and downstream of the river or to any other point in the valley through fissures. As part of the experiment, water was injected into the fissure at a rate of 2 m^3/min since the fissure was dry. This injection caused two seepage points to appear downstream. After that radiotracer was instantaneously injected into the fissure. Interpretation of the tracer response at the seepage points and the river helped to conclude that

- river was not connected to the fissure
- the flow from the injection to the seepage points was not a pipe or conduit flow.
- The fissure was localized and not part of any extended geo-fault.

The Borda reservoir was constructed in a limestone terrain in Yavatmal district of Maharashtra in central India. On completion of the dam in 1988, it was found that the reservoir was unable to retain water for a long period. Four tracer injections each of 25 mCi of ^{198}Au in the form of $HAuCl_4$ were made in the reservoir. From the distribution of radiotracer on the reservoir bed it became possible to demarcate the high seepage zones which were located along the two streams feeding the reservoir. A radiotracer study in Chaskaman dam in Maharashtra illustrated that the technique could also be used for interconnection investigations. Heavy seepages (~3-4 cusec.) were observed downstream of the Chaskaman dam. First ^{82}Br was injected into the reservoir and the tracer appeared at the seepage point downstream after 4.5 hours, showing contribution of the reservoir water to the seepages. Next groundwater velocity measurements using radiotracer technique were carried out in boreholes in the dam axis at different depths in the water column. Maximum filtration velocity of 4 m/d was found at about 60m depth in the boreholes which delineated the seepage zone. Finally, radiotracer experiment was carried out by injecting radiotracer at that depth in the boreholes. The tracer appeared in the seepage point after sometime, confirming the interconnection between the borehole water and seepage downstream.

A view of the Chaskaman dam in Maharashtra where radiotracer experiments provided information about the seepage sites

Effluent dispersion study site at Worli, Mumbai

Radioisotopes in Effluent Management Studies

Final disposal of effluents through marine outfalls is widely used in coastal areas. Understanding the ability of coastal waters to disperse effluents to acceptable limits is essential for proper siting of the outfall. The dispersion process in coastal waters is mainly governed by a complex interplay of the hydrodynamic conditions and is often difficult to calculate from empirical relations. This necessitates real time determination of dispersion characteristics using tracers. The first tracer experiment to investigate the dilution and dispersion pattern of effluent disposed into the sea was carried out for M/s Ballarpur Industries, off Karwar coast during December 1986. The purpose of the investigation was to select a proper effluent discharge point near Baitkal point. About 1 Ci of bromine-82 as NH_4Br was used as tracer. Two tracer injections were carried out. For the first experiment tracer concentration was monitored at 300 m and for the second experiment at 700 m from the Baitkal point. The tracer dilutions at both the points were found to be high (>10^6). Thus the proposed disposal point near Baitkal point was found to be suitable. Similar effluent dispersion experiment was carried out off Mangalore coast during 1987 for Mangalore Chemicals and Fertilizers. During 1992 a series of radiotracer experiments were carried out off Mumbai coast namely Colaba and Malad in collaboration with National Environment Engineering Research Institute (NEERI), Mumbai. Dilution and dispersion pattern of domestic sewage emanating from existing and simulated marine outfalls respectively at Colaba and Malad creek was investigated. At Colaba treated sewage is taken through an under sea pipeline by gravity to a distance of 1.1 km and discharged (~ 1400m^3/h) vertically upwards from a depth of about 10 m by a 75 m long diffuser, laid transverse lateral to the current direction. Dilution factor of about 5.5 x 10^3 was obtained at a distance of 4.9 km from the outfall during a high tide disposal. A 2D advection-dispersion model was used to simulate the spatial and temporal distribution of the radiotracer data. From the model simulation dispersion coefficients were obtained. At Thane creek (1996, 1998), and Worli (1999, 2000) similar radiotracer investigations were made. Some of these investigations helped to validate model studies carried out by the collaborators.

With developments in instrumentation, availability of portable computers and developments in mathematical modeling and interpretation methods, the applicability of radiotracers has been further expanded to investigate the fast and complex industrial systems and using radiotracer techniques mean residence times of the order of one second have been measured.

Radiation Processing

Radiation technology has sneaked into our daily routine to enrich the quality of life in many ways. Today, radiation processed materials are used for a variety of applications. For example, the car you drive or the television you watch may be equipped with radiation crosslinked wires or cables, *the long lasting* alkaline battery you use in the camera or watch may use radiation cured membranes to enhance their lifetime or that beautiful blue coloured *affordable* diamond ring you presented to your wife on your anniversary might be studded with diamonds processed by radiation technology. The disposable syringe, catheter and other devices and medicines generally used in a hospital, might have been sterilized by radiation processing to make them *absolutely safe*. The examples are numerous.

High energy (ionizing) radiation has the unique ability to generate reactive free radicals or ionic species at any temperature in any phase – solid, liquid or gas. Unlike the conventional heat energy, which is mainly deposited in the translational, rotational and vibrational modes of the absorbing molecules, the high energy radiation mainly interacts with the orbital electrons and excites the absorbing molecules to higher excited states that result in the formation of highly reactive ions or radicals. Subsequent reactions of these reactive species form the basis of industrial radiation processing. These procedure exploit one of the two possible outcomes of interaction of radiation with matter.

- Biological effects.
- Chemical effects

Thus, radiation processing is essentially an industrial application of radiation chemistry. It differs sharply from the use of ionizing radiation for such purposes as radiography or nucleonic gauges wherein radiation transmission or backscatter is used to determine characteristics of the absorber. For radiation processing, two types of sources of ionizing radiation are used :-

- Gamma radiation sources like cobalt-60 and cesium-137, and
- Electron beam accelerators in the energy range 0.2-10 MeV.

The limitation in the choice of radiation sources is to ensure that no radioactivity is induced in the irradiated material, the sources are available at sufficiently high power and are economical to produce. In the initial years mainly Cobalt-60 was preferred because it could be easily produced in nuclear reactors and its high energy gamma radiation had high penetration making it easy to irradiate thicker materials.

Commissioning of ISOMED

The turning point in radiation processing programme in India

Radiation sterilization of medical supplies was among one of the first applications of radiation processing established on an industrial scale in the world. This is due to the fact that sterilization is one of the most important processes in healthcare industry and conventional methods of sterilization like steam sterilization or chemical sterilization using ethylene oxide gas have their own limitations. The healthcare industry was looking for an additive free reliable alternative method for sterilization of medical products. Exposure to high energy radiation offered a simple and efficient method of inactivating microorganisms at room temperature and in the final packaged form. Availability of high energy radiation sources ensured emergence of radiation sterilization of medical products as a commercially viable technology.

Radiation Sterilization

High-energy radiation has the unique ability of inactivating microorganisms in a simple, efficient and reliable manner. The ionizing radiation emitted by sources such as Cobalt-60 interact with critical molecules like DNA and proteins present in the biological cell resulting in inactivation of the unicellular microorganism. This has formed the basis of producing radiation sterilized single use medical products which is now a well established industry worldwide including in India.

Radiation sterilization offers following key advantages over conventional processes:

- Simplicity and ambient temperature processing
- Very high reliability
- Absence of any residue after processing
- Ability to sterilize materials in the final packaged form
- Wide choice of packaging materials.

As mentioned earlier, the Radiation Processing technology in India, was established in 1972 with financial contribution from UNDP, IAEA and the Indian Government. This facility was formally commissioned on January 1, 1974 and named as ISOMED.

The establishment of ISOMED ushered in a new era for healthcare industry which could switch over from producing re-usable medical devices to single use, disposable type medical devices important in the healthcare sector and could help improving the quality of healthcare in the country. New small-scale industries were developed across the country to utilize the benefits of radiation sterilization for production of sterilized medical products such as syringes, catheters, rubber gloves, cotton dressings, surgical instruments, sutures and many other products. Beginning with a modest 12 users in 1974, ISOMED services are presently being utilized by over 1600 users across the country demonstrating the acceptance of radiation sterilization technology by healthcare professionals and industry in the country. ISOMED has emerged as a fore-runner of the successful radiation processing plants in the country. The commissioning and operation of ISOMED enabled radiation technologists in the country to gain experience in designing and commissioning similar facilities indigenously and two more such commercial plants for radiation sterilization of medical products, one at the Kidwai Memorial Institute of Oncology, Bangalore and the other at the Shriram Institute for Industrial Research, Delhi were commissioned in 1987.

It was also realized by the R&D team at ISOMED that radiation sterilization can play a significant role in providing quality medical care, particularly in the rural areas, where infrastructural facilities are inadequate. This led to development of a number of sterile surgical and medical kits, specifically for rural population. One such product developed and promoted by ISOMED is the radiation sterilized "Dai Kit" that consists of a radiation sterilized packet containing the necessary basic items normally required for delivery procedures in rural homes. The usage of such kits is reported to have significantly reduced infant morbidity and mortality rates in India. The International Institute of Population Studies (IIPS), Mumbai in its study 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. The successful usage of such kits has encouraged many small scale entrepreneurs to take up manufacturing of such kits on a larger scale.

Participants at one of the IAEA/RCA training course on radiation sterilization of medical products organized at ISOMED

ISOMED plant at Mumbai for sterilization of medical products

Shivraj Patil, then Minister of Science and Technology, inaugurating the sterilization plant at the Shriram Institute for Industrial Research, New Delhi

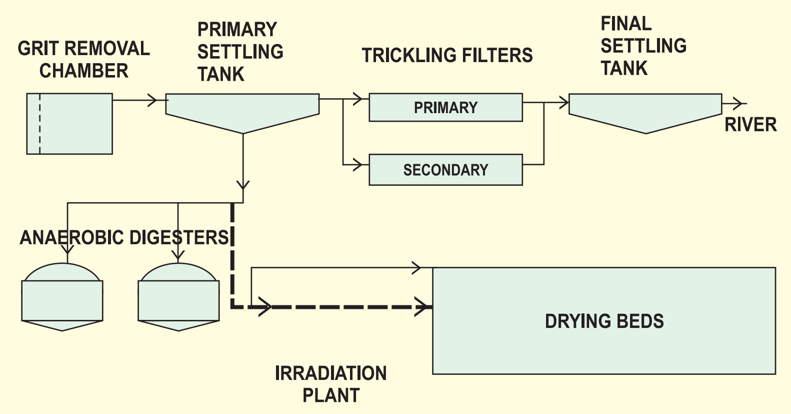
ISOMED is recognized as a Centre of Excellence by IAEA for its Regional Cooperation Agreement programme in the Asia Pacific region. It has played a leading role in establishing this technology in the South-East Asia region by providing training to a large number of scientists and technologists from countries such as Bangladesh, China, Korea, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam under the auspices of IAEA/RCA programme.

Setting up of Facility for Radiation Hygienization of Sewage Sludge

The successful commissioning of ISOMED plant and the adoption of radiation technology by the healthcare industry has generated confidence in radiation technologists to explore new avenues of utilizing radiation technology. Considerable work has been carried out the world over for using radiation for environmental remediation, specially on hygienization of sewage sludge by high energy radiation.

Sewage is composed of drain water mainly consisting of human waste discharged from domestic premises. It typically contains more than 99.9% water and about 0.1% solid. This solid waste, which is predominantly organic in nature, is broken down to simple organic compounds in sewage treatment plants and results in sewage sludge as the by-product. The sludge produced, though a rich source of many macro and micro nutrients for the soil, carries a heavy microbiological and pathogenic load. Consequently, its disposal is a challenge to the urban development authorities. The various options for dealing with it namely incineration, land fill, sea disposal and application to agricultural land, have their own limitations. Also, the farming community has realized that excessive use of chemical fertilizers is not conducive to sustained long term agriculture. The sewage sludge can be beneficially utilized for supplying nutrients (N,P, K and micronutrients) to the crops, improving soil physical properties and soil organic matter. This could result in increased crop productivity as well as restoration of soil fertility. For the sewage treatment plant operators, it offers a way of generating a value added by-product from the waste whose disposal otherwise is a matter of environmental concern. Thus, recycling of the sewage sludge to agricultural land could be an important outlet provided it is carried out in a manner that protects human and animal health as well as environment at large. The sludge, even after conventional treatment, contains a heavy pathogenic load. Therefore, it needs to be hygienised before application in agricultural processes on a large scale.

Working on the principle that pathogens present in the sewage sludge can be effectively removed by exposing it to high-energy radiation, the DAE decided in 1986 to set up a Sludge Hygienisation Research Irradiator (SHRI) at Vadodara, in collaboration with the Gujarat Government and the Vadodara Municipal Corporation, to demonstrate this technology and gain hands-on experience. The plant was successfully built and commissioned in 1992 next to the Gajarawadi sewage treatment plant. Integrated thus with an existing municipal Waste Treatment Plant (WTP) in the city, this plant can hygienise the sludge which upon drying can provide safe organic manure that can be directly applied to fields as fertilizer and soil conditioner. At maximum design source loading of 500 kCi, it has the capacity to hygienize 110 m^3/d of sewage sludge at a dose of 3 kGy.



Municipal Sewage Treatment Plant with Irradiation Facility

At SHRI, sewage is irradiated with gamma radiation emitted from an array of cobalt-60 sources. The sewage is circulated around the radiation source for a predetermined time to deliver the required radiation dose so as to reduce the microbiological load to acceptable limits. Validation of the process has been carried out by regularly monitoring E-Coli as the indicator micro-organism for the presence of pathogens. A radiation dose of 3 kGy has been found to be adequate to reduce the microbial population by a factor of over 10^4, thus reducing their concentration to less than 1000 per gram of the dried sludge as recommended for Class "A" sludge by the United State Environment Protection Agency (US EPA). If blended with suitable micronutrient and other plant supplements, it can yield a value added product, which will improve quality of the soil. Extensive field trials were conducted under the supervision of Krishi Vigyan Kendra, Baroda (under ICAR) to establish efficacy of the hygienized sludge as a manure for a variety of crops.

Operation and maintenance of the plant has been trouble free and easy. The plant can be designed, built and operated based on indigenous know how. The main requirement of the process is availability of cobalt-60 radiation source which is produced indigenously in nuclear reactors. This is the only operating facility of its kind in the world today and it has provided opportunities to many scientists specially from other countries to study the technology.

Radiation Processed Biomaterials : Hydrogels for use as burn and wound dressings

Polymeric biomaterials are widely used in the medical field in a variety of ways, namely, as therapeutic devices, drug delivery systems and clinical diagnostic devices. In recent years, hydrogels have emerged as an important class of biomaterials as they possess excellent biocompatibility. These hydrogels are three dimensional crosslinked network structures that are produced by simultaneous polymerization and crosslinking of suitable monomers or by crosslinking of linear polymers. Conventional crosslinking methods involve use of toxic additives to bring about polymerization/crosslinking and thus are not suitable for production of biocompatible hydrogels. Ionizing radiation possesses the unique ability of initiating polymerization and/or crosslinking without having to add toxic chemicals. Therefore, radiation processing is emerging as an excellent tool to produce hydrogels for a variety of medical applications. .

Healing of wide and serious burn wounds is a difficult medical problem as the process takes a lot of time and the dressing used for protection has to be changed regularly till the healing is complete. BARC initiated the program of utilizing radiation processing for developing suitable hydrogel for use as wound and burn dressings. These efforts have resulted in development of (poly viryl alcohol) PVA based hydrogel dressing that possesses excellent characteristics for the purpose. The technology of producing radiation processed hydrogel dressing offers following distinct advantages over conventional chemical processing:

- The technology is simple, easy and clean
- There is no need to maintain special sterile rooms and still the end product is sterile
- The production can be carried out both as a continuous as well as a batch process.

These dressings contain about 90 % water, yet have the capacity to absorb more water, almost equal to their weights. The hydrogel dressings reduce depth of burning by cooling the wound, provide humid environment, form a layer of growth promoting biochemicals (exudates), keep new skin intact (non adherent) resulting in early and clean healing. These dressings have also been observed to heal difficult wounds like leprosy and diabetic ulcers, bed sores and post surgical wounds. Burn injuries from fireworks, chemicals, petrol, electrical appliances and road accidents can also be treated using the dressings. Clinical trials have established their safety and efficacy. The product has been extensively tested in the local hospitals and has been patented. The technology has been transferred to a private entrepreneur and the commercial product is now available in the Indian market.

Commercialised radiation processed hydrogel for use as burn dressing

Diabetic foot ulcer before and after 15 days treatment with hydrogel

Radiation Vulcanization of Natural Rubber Latex

Technologists in various fields today are facing an increasing challenge to produce high quality and safe materials in a cost effective manner. The challenge is even more formidable if the material or the product has to come in contact with body fluids. For the last few decades, the rubber industry has realized that conventional vulcanization of natural rubber latex using chemical accelerating agents leads to formation of carcinogenic nitrosoamines in the product when processed by conventional sulphur vulcanization process. During the 1980s, under the IAEA/RCA programme, it was established that natural rubber latex could be crosslinked by irradiating it in presence of a crosslinking agent like n-butyl acrylate. The tensile strength of radiation processed natural rubber increases multifolds without the addition of conventionally used sulphur, thereby enabling to get nitrosoamine-free high quality end products of rubber.

A cobalt-60 radiation plant for vulcanizations of natural rubber latex was built and commissioned for the Rubber Board of India at Kottayam, Kerala in 1992. The current activity in the plant is about 50 kCi and it can process about 1.5 tons latex per day at a dose of 15 kGy.

Electron Beam Accelerators

Radiation processing tools for the new era

In recent years, electron beam (EB) accelerators as a source of radiation have emerged as a preferred alternative for industrial radiation processing. They offer the following advantages over gamma radiation:

- Ability to amalgamate with the existing industrial infrastructure for on-line processing,
- Ability to provide a dose rate that is several orders of magnitude higher than that of radioisotopes, thereby resulting in very high throughputs while minimizing oxidative degradation of the substrate, and
- Greater public acceptance.

Recognizing the potential of use of electron beam (EB) accelerators for modification of polymeric materials and other radiation processing applications, the first EB machine in India, the ILU-6 pulsed typed EB accelerator was procured under Indo-Russian collaboration and installed at BARC in 1988.

ILU-6 Electron beam accelerator with continuous conveyor system

This provided radiation technologists an opportunity to gain hands-on experience in developing applications using electron beam irradiation. It also offered industry a facility to critically evaluate technical and economic benefits of radiation processing on a large scale. Radiation induced crosslinking of a polymer can enhance its useful working range as well as its resistance to aggressive solvents, thereby imparting high performance characteristics to the materials. Thus, simple thermoplastic polymers after crosslinking can replace costlier special heat resistant polymeric materials for many applications.

During early 1990s, work was initiated by BARC in collaboration with academic institutions such as the Indian Institute of Technology, Kharagpur and also with the Indian Cable manufacturing industries to develop electron beam crosslinkable formulations suitable for wire and cable industry. Meanwhile, development work was undertaken in collaboration with other polymer based companies to develop other suitable products. This required development of suitable underbeam handling systems for uniform irradiation of specific products. One major hurdle in the initial years was that small industries were themselves not in a position to put up an in-house accelerator due to high initial cost of establishing the facility. It, therefore, became necessary that besides offering the EB machine for R&D to industry, service facility needed to be provided wherein their products could be processed. Therefore, the electron beam accelerator was relocated at BRIT Complex, Vashi and recommissioned in April 2001 for easy availability and stronger interaction with the industry. Some of these studies have culminated in development of commercial products. The facility generated a revenue of about Rs. 140 lakhs within 24 months of its operation.

Radiation crosslinking of polyethylene "O" rings for drum fittings

Low density polyethylene (LDPE) has a melting temperature of 110^{o}C and softening temperature of about 60^{o}C. However, crosslinked LDPE can retain its dimensional stability at higher temperatures. Process optimization studies were carried out for radiation crosslinking of polyethylene "O" rings to impart dimensional stability at temperatures as high as 200^{0}C. In order to induce uniform crosslinking of the product on a commercial scale, a rotating multi – spindle conveyor system has been designed to meet the desired objective. The process has been commercialized and presently, 100,000 rings can be irradiated per day using a 16-spindle underbeam geometry. Radiation crosslinking has the additional advantage since no chemical compunds are added to the product, the "O" rings can be used as gaskets even when these have to come in contact with edible oils thus meeting the FDA specifications. Four major companies use radiation technology for this purpose and more than 6 million rings have been processed till now.

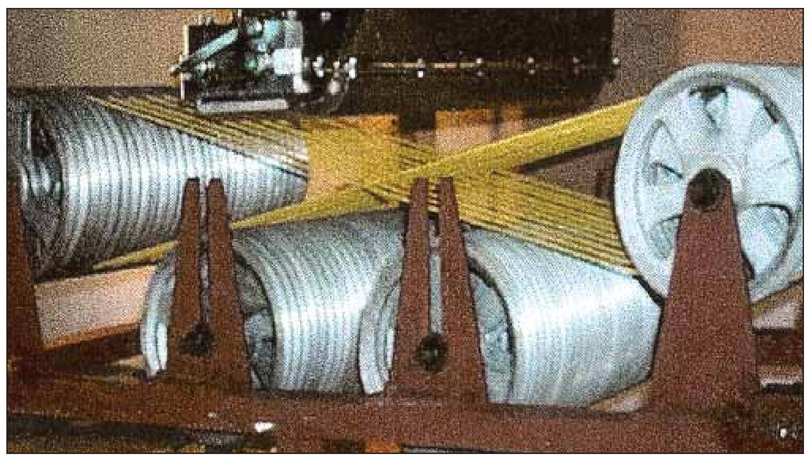
Crosslinking of polymers for use as wire and cable insulation

Use of high-energy radiation using EB accelerators is well established the world over for crosslinking of wires and cables as it results in a product that offers distinct advantages over chemically crosslinked cables viz. higher operating temperature, much lesser thickness of the insulating material and high throughput. In order to bring this technology to India, extensive work was carried out at BARC in collaboration with Indian cable manufacturers and other research institutions to develop formulations for various types of insulation such as polyethylene, polyvinyl chloride and ethylene propylene diene monomer based materials using both these methodologies. Suitable under beam conveyor systems for uniform irradiation of the products were designed and installed at the 2-MeV ILU-6 accelerator and over 100 km of crosslinked wires and cables of varying insulation thickness have been processed. The hands-on experience gained in this technology has helped Indian cable industries to establish in-house EB facilities. Two of the major cable industries have installed their own EB machines which are currently being operated on commercial basis for meeting the demands of Indian railways, mining industry, automobile and home appliances industry.

Radiation Processing of Polyethylene 'O' rings at EB accelerator

Main features

- Crosslinked rings have service temperature upto 200^{0} C
- Process throughput of 1 lakh rings/day
- Commercial service being offered to industries
- Over 6 million rings processed



Electron beam crosslinking of wires

Colour enhancement of diamonds

Gem and jewelry export constitutes one of the major items in Indian exports. Coloured diamonds and precious stones command better saleability in the market. Use of high energy electron beam accelerators for enhancing the colour of natural diamonds has emerged as a novel technique that has been well accepted in the diamond industry. This is because radiation treated coloured diamonds are much cheaper than naturally occurring coloured diamonds. The process is now regularly deployed in India on a commercial basis and a large number of diamond exporters, registered with Gem and Jewelry Export Council, have harnessed the technology for producing coloured diamonds.

Value addition to even valuable materials such as diamonds

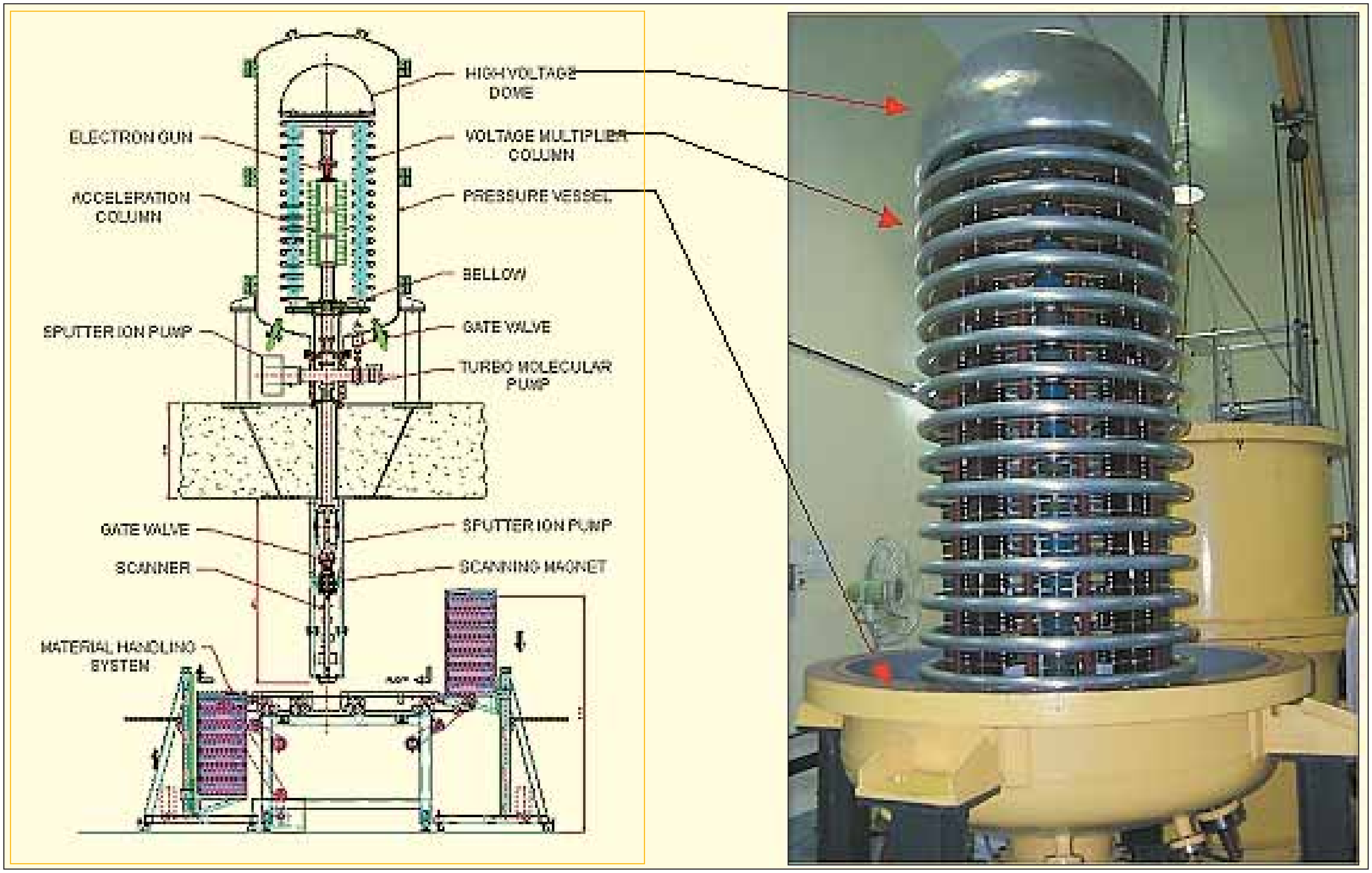
Electron beam curing of acrylic and epoxy coatings

While the 2-MeV accelerator at BARC was useful for applications such as crosslinking of wires and cables and bulk polymeric materials, there was a need to develop a low energy accelerator for developing applications such as curing of films and surface coating. Commissioning of an indigenously developed 500 keV, 5 kW accelerator by the Accelerator and Pulsed Power Division, BARC and 750 keV DC accelerator for industrial applications at Centre for Advanced Technology (CAT) have recently provided tools for carrying out surface curing applications. Wood, being a natural polymer, is highly vulnerable to damage caused by various environmental conditions and microorganisms. Therefore, wooden objects need to be protected from damage by painting or coating. For this purpose conventional techniques such as thermal and chemical processing with highly volatile solvent based chemicals are presently being used. Emission of these toxic chemicals in the environment create problems for conventional processes as they fail to meet stringent environmental regulations. Electron beam (EB) curable coatings offer solution to these problems. The advantages of EB curing over the conventional processes are high production rate, improved product performance, precise process control, energy efficiency, absence of emission of volatiles and processing at room temperatures. Coating compositions curable by EB generally comprise of acrylate based oligomers, reactive diluents and other functional additives. Work has been initiated in collaboration with the Shriram Institute for Industrial Research and epoxy and urethane acrylates based oligomers with reactive diluents to develop formulations for providing EB crosslinked coatings on wood substrates for providing unique characteristics like scratch and stain resistance.

Summary

In retrospect, it has been a challenge for radiation technologists in the country to bring this new technology to the Indian industry in more than one way. This required first, understanding of the new technology on a small scale, constant interaction with professionals in industries to demonstrate advantages of radiatin technology over the conventional technology, demonstrating upgradation of the technology to suit commercial scale and sometimes integrating it with their existing technology. The focus from the beginning has been on indigenous production of sealed sources like iridium-192 and cobalt-60 and associated equipments. This has helped in faster growth of many applications like industrial trouble shooting, process optimization and development of new materials. Development of human resources through advanced training courses or on-the-job training for various applications has ensured that the necessary manpower remained available for industry to utilize the potential of these applications. India has been designated as the lead country for IAEA/RCA programme “Thematic Sector - Industry” since 2001.

Work done over the years has also been successful in establishing radiation processing as a commercially viable technology in the Indian industries. This is evident from the setting up of different radiation sterilization plants in the country and installation of two electron beam machines in the private wire and cable sector in recent years. Successful operation of SHRI facility and successful demonstration of the use of radiation hygienized sludge as a fertilizer and soil conditioner has offered new avenues for using radiation



750 keV DC Accelerator developed at CAT, Indore

technology in the area of urban sludge management. Recently BRIT has signed MoUs with private companies to set more gamma based irradiators for radiation sterilization and related activities. Realizing the immense potential of EB technology for processing of a variety of materials, BARC is setting up an EB centre at Kharghar, Navi Mumbai in collaboration with Society for microwave and electronic engineering reserach (SAMEER). A 3-MeV accelerator and a 10-MeV accelerator will soon be installed to meet the requirements of Indian industries. Availability of a 10-MeV accelerator in the near future is expected to further enhance the scope of applications in areas such as food processing, radiation sterilization and crosslinking of thicker sections of polymer materials for many applications. A small beginning has been made, but then all journeys start with a small step.

Carbon-14 measurements being conducted at a shallow well near Jodhpur, Rajasthan