DOWN THE MEMORY LANE: SEVEN DECADES OF BIO-SCIENCE RESEARCH

K. B. Sainis
Former Director, Bio-Medical Group
Bhabha Atomic Research Centre
Mumbai - 400085, India

Email: sainis1949@gmail.com

Two years ago, India completed 75 years since independence, a memorable milestone indeed. As a part of the exercise of taking stock of the nation's achievements and charting a course for the future, developments in scientific research and its applications also need to be reviewed. Department of Atomic Energy (DAE) has been at the forefront of national emergence. Its self-reliant nuclear programme, vision and nurture of talented young engineers and scientists have contributed immensely to India's progress towards strengthening not only its national security but also energy security, health security and food security. Bhabha Atomic Research (BARC) has been spearheading this effort. The vision of our Founder, Dr. Homi Jehangir Bhabha, extended much beyond energy production by harnessing nuclear power. He also emphasized the development of non-power applications of nuclear energy and radioisotopes for industry, agriculture and healthcare along with building a strong directed as well as futuristic basic research programmes. I am very proud to state that the Bio-Sciences/Bio-medical Group of BARC has distinguished itself, in the seven decades of its existence, through its contributions in food security by improving crop productivity, food preservation methods and to healthcare by establishing radioisotope based diagnostics and treatments under nuclear medicine while at the same time the group has consistently pursued quality basic research in radiation biology, biochemistry, molecular and cell biology, biotechnology, food science and agriculture.

The Bio-sciences group has its origins in the Cell Biology Unit of Atomic Energy Commission in Tata Memorial Hospital (TMH) created in 1948 with Late Dr. A R Gopal-Ayengar as its Head. It later became Biology Division of DAE with Dr. Gopal-

Ayengar as Assistant Director in 1952. The laboratories were first housed at the then Indian Cancer Research Centre attached to the Tata Memorial Hospital. Its research activities gathered momentum with cytologists such as Dr. K.C. Bora, biochemists such as Dr. M. B. Sahasrbuddhe, Dr. A. Sreenivasan and food technologists such as Dr. P. B. Mathur joining the team. The laboratories then moved to the Richardson & Cruddas building in Byculla, South Mumbai blossoming into the Biology Group of Atomic Energy Establishment, Trombay with Dr. Gopala-Ayengar assuming charge as its first Director in 1962. Medical Division, which was a separate entity, primarily tasked with healthcare services to DAE employees in Mumbai operated from Sir J. J. Hospital also had a research programme in mammalian radiobiology and clinical research with radioisotopes. It was initially a part of the Biology Group. In 1963 another Division, Biochemistry and Food Technology Division was created within the Biology Group. A National Botanical Garden with an area of approximately 6,06,000 sq. metres was developed at Atomic Energy Establishment, Trombay, later renamed as BARC after Dr. Bhabha's shocking and untimely demise. After some years this garden was excluded from Biology Group. In 1963, Radiation Medicine Centre was created in the TMH complex under the Biology Group. In 1967, the group was designated as Bio-Medical Group (BMG), again, with Dr. Gopala-Ayengar as Director till he retired in 1969. Over the years, changes in the name and the composition of the group were necessitated by structural reorganization from time to time. Nevertheless, the vital programs initiated in the early years remained unaltered.

In 1971 or early 1972 late Dr. K. Sundaram succeeded Dr. Gopala-Ayengar as Director, BMG. Biology Division had then become Biology and Agriculture Division. Bio-Organic Division was also created at that time and Dr. Sundaram held office till 1986. In between during the three-year assignment of Dr. Sundaram in IAEA at Vienna, Shri. N. S. Rao, Dr. V.R. Shah, and Dr. S. M. Sharma were designated Head of the Biology Group, Medical Group and RMC respectively. After Dr. Sundaram's retirement the group was split, late Dr. N. K. Notani became Director of Biology Group and late Dr. M S. Chadha became Director, Biochemical Group. After Dr. Chadha's retirement in 1990, Dr. Notani became Director, BMG. He was succeeded by late Dr. C. R. Bhatia as Director, BMG till he left to become Secretary, DBT in 1992. Dr. D.V. Gopinath who was Director, Health safety and Environment Group also held the charge of Director BMG. In 1994, the group was again split and Prof. P.C. Kesavan, who came from JNU, became the Director of Bio-Sciences Group (BSG). It again became BMG when Dr. Mrs A. M. Samuel took over as Director after Prof. Kesavan retired in 1998. She retired in 2002 and again BSG and Medical Group were created and I became Associate Director, BSG and Dr. B. J. Shankar was designated Associate Director, Medical Group. In January 2006, Medical Division and RMC were again merged with BSG and I was designated Director, Bio-Medical Group. I held office till the end of October 2013. The group was again split and Dr. S. K. Apte became Director, BSG. Dr. S. Chattopadhyay, Dr. V. P. Venugopalan, Dr. S. K. Nayak, Dr. T. K. Ghanty and Dr. A. K. Tyagi were designated successive group Directors of BSG after Dr. Apte's retirement in 2014.

Currently the BSG is headed by Dr. P.A. Hassan as Associate Director. In between there were occasions when Director, BARC, Director Physics Group, BARC and even Director, TMC held charge of Director, BMG. Shri N. S. Rao (Biology Group), Dr. D. S. Pradhan, (Biology/Biochemical Group) Dr. S. M. Sharma, Dr. V. R. Shah, Dr. Usha Desai, Dr. Mrs. Samuel and Dr. B. J. Shankar (All from Med Group), Dr. S. K. Apte, Dr. S. F. D'Souza (BSG/BMG), Dr. S. P. Kale, Dr. S. Chattopadhyay, Dr. V. P. Venugopalan, Dr. S. K. Nayak, Dr. S. K. Ghosh and Dr. T. Ghanty (all BSG) have also served as Associate Directors. The activities of the BSG are today physically located at, Trombay, Kollam, Kerala, BARC-Vizag, Andhra Pradesh and Gauribidanur, Karnataka.

As early as 1927, Prof. H. J. Muller showed that X-rays could cause mutations, i.e., changes in heritable characteristics, in the fruit fly. These effects of radiations were most dramatically revealed to the world at large with the atomic bombing of Hiroshima and Nagasaki Hiroshima in August 1945. The survivors constitute a most extensively and critically studied cohort of radiation exposed population that has been providing important data on the nature and extent of radiation induced damage. In the famous "mega mouse" experiment thousands of mice were exposed to radiation to study induction of mutations, the impact on life span of animals due to external exposure as well as ingestion of radioactive material were undertaken. Similar studies were also initiated globally on other living organisms like plants and microbes. BARC was no exception. United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) was constituted in 1955 and it estimates the exposure of human population from various sources of ionizing radiation, both natural and man-made, e.g., radioactive fall-out from nuclear weapons tests, discharges from nuclear facilities, medical radiation and the ensuing potential health risks like cancer and hereditary effects. India has been a founder member of this now 31 nations scientific committee. Group Directors of BMG/BSG and HSG as well as some senior scientists with domain expertise have represented India in this committee's deliberations. The availability of radiolabelled biomolecules provided the much-needed sensitive tracers to delineate pathways of a myriad biochemical reactions underlying physiological processes and some of them proved very useful as radiopharmaceuticals, diagnostic as well as therapeutic tools. These developments have transformed the conduct of research in biology. The understanding of the effects of radiation continues to improve with better understanding of the naive unexposed, and hence undamaged, living system.

1. Sustainable Agriculture

Dr. Gopal-Ayengar initiated several research programmes. To study radiation's mutagenic effects, he established the Gamma Garden at the Experimental Field Station, Trombay with a 500-curie cobalt-60 source. This was utilised to do induce mutations in ornamental plants. Research on mutation breeding had humble beginnings. In the 1960's, mutants generated by neutron irradiation of Geb 24 rice seeds flowered 21 days earlier, with 15% more yield. Also, superior performance of large pod mutant groundnuts was observed in trials conducted in Trombay, Mandala, Jalgaon, Sai, and Talaja, in

Maharashtra, and in Gujarat. This led to the submission of the proposal for the release of two groundnut mutants, TG-1 and TG-3, to the Central Varietal Release Committee in the 1970's. Mutation breeding experiments using irradiated seeds of different crop plants like groundnut, linseed, pulses, jute, and rice were also undertaken. TG1 (Groundnut) was the first mutant variety developed at Trombay and released for commercial cultivation in 1973. Today, radiation-induced mutation-based crop improvement is a flagship programme of the DAE and so far 62 such mutants of twelve different crops have been developed in collaboration with several agriculture universities and after a series of mandatory trials stipulated by ICAR, they have been gazette notified and released for commercial cultivation by farmers. These include crops like groundnut (16), black gram (8), green gram (9), soybean (2), mustard (9), sunflower (1), pigeon pea (5), cowpea (2), rice (7), jute (1), linseed (1) and sorghum (1). A large number of selections are in different stages of development and trials. They are higher yielding, early maturing, and some show disease and drought resistance. Our contributions are especially significant in the oil seeds, pulses and recently in rice crops. Furthermore, Trombay mutant varieties contribute very significantly to the national breeder and foundation seeds indent.

Recently, the Indian Council of Agricultural Research recommended foliar spray of thiourea for achieving higher yield of Soybean following extensive research done by our scientists in BSG and their collaborators from Agriculture Universities. More importantly this work was backed by exhaustive and excellent basic research at molecular level conducted by our young scientists in Nuclear Agriculture and Biotechnology Division (NA&BTD). The Division also has programmes on soil science (utilization of fertilizers), pesticide residue assessment and integrated pest management. In the 1970s, the mosquito larvicidal properties were demonstrated in garlic extract and the active principles were found to be diallyl disulfide and diallyl trisulfide. This work was published in Science in 1971. Sterile Insect technique and method for Biological Control of insect pests using crystalliferous *Bacillus thuringiensis* and *B. sphaericus* were also developed.

2. Plant Biotechnology

Plant tissue culture and plant biotechnology has been another important area of research in BSG. In the early days, biotechnology research focused on haploid plants generation, protoplast culture, plantlet regeneration from protoplasts, somaclonal variants, micropropagation techniques etc. In the early 1980's, anther and pollen cultures of potato, rye, capsicum, and Physalis species were started at BARC in collaboration with Max Planck Institute, Germany. Protocols were developed for micropropagation of several commercially important plants like several elite varieties of banana, pineapple, sugarcane, sandalwood, and several medicinal plants that produced anticancer, anti-HIV and antimalarial drugs. A bioreactor for cultivation of cultured plant cells was developed and the technology was transferred to Kabra Drugs. The banana micropropagation technology has been transferred to Krishi Vigyan Kendras as well as private entrepreneurs. First transgenic tobacco plants containing kanamycin resistance were

developed in BMG and later transgenic plants containing herbicide resistance gene Bar were also generated. After the year 2000, a spin off technology was developed for biodegradable waste management called Nisargruna Biogas Plant. This is a biphasic bio-methanation technology that uses aerobic predigester followed by anaerobic main digester and processes various kinds of waste like kitchen waste, food waste, cow-dung and abattoir waste. Currently there are more than 300 such installations all over India.

3. Radiation preservation of food and food products

Research on preservation of food grain and food products started under the leadership of late Dr. A. Sreenivasan after the group moved to Trombay and a separate laboratory, FIPLY (Food Irradiation and Processing Laboratory) was built for that purpose. A package food irradiator with a Co-60 source was donated by Atomic Energy of Canada Ltd for this purpose. Later on, this facility was further augmented by installing a Cs-137 source. Work on radiation mediated microbial decontamination and disinfestation of food grain, meat, fish, fruit and vegetables and delayed ripening of fruit (especially mangoes) and enhancement of shelf life has been going on there since then. Combination of irradiation and GRAS chemicals as well as other hurdles technologies like low temperature, moisture control have also been employed. Development of new packaging materials was also undertaken. Several microbiologists, biochemists, food technologists, toxicologists and some chemical engineers have sustained this programme. An extensive study on the wholesomeness of irradiated wheat including genetic toxicology was undertaken and the irradiated wheat was successfully demonstrated as safe for human consumption. In 1995 the Government of India, Ministry of Health accorded clearance for radiation processing of onions and potatoes for prevention of sprouting which would enhance shelf life. First technology demonstration plant for this purpose, "KRUSHAK", was commissioned at Lasalgaon near Nasik in 2002.

On 26 April 2007 the first batch of Alfonso mangoes irradiated at KRUSHAK were air-shipped to USA and there has been no looking back since then. By 2012, a process for preventing browning and extending shelf life of litchi fruits for 45-60 days by a sequential dip treatment using GRAS chemicals was developed by BARC and the technology was transferred to SCRIMAD, Madagascar. FTD's contributions resulted in obtaining a class specific approval of the Ministry of Health for radiation processing of different food items. Over 7 such classes of foods covering nearly 100 food items have been approved after the amended Atomic Energy Act (Radiation Processing of Foods and Allied Products) Rules 2012 have come into effect. BARC also developed a fruit vegetable dip treatment machine for processing litchi and other fruits. A high-throughput plant was set up at NRCL, Muzaffarpur, for processing 15 tons of litchi fruits. By 2020, GRAS preservatives were also approved for treating mangoes to extend shelf life. Based on the success of these programs, as many as 28 food irradiation facilities are commercially operating in India today and the MoFPI has come out with a notification for expression of interest to avail financial support to set up 50 such plants for radiation processing of food.

In the last decade or so several new products have been developed e.g. ready to eat food, food for immunocompromised individuals and defence forces working in remote areas and at high altitudes. Apoptosis in bacteria was investigated. A technology for making banana juice was also developed. A cytotoxic and immunosuppressive red pigment (Prodigiosin) was isolated from small prawns, Jawla. Studies were also carried out to detoxify Salmonella using gamma radiation. A technology for conversion of cane sugar to invert sugar was developed and transferred.

4. Radiation Medicine Centre (RMC)

Steered by late Dr. R. D. Ganatra and Dr. Jeejeebhoy and located in the TMH complex in Parel, RMC was started in September 1963 and it became the first WHO recognized centre for investigation and treatment of thyroid diseases in India using radioisotopes (mainly I-131). It is a pioneer in nuclear medicine in India, Radioimmunoassay, Tc99m labelled radiopharmaceuticals and scintigraphy have been the most dominant diagnostic tools till 2002 when India's first Medical Cyclotron for production of F-18 and PET Scanner became functional there and that has benefitted a huge number of patients of cancer and other diseases. RMC also provides services in nuclear cardiology, radioanalytical clinical services and radioisotope therapy for thyroid and other cancers. Additionally, spoligotyping of clinical Mycobacterial strains of different lineages, development of an ELISA assay for antigens of *Mycobacterium tuberculosis* and studies related to innate immune response to Mycobacterial infections have been carried out at RMC. In recent years Lu-177 based scintigraphy and therapy have been started.

5. Medical Division

This Division has provided quality healthcare to more than 100,000 DAE employees and their families in Mumbai. BARC Hospital in Anushaktinagar is a 390-bed tertiary care facility equipped with ICCU, NICU as well as modern diagnostic equipment like CT and MRI and a state-of-the-art dental care facility. It is supported by zonal dispensaries and occupational (industrial) health dispensaries. The present main building of the hospital was occupied in mid 1970s. An annexe was added many years later. During the recent years several new equipment have been added to augment patient care. Medical Division also has a strong academic programme in 10 specialities leading to DNB.

6. High Level Natural Radiation Areas in Kerala

The study of radiation effects in various biological systems has been the most important mandate of the Bio-science Group. These effects are known to be dose dependent. Globally there is a growing interest in the effects of very low doses of ionizing radiation as these have tremendous implications to the International Council for Radiological Protection (ICRP) prescribed limits of exposure for radiation protection of workers and general public. One of the flagship projects of BMG is the studies on the human population living on the south west coast of Kerala which is rich in monazite sand. This

population is continuously exposed to high level natural radiation at all stages of development. It has a high population density and people have been living there for tens of generations for nearly a thousand years. The external radiation dose varies between 1.5 to 45 mGy. The importance of this area to radiation biology was recognized by WHO in the early 1960s A project called Monazite Survey Project was initiated on Dr. Gopal-Ayengar's initiative in mid1960s. Cytogenetic studies on the population were started by K. P. George. In the 1970s a systematic study of this population was undertaken with respect to house dose, demographic profile, reproductive performance, assessment of cytogenetic parameters etc. Early results with rats and in adult human beings did not show increased genetic damage in the exposed population. A dedicated laboratory (LLRRL) was commissioned in Kollam for this purpose in 1999. Under its aegis, a more extensive study on screening of newborn children was undertaken in which nearly 2,00,000 new-borns have been screened for the incidence of nearly 100 different congenital malformations detectable at birth, still births and twins, Down's syndrome, chromosomal aberrations (stable and unstable, structural and numerical), micronuclei frequency, telomere length etc. None of these showed any significant difference between those born to parents from High Level Natural Radiation Areas (HLNRA) and those born to parents from Normal Level Natural Radiation Areas (NLNRA). A case control study on mental retardation and cleft-lip and cleft-palate also did not reveal any deleterious effect of high natural radiation. The older exposed population from HLNRA shows lesser DNA damage than their age matched NLNRA counterparts, indicating a better DNA repair and a radio-adaptive effect. At the molecular level, studies on DNA mutations based on more than 50 hypervariable loci in human DNA and more than 200 families have also not indicated any change due to HLNR exposure. These studies are regarded as unique and extensive and have drawn the attention of the global low dose researchers and radiation protection community alike. The exposure here mimics the likely continuing exposure scenario after a nuclear accident like the one in Fukushima. In Kerala as well as in China, where a similar high natural background radiation area exists, the excess relative risk of cancer has been found to be marginally negative according to the analysis performed by reputed Japanese epidemiologists. The work done in last two decades in LLRRL has been published in reputed journals in the field and has been taken note of by international bodies like UNSCEAR. This is a stupendous achievement and efforts are on to harness newer developments in genomics to understand global gene and protein expression profiles, epigenetic changes and microRNA mediated gene regulation as well as look for changes in specific genes as indicators of low dose radiation associated effects or lack of them. Correlating individual exposure to health effects as an end point is a daunting task and is likely to be part of future research endeavours.

7. Basic Research

Basic research is very fascinating to most youngsters in biology. Evaluating the effects of radiation on different biological systems has been a topic of interest in bioscience group since its inception. The research programs included cytogenetics (plants, animal &

human), *in vitro* cell systems and molecular studies. In the Biochemistry and Food Technology Division several studies were undertaken to evaluate the effect of ionizing radiation on processes such as carbohydrate metabolism, nucleic acid and protein metabolism and energy metabolism and vitamins. Studies on carcinogenesis were also initiated in mid 1970s. Enzyme immobilization research was initiated during that time which led to larger programme on enzyme biotechnology and has now matured to the stage of development of biosensors for a pesticide and urea. The studies on pathways of genetic recombination in *E. coli*, UV sensitivity of *E. coli*, transformation in *Haemophilus influenzae* and responses to osmotic, salinity and oxidative stress in cyanobacteria, radiation resistance in *Deinococcus radiodurans* and cyanobacteria, use of thermoluminescence (TL) technique to probe photochemistry of photosystem II, and organization of multiprotein complexes in photosynthetic carbon fixation were undertaken in MBD. A proteomic map of *Deinococcus radiodurans* after radiation exposure has been constructed Several critical genes regulating DNA repair and radiation resistance in that organism have been identified. Mechanism of formation of multiple forms of superoxide dismutase under oxidative stress was demonstrated in cyanobacteria. DNA markers for rust and drought resistance in rice were developed. Evidence for the existence of a multienzyme photosynthon complex containing RuBP Carboxylase was gathered.

DNA repair, redox regulation in mammalian cells, radiation protection, apoptosis or programmed cell death in cancer cells, modification of tumor cytotoxicity by tumor microenvironment have been investigated in RB&HSD. A V-D-J recombination mediating enzyme complex in thymocyte nuclear extract was shown using a synthetic substrate. Many genes that regulate these processes were identified. Augmentation of cell mediated immune response was shown in low dose exposed mice but for the first time differences were also revealed based on the genetic background of the animals and the type of antigen and response. Positive bystander effect of radiation exposure was demonstrated in lymphocytes for the first time. Mechanism of radio-adaptive effect in lymphocytes has also been investigated.

Several naturally occurring substances including extracts of medicinal plants were evaluated for their antioxidant and radioprotective actions. One of them, Chlorophyllin is a component of the recently DCGI approved and commercialized radio-modifier tablet, AKTOCYE® which has proved useful in the treatment of haemorrhagic cystitis, a side effect of radiotherapy. An acidic arabinogalactan obtained by activity-based purification of stem extracts of *Tinospora cordifolia* has been shown to be a strong stimulator of macrophages, dendritic cells and B lymphocytes. It protected against endotoxic shock, induced maturation of dendritic cells and enhanced their cytotoxicity to tumor cells, enhanced innate immunity against Mycobacteria and also inhibited growth of *Mycobacterium tuberculosis* in mice.

In mammalian Radiation Biology, radiosensitization of cancer cell by hypoxic sensitizers and hyperthermia and radioprotection by a variety of agents such as caffeine and anaesthetics were thoroughly investigated using mice as well as several cell lines. These

studies were extended to include ion beam irradiation and alfa particle irradiation, the latter using a newly developed BARC Alfa Irradiator. A host of chemicals were also evaluated for their genotoxicity using micronuclei formation, DNA fragmentation (SCGE or Comet assay), gamma H2AX foci etc. Studies on toxic effects of thorium incorporation and methods for its decorporation have been under investigation. Furthermore, these basic research programmes enabled our scientists to establish sensitive, state-of-the-art, high throughput techniques in our laboratories and achieve recognition by their peers elsewhere. These include establishment of facilities for genomics, proteomics, gene expression analysis, transgenics and gene cloning, knock-out and silencing, DNA sequencing, microarray, flowcytometry, confocal microscopy, surface plasmon resonance, transmission electron microscopy, MALDI-TOF spectrometry etc.

8. Bioremediation

A highly radioresistant bacterium, *Micrococcus radiophilus* was isolated in late 1960s in FIPLY. In the mid-1990s work on the highly radioresistant bacterium, *Deinococcus radiodurans* was initiated to understand the mechanism of its extreme radioresistance. *E. coli* and *Deinococcus* were genetically engineered to express a phosphatase gene and were shown to sequester uranium. Bioremediation of tailing ponds near the uranium mining sites using some indicator plants was also carried out. These achievements have resulted in addition to recognition to individual scientists for reporting some significant observations for the first time, in opening up possibilities for useful deployment of technologies or products based on them.

9. Bio-Organic Chemistry

A separate Bio-organic Division was created within the BMG in 1971. It had several organic chemists and some biologists too. Several bioactive natural products were isolated and synthesized. Some of them were evaluated for their insecticidal properties. A success story was about the synthetic pheromones that were used to make pheromone traps for reduction of insect pests like cotton boll worm and sugarcane pests. Plant growth regulator triacontanol and its analogs were synthesized. A convenient method for the preparation of important radiopharmaceutical, namely hexamethylene propylene amine oxime (HMPAO), which had extensive use in cerebral perfusion imaging was developed. In collaboration with BRIT, radiopharmaceuticals for preparation of technetium complexes for brain imaging had been synthesized and the kits made from these were under final stages of evaluation for clinical trials. In recent years this Division has undertaken programmes on anti-cancer drugs and their mechanism of action. Furthermore, ligands for extraction of valuable radionuclides from reactor waste (CMPAO for actinide extraction) and nuclear imaging agent like MIBI (for nuclear cardiology) and PSMA-617(for prostate cancer) have been synthesized and are being used for treatment of patients.

10. Human Resource Development

The long-term mandated research programmes of BMG/BSG could not have been sustained without adequately trained human resources. In the early days the research projects were led by scientists trained for PhD and/or post-doctoral research abroad. In this context, the most important role of BARC training school in initiating as well as sustaining Indian Nuclear Programme in the last seven decades needs to be underscored. Several young graduates from Physics and Chemistry streams of training school joined the BMG in the 1960s and initiated new lines of research in biosciences, especially in radiation biology, immunology and biophysics. The bioscience research in BARC turned a new leaf in 1971 with the introduction of Biology-Radiobiology training programme in BARC training school. During the periods 1971 to 1977, then from 1994 onwards a number of young biologists with varying specializations were recruited through this route. These researchers, along with some of their chemistry and physics counterparts strengthened the research, development and deployment (RDD) programs of not only the Bioscience/ Bio-Medical group but also those of Radiochemistry and Isotope Group, Physics group and Health and Safety Group in BARC. Furthermore, they are actively involved in the RDD projects of our sister institutions like BRIT, IGCAR and RRCAT. The introduction of a large pool of talented researchers over the years, many of whom, through their dedicated and assiduous work brought the quality and productivity to appreciable levels. This also provided the overall sustenance and expanded the scope of research programmes in the Group.

In the field of nuclear medicine, the commencement of two courses viz. Diploma in Radiation Medicine (DRM) for doctors and Diploma in Medical Radio Isotope Technology (DMRIT) for science graduates affiliated to University of Mumbai in 1973 provided a very large trained manpower of clinicians and technicians for large scale utilization of radioisotopes and nuclear medicine in the country. In 1982 the National Board of Examination (GOI) accredited RMC for DNB (Nuclear Medicine). In 2015, MD (nuclear Medicine) course under HBNI replaced the DRM/DNB programme and M.Sc. (NMMIT) and M.Sc (Hospital Radiopharmacy) courses have been introduced under the aegis of HBNI. The impact of these courses on clinical nuclear medicine practice in India has been tremendous.

The Category I and Category II training programmes introduced two decades ago have provided a much-needed technical assistance in the laboratories. Another very significant human resource for the group has been the PhD students joining through BARC-University of Mumbai Collaboration, UGC-CSIR NET and in recent times to a large measure through HBNI's PhD programme. Many BSG/BMG scientists have been recognised as PhD guides for UOM, HBNI and other universities.

11. Research Equipment

Biological research requires several sensitive and expensive equipment and chemicals most of which are imported. Over the decades, the research programs in bioscience group were managed though the import delays and international trade policies, including the periods after India's peaceful nuclear experiments in 1974 and 1998. Even importing a liquid scintillation counter was not easy. Some scientific equipment like a DNA microarray system and image analysis system were built in-house with the help of multidisciplinary expertise. Several advanced instruments including nucleotide synthesizers, DNA sequencer, flow cytometers, MALDI-TOF, NMR spectrometer and transmission electron microscope were procured, through the institutional grants provided from the five-year plan outlays, which made life easier for the younger recruits. In recent years a significant emphasis was placed on patenting and product development and significant progress on that front has also been achieved.

The large and diverse work force of former and present colleagues - both within the bioscience group and in other divisions of BARC/DAE - leaves a credible history behind, placing the bioscience group fully equipped for the imminent challenges and leading to a bright future.

12. Epilogue

An article, "Biology & Medicine: Excitement of Research and Deployment of its Outcome–The Twain Do Meet in BARC" written by the author in BARC Newsletter in 2013 had summarized the then biomedical group achievements and articulated some of the future opportunities and challenges. The sustained progress seen from the collective efforts over the last decade reassures that the present team of biologists are fully equipped for the challenges - with a credible history behind and a bright future ahead.