Atoms in the Service of the Nation

K N Vyas & M Ramanamurthi

Nuclear power generation has demonstrated excellent performance in almost all aspects viz. operational and safety records, capacity utilisation, carbon footprint and quantity of waste generation. Issues pertaining to proliferation and waste storage are currently well within the realm of being managed and with the advent of new generation of reactors, these concerns are going to be further minimised

For the full industrialization of the developing countries, for the continuation of our civilization and its further development, atomic energy is not merely an aid, it is an absolute necessity. The acquisition by man of the knowledge of how to release and use atomic energy must be recognised as the third epoch of human history. ***Homi Jehangir Bhabha***

Science and Technology (S&T) capabilities are fundamental for social and economic progress of a nation.

The great era of scientific discoveries in the early part of the 20th century was born out of a thirst for advancement of human knowledge towards furthering the frontiers in the understanding of nature. This innate urge of man to explore, understand and perhaps conquer the forces of nature gave rise to many paths of discovery in science in a multitude of disciplines. Understanding the nature of matter to the minutest detail was one such curiosity which led to the discovery of atomic structure. That atom consists of a nucleus at the core surrounded by electrons revolving in fixed closed orbits was the work of Rutherford and Bohr. Natural radioactivity and spontaneous disintegration of atoms had already been reported by Becquerel and Rutherford respectively. But with the discovery of neutron in 1932 by Chadwick, the branch of science known as nuclear science definitively took on a momentum of its own.

Einstein had propounded the equivalency of energy and mass and had conjectured that the large amount of energy stored in matter would be eventually harnessed. Artificial radioactivity caused by bombardment of stable nuclei with alpha particles had already been reported by the Curies in 1934. The discovery of nuclear fission accompanied by the liberation of a large amount of energy in 1938 by Otto Hahn and Fritz Strassman in 1938, the prediction of the nuclear chain reaction for creation of a self-sustaining fission process by Leo Szilard, successful demonstration of a self-sustaining nuclear chain reaction by Enrico Fermi and the ultimate construction and the use of a nuclear weapon in 1945 changed the world forever. A new epoch had begun in the history of mankind, characterized by its ability to annihilate itself many times over with these diabolical weapons.

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Dr. M. Ramanamurthi is currently the Heading the OCES (Orientation Course for Engineering Graduates and Science Post Graduates) Programme Implementation Section of the BARC Training School.. e has been invited to several national and international conferences to speak on the subject of human resource development in the field of nuclear science and technology.

Dr. Homi Bhabha presiding over the first conference on Peaceful Uses of Atomic Energy at Geneva, 1955

An epoch marked by the discovery of a force of nature revealed to man by the pioneering efforts of a dedicated band of Nobel Prize winning scientists, all of whom had nothing more to seek than the unravelling of the mysteries of nature.

Atoms for Peace- A Utopian Landscape

But out of every situation arises a new hope, a new solution. The two world wars in the 20th century had devastated the world with the loss of tens of millions of humans in a barbaric and cruel display of man's inhumanity to man. The horrendous effects of the two nuclear bombs dropped on Japan in 1945 were an eye opener and shocked mankind as no other weapon of mass destruction had ever done before.

Out of these troubled times did emerge hope for the dawn of an era of exploitation of the power of atom for peaceful purposes. 'Atoms for Peace' was an initiative of the US President, Mr. Dwight D. Eisenhower, launched in the 470th Plenary in the United Nations General Assembly in 1953, with none other than Smt. Vijayalakshami Pandit of India being the President of the assembly. The speech was a tipping point for international focus on peaceful uses of atomic energy, promising the use of radioactivity for various peaceful purposes, especially in energy generation for harnessing the power of the atom- 'To find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life'. The International Atomic Energy Agency (IAEA) was thereafter founded by the UN charter and announced in Geneva in 1955, in a conference chaired by Dr Homi Bhabha, the father of the Indian Atomic Energy Programme. The objectives of IAEA were indeed laudable, aiming to exploit the peaceful uses of atoms for the benefit of all mankind and to prevent nuclear weapons proliferation.

The journey of the Indian Atomic Energy programme began in 1954 with the founding of the Atomic Energy Commission under the leadership of the legendary Dr Homi Jehangir Bhabha- Scientist, Administrator and a visionary par excellence. Much has been achieved in the sphere of the exploitation of the power of the atom for various purposes. We shall dwell on some of these applications in the following pages, to provide a glimpse of the breadth of our programmes aimed at ensuring food security, energy security and national security and in various other medical, social and industrial applications. This would be by no means a complete compendium of all that is possible and achieved in this sphere. Nevertheless, it would certainly serve to underline our motto of the nuclear energy programme of the country- the use of nuclear and radiation technology for providing better quality of life to its citizens.

Radiation- A Double Edged Sword

Radioactivity, the emission of radiation from the atom had been discovered much before the advent of the nuclear fission era, and the controlled applications of these radiations for cancer therapy had already begun in some parts of the world. Well might it be said that the world first came to learn of applications of radiation and radioactivity as a therapeutic and palliative for cancer cure in the early part of the 20th century. In the subsequent decades, nuclear fission made possible the harnessing of nuclear energy for electricity production. However, the peaceful uses of the atom have developed several other large scale applications in agriculture, medicine and industrial sectors. All these applications depend upon the generation of artificial radioisotopes which have uses due to the radioactivity emanating from them. These artificial radioisotopes are created in reactors or particle accelerators by bombardment of stable isotopes leading to a nuclear reaction and subsequent transmutation to form the radioactive isotopes. More than 200 radioisotopes are used on a regular basis for various applications as delineated in the following paragraphs.

Health – Care to Cure

Application of radioisotopes in healthcare has grown into one of the most important peaceful uses of atomic energy. In the present context, a total number of over 6,00,000 patient investigations (including immunoassays), as per statistical data, are carried out annually in India. This relates to a span of over 500 centres across the country that are benefitting from using radio pharmaceuticals. Regarding radiation therapy, there are more than 270 radionuclidic therapy

units which are currently operating in 62 cities in India. BARC is working in close co-operation with other constituents of DAE to widen the scope of this technique for the benefit of the common man, with an aim to bring the benefits of these techniques to everyone.

Nuclear Medicine – Diagnosis

Nuclear medicine is a medical specialty that uses trace amounts of radioactive substances (called radio pharmaceuticals) in the diagnosis and treatment of a wide range of diseases and conditions in a safe and painless way. R*adio pharmaceuticals* can be administered by injection, inhalation, or orally and *selectively localized a*nd retained at *sites* of *diseases* and thus allow an image to be obtained of the loci using gamma scintigraphy or to deliver cytotoxic dose of radiation to specific disease sites without adversely affecting the surrounding normal tissues. Nuclear medicine procedures help in identification of abnormalities in organ function even in very early stages of a disease. Nuclear medicine has proven its worth in the diagnosis of diseases such as cancer, neurological disorders (like Alzheimer's and Parkinson's diseases), and cardiovascular disease in their initial stages, permitting earlier initiation of treatment as well as reduced morbidity and mortality.

The most common isotopes for imaging are ^{99m}Tc, ^{123}I, ^{201}Tl, ^{111}In and ^{18}F. Technetium-99m is the most widely used radioisotope in diagnostic nuclear medicine, and it is estimated that over 80 per cent of the nearly 25 million diagnostic nuclear medicine studies carried out annually are done with this single isotope.

The Medical Cyclotron with Positron Emission Tomography (PET) scanning facility set up at Radiation Medicine Centre (RMC) of BARC, routinely produce ^{18}F-labelled FDG molecules for diagnosis of cancer as well as cardiac disorders. During the year 2015, about 133 consignments of PET radiopharmaceuticals such as ^{18}F-FDG, ^{18}F-FLT, ^{18}F-NaF and ^{18}F-FMISO were supplied to various hospitals in and around Mumbai accounting for nearly 240 Ci of ^{18}F radioactivity.

Targeted Radionuclide Therapy

Therapeutic radiopharmaceuticals consisting of a target-specific moiety with a beta-emitting radionuclide designed to deliver therapeutic doses of ionizing radiation to specific diseases sites is one of the rapidly growing fields of nuclear medicine. A number of therapeutic radiopharmaceuticals based on radionuclides such as ^{131}I, ^{177}Lu, ^{32}P, ^{153}Sm and ^{188}Re developed by BARC have been supplied to different nuclear medicine centres. ^{177}Lu-DOTA-TATE is used for the treatment of neuroendocrine cancers, while ^{153}Sm-EDTMP and ^{177}Lu-EDTMP are used for bone pain palliation. At the Thyroid Clinic of RMC, entire gamut of thyroid problems including the complete work up of thyroid cancer is being attended to and treated using ^{131}I. More than 40,000 patients have been provided with the therapeutic treatment using radiopharmaceuticals developed at BARC, in year 2015.

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Radiation Therapy

Radiation therapy is a treatment involving the use of high-energy radiation either by using special machines or from radioactive substances. The radiation may be delivered using a machine outside the body, known as external-beam radiation therapy or teletherapy, or alternatively it may come from radioactive material placed in the body near cancer cells, known as internal radiation therapy or brachytherapy. The aim of radiation therapy is to impart specific amounts of the radiation at tumours or parts of the body to destroy the malignant cells.

External Beam Radiotherapy

External beam radiotherapy usually involves using a machine either a ^{60}Co-teletherapy unit or a linear accelerator, which focuses high-energy radiation beams onto the area requiring treatment. External beam radiotherapy can be used to treat Breast Cancer, Bowel Cancer, Head and Neck Cancer and Lung Cancer. A teletherapy machine christened Bhabhatron has been designed by BARC. Bhabhatrons are installed at about 50 cancer hospitals in the country. Compared to any imported telecobalt machines, the indigenous machine is cheaper and superior in features. BARC developed "Imagin" simulator is used for localization of treatment areas and for verification of treatment plans prior to starting treatment.

Brachytherapy

Internal radionuclide therapy is the treatment of disease by placing sealed radioactive sources, at or near the target area on a temporary or permanent basis. Brachytherapy makes it possible to treat a cancer with a larger dose of radiation than can be given with external beam radiation therapy.

In some of the cases, the implants are kept in the body for a specific amount of time ranging from a few minutes to a few days. Iridium-192 is the isotope of choice for temporary implants. For permanent implants, radioactive seeds or implants are placed into the tumour or treatment site, where they remain permanently. The radiation dose emitted from such radiation source reduces over weeks or months to almost zero. Finally, the seeds remain inactive with no lasting impact in the treatment site. Permanent

Civilian Application of Nuclear Energy

brachytherapy is mainly used for the treatment of prostate cancer.

Tiny titanium encapsulated Iodine-125 seeds, developed by BARC have provided a new avenue for the treatment of eye cancers. Presently 3 hospitals are using 'BARC I-125 Ocu-Prosta seeds'. Over 120 patients have been treated so far. "BARC I-125 Ocu-Prosta seeds" are also clinically deployed in a hospital as permanent seed implants for the treatment of prostate cancers. Mould brachytherapy using beta-emitting radionuclides is a viable option to treat superficial skin cancers close to the vital organs. BARC has developed a method for the preparation of ^{32}P sources. After successful preclinical evaluation, ^{32}P sources have been clinically deployed in AIIMS, New Delhi.

Food Security -Supplementing the Food Basket

India has witnessed impressive economic growth in recent years, but the growing population of our country places huge demands on our agricultural resources. The problem is further accentuated by the fact that the agriculture's share in the country's economy is declining, raising the concern of food security. The situation calls for technology-driven sustainable management of natural resources for achieving food, nutritional, environmental and livelihood security to ensure all-inclusive growth in the country. Use of ionizing radiation-based technologies provides safe, hygienic and economically viable solutions to address the issues of agricultural productivity.

Nuclear Agriculture

For the past several decades, ionizing radiation is being employed by BARC to induce mutations in plant breeding, and 42 varieties of different crops have been released to Indian farmers for commercial cultivation in the country. These include new kinds of groundnut, mungbean, blackgram, pigeon pea, soybean, cowpea, mustard, sunflower, and rice, which are endowed with one or more improved and desirable attributes such as higher yield, earliness, large seedsize, along with resistance to biotic and abiotic stresses. Mutation in rice and wheat is also being carried out to improve yield and disease resistance. Besides, micropropagation protocols involving rapid multiplication of stock plant material to produce a large number of progeny plants have been developed for furnishing improved varieties of banana, sugarcane, grape, pineapple, potato, turmeric and ginger.

Food Preservation-Produce and Preserve

Pest infestation is another impediment in food security and safety, as this causes substantial losses of agricultural productivity globally including India. One of the major tragedies of Indian agricultural system is that almost 30 percent of the food produced is lost due to spoilage because of pest attack, contamination and moulds infestation. These are encountered both during harvesting as well as post-harvest handling and storage of the edible and cash crops. Prevention of post-harvest losses can plug the widening gap between food production and demand. Conservation of agricultural produce has, therefore, assumed paramount importance if we have to leverage the increasing yields and feed the growing population to boost Indian economy. The most popular pest control methods, such as use of synthetic pesticides and other protocols are fraught with several problems such as potential health hazards, disturbance of ecology and also development of resistance in the pests against the synthetic pesticides. Radiation processing can provide a viable, effective, and eco-friendly alternative to chemical fumigants and microbial decontamination, as the latter affect human health and environment adversely. There is an utmost need to adopt and integrate the irradiated foods into the country's supply chains and promote the widespread use of this technology to ensure food safety and security. This technique involves exposure of food and agricultural commodities to controlled doses of radiant energy to achieve desirable effects such as disinfestation of insect pests in stored products; disinfestation of quarantine pests to overcome international trade barriers; delay in ripening and senescence in fruits and vegetables; inhibition of sprouting in tubers, bulbs and rhizomes; destruction of microbes responsible for food spoilage; and elimination of parasites and pathogens of public health importance in food. This is the only method of killing bacterial pathogens in raw and frozen food. It can be applied to pre-packaged commodities even under frozen conditions.

It may also be highlighted that radiation brings its effects through direct deposition of energy, and in no way, it makes the product radioactive. Radiation processing of food has been approved by various International and National organizations viz. International Atomic Energy Agency (IAEA), Food and Agricultural Organization (FAO), World Health Organization (WHO), World Trade Organization (WTO), Codex Alimentarius Commission, United States Department of Agriculture (USDA), Food Standards Australia New Zealand (FSANZ), and Food Safety and Standards Authority of India (FSSAI) to ensure 'Food Security & Safety', and overcome 'Technical barrier to International Trade'. Recently, harmonization of food irradiation rules with international regulations has taken place in India through class-wise clearance of irradiated food items by the FSSAI. Irradiation of more than 60 kinds of food, ranging from spices, grains, grain products, fruits, vegetables and meat are being carried out globally. To this end, BARC has developed irradiation technologies for preservation of fruits (litchi, mango, cherries) and vegetables (potato, onion), sea foods, spices (turmeric,

chilli) and many of these technologies are available in commercial domain. Fifteen food irradiation facilities are currently operational in India. One of these facilities at Nasik is being regularly used for irradiation of mangoes, onions and potatoes for preservation and increasing their shelf-life and promoting international trade. The volume of irradiated food in India has been steadily increasing. A total of nearly 34,000 tons of produce has been irradiated by the Radiation Processing Plant, Vashi, Navi Mumbai till 2015. Irradiated mango is being exported to the USA since 2007. The knowledge of irradiation technology is also being disseminated to various agricultural universities and institutions.

In summary, it is important to note that the green revolution has undoubtedly increased the availability of food stock manifold over the decades, but challenges of demands in the coming decades warrant further improvement and refinement in these techniques for improved crop yield and quality. The irradiation-based strategies have the potential to bring about a paradigm shift in the agriculture sector and propel our nation towards prosperity.

Energy Security- Nuclear is Clean and Green

Global Warming- A Perilous Precipice

All indicators of climate change and global warming over the last few years point to the unavoidable conclusion that planet Earth is today teetering on the brink of a perilous precipice, caused by global warming and the attendant climate changes taking place on the globe. Carbon Dioxide levels in the atmosphere have reached an unprecedented 400 ppm and the temperature rise of more than 1°C has taken place mostly over the last three decades. This rise has affected the climate significantly and consequences such as increasing sea levels, severe and frequent heat waves, unpredictable rains and storms, etc. are already upon us. The predominant cause of these is the nature of human activity, accelerated at a tremendous pace over the last few decades, inclusive of the increasing loading of the atmosphere with carbon dioxide due to the use of fossil fuels-wood, coal, natural gas and oil.

Nuclear Energy Goals-The Way Ahead

Over time, it is becoming increasingly evident that nuclear energy provides a solution to the vexing but real problem of global warming, being endowed with the lowest carbon footprint amongst all energy producing sources-including the renewable sources such as solar, hydro and wind power.

Being a rapidly growing economy with international obligations to curtail carbon emissions, India today needs to rapidly ramp up power production using nuclear energy. With 21 operating plants and 12 plants in the pipeline, we are poised a period of enhanced growth in this sector. The atomic energy sector is projected to make a significant contribution to energy security and climate mitigation over the next few decades.

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Societal Applications- Towards the Common Good

Sludge Hygenisation- From Waste to Wealth

Large amount of sewage sludge is generated in India on a daily basis. The sludge is laden with infectious microorganisms and improper disposal of the sludge can result in the spread of diseases thereby becoming a public health hazard. At the same time, it also has essential micro and macro nutrients, especially organic carbon, useful for soil and crop production. Radiation Technology has been used to hygienise the sludge to protect public health and environment and in addition, manufacture the manure with desirable qualities for use in the farming sector. Ahmedabad Municipal Corporation (AMC) has taken the lead to set up the first plant in India to treat 100 tons/day sludge and produce manure using a fully automatic process. Irradiation facilities such as these can be set up to treat whole city sludge at a single central location using a fully automatic process. The technology has high potential in contributing towards meeting the objectives of the Swachh Bharat Mission.

Hydrogel- Healing the Wounded

Hydrogel, a thin transparent sheet of gel is an excellent medical tool particularly useful as burn and injury dressings. It is prepared by cross linking molecules of hydrophilic polymers like PVA either chemically or by Gamma/ Electron Beam irradiation. A 3D network of gel like structure is formed which holds large quantities of water. Gamma irradiation achieves gel formation and sterilization in one step.

Hydrogel provides moist environment and a cooling effect on the wound due to a regulated oxygen supply to the wound through a sterile cover. It adheres firmly yet gently to the healthy surface but does not adhere to wet wound surface resulting in painless dressing. Being transparent, the progress of the wound healing can be easily observed. Raw Materials required for manufacture are low cost and locally available. The process was developed by BARC scientists and technology has been transferred for commercial production. It's an import substitute product and now available at a low cost in the Indian market.

Water- The Elixir of Life

Water is becoming a scarce commodity largely due to the increasing demands on this resource from domestic, agricultural and industrial sectors. Isotope hydrology techniques enable accurate tracing and measurement of the extent of new and renewable underground water resources at various locations. It also provides information about the origin, age and distribution of groundwater, as well as the interconnections between ground and surface water and aquifer recharge systems. The technique is also used for monitoring surface water resources for leakages through dams and irrigation channels, the dynamics of lakes and reservoirs, flow rates, river discharges and sedimentation rates etc. The data obtained is used towards resource planning and sustainable management of these water sources.

Our scientists have developed low cost and user friendly kits for measurement of contaminants in water. These kits are being used for the detection of contaminants like fluorine in groundwater and chromium in water of river Ganga. Technologists of BARC have also developed a membrane for filtration for the removal of bacterial contamination and for desalination of brackish water as well as sea water. All these technologies for water purification have been transferred to Indian industries and serve a large section of the society providing low cost solutions.

Industrial Applications – Support to the Manufacturing Sector

A host of applications are in use and serving the industrial and manufacturing sector as aids and tools towards implementation of good manufacturing practices. Following is a briefly listed overview of a few such important applications.

Radiation Sterlisation of Medical Products

Products such as syringes, cotton wool, burn dressings, surgical gloves, heart valves, bandages, plastic and rubber sheets and surgical instruments, powders, ointments and solutions and biological preparations such as bone, nerve, skin, etc, used in tissue grafts.

Radiography

Radioisotopes which emit gamma rays are more portable than x-ray machines, and may give higher-energy radiation, which can be used to check welds of new gas and oil pipeline systems, with the radioactive source being placed inside the pipe and the film outside the welds. Other forms of radiography (neutron radiography/ autoradiography), based on different principles, can be used to gauge the thickness and density of materials or locate components that are not visible by other means.

A Glimpse into the Future

It has been our objective to communicate to the readers the breadth of applications of nuclear technology straddling almost all walks of life, leading to economic and societal benefits to the nation. These are the benefits which shall continue to be leveraged for a considerable period in the foreseeable future, as they are almost irreplaceable in the type and range of applications. Nuclear power generation is, of course one of the important segments, currently contributing significantly to the energy basket worldwide. Scepticism on this front has been unfortunately dogging the industry, leading to closure of this extremely carbon friendly energy source and a shift to renewable power sources – solar, hydro, wind and geothermal. Unfortunately, not only are their carbon footprints higher than that of nuclear energy, their somewhat unpredictable nature and low efficiencies may be unable to meet the base load requirements in many countries aggressively pushing ahead with these renewable sources. This is leading to the increase in the use of natural gas, with an even higher carbon footprint, despite the issue of global warming and climate change looming large upon the horizon. In such a scenario, it is imperative that the world should take a dispassionate view and avoid reducing the role of nuclear energy in the energy basket. Nuclear power generation has demonstrated excellent performance in almost all aspects viz. operational and safety records, capacity utilisation, carbon footprint and quantity of waste generation. Issues pertaining to proliferation and waste storage are currently well within the realm of being managed and with the advent of new generation of reactors, these concerns are going to be further minimised.

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