Evolution of Health and Safety Programmes

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Preamble

Health and Safety programmes in the Department of Atomic Energy (DAE) cover DAE's nuclear facilities and institutions using radiation sources nationwide for medical, industrial, agricultural and research purposes. The operating management of the nuclear installations and users of radiation carry out their activities judiciously without undue risk to workers, members of the public and the environment. Health and safety programmes in India were evolved side by side to support these objectives.

India's nuclear energy activities cover the entire nuclear fuel cycle: uranium and thorium exploration, mining, milling; fuel fabrication; operation of nuclear power and research reactors, decommissioning and safe management of nuclear waste. The other areas covered are accelerators, radioisotope production, applications of radioisotope in industry, diagnosis and treatment and transport of nuclear and radioactive materials.

This chapter chronicles the evolution of health and safety programmes in DAE. The emphasis of DAE right from its inception was on achieving highest levels of safety of various processes. Instruments and facilities established indigenously to meet health and safety requirements are also discussed,

1. Health and Safety programmes - early years

On February 27 1960, Dr Homi Bhabha issued an office order which stated thus: *"Radioactive material and sources of radiation should be handled in Atomic Energy Establishment ,Trombay (AEET) in a manner, which not only ensures that no harm can come to* *workers or anyone else, but in an exemplary manner so as to set a standard which other organizations in the country may be asked to emulate".*

The health and safety programmes of DAE put this most quoted mandate into practice in the units of DAE. Radiation safety programmes evolved over the years along with the atomic energy programme in India to meet the current safety requirements followed in international practices and national regulations.

The remaining paragraphs of Dr Bhabha' s office order which delegated powers of entry and inspection, in any Division in AEET, to the Head, Health Physics Division are very relevant to India's health and safety programme. Probably, Bhabha had in his mind two safety related occurrences of pre-1960 referred to in the DAE Annual reports and the absence of a formal Atomic Energy Act and rules with safety provisions when he issued the order. (An Act which contained safety provisions was then in draft stage).

In the first incident, scientists found that many tables, equipment, switches etc in several rooms in the physics laboratories in the Tata Institute of Fundamental Research (TIFR) were contaminated with polonium-210, an alpha particle emitting radioactive substance. Shri S D Soman who was already working in TIFR gave special training to some workers and satisfactorily decontaminated the rooms with their help. The second incident, which occurred in 1958 contaminated many rooms with uranium oxide dust while scientists in the Chemistry Division at Cadell Road were producing uranium metal by fused salt electrolysis. Shri. Soman organized the decontamination of these rooms as well.

As a follow up of Dr Bhabha's office order, the health and safety staff published a document called "Manual for Radiation Protection in AEET". This 124 page document is the first formal "regulations and standards" on radiation protection in India. This model document prescribes in detail the duties and responsibilities of officers in charge.

The work related to the health and safety of workers started in 1953-54 with the setting up of the Medical Section in the Medical and Health Division. The Section concerned itself with safeguarding the health of persons exposed to radioactive materials, suggesting and supervising the setting up of the monitoring facilities for personnel and equipment, setting up standards of safe radiation doses, compiling educational material on radiation hazards and carrying out research on basic questions on radiation biology.

Personnel Monitoring with a weekly film badge service to evaluate radiation dose received by radiation workers started in 1953-54. Shri K N Iyengar who later got transferred to Nuclear Physics Division, AEET, started the service. The Health Physics Section prescribed 300 mR (Roentgen-R- is a unit of radiation exposure; mR is a thousandth of a R) as the permissible weekly dose. The Section notified anyone who received above 300 mR and investigated the cause of over exposure. Medical department kept the yearly dose records of workers.

During 1956-57 the scientists in AEET used to bring samples of dust and rain water collected from Delhi, Kolkata, Nagpur and Bangalore by air and evaluated their radioactivity. They later added Srinagar to the sampling network. They started studying in detail nuclear fallout from atmospheric test explosions of atomic and hydrogen bombs during 1957-58 using samples from seven stations and submitted the data to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). They also started measuring activities of strontium-90, Cs-137 and Iodine 131, the most important fall out nuclides in the biosphere. By 1958, AEET scientists started a countrywide programme of radiological hazard control and offered about 1000 film badges weekly to 25 institutions.

In 1959, Dr. A S Rao, a close associate of Dr Bhabha, assigned to Shri P.N.Krishnamoorthy who was already working in TIFR, the responsibility of the Radiological Measurements Laboratory (RML) which Rao set up to provide radiological protection services to institutions outside the Department of Atomic Energy (DAE).

In 1963, DAE set up a separate Directorate to enforce radiation protection provisions in radiation installations outside the jurisdiction of DAE. Health Physics Division continued its activities in DAE.

The use of radioisotopes in medicine, industry, agriculture and research increased rapidly. RML provided personnel dose monitoring services, surveyed medical x-ray units and started developing and making radiation measuring instruments. The extracts from the annual reports of DAE from 1959-1964 indicate the rapid progress made in the field of radiological protection.

The Central Government promulgated the Atomic Energy Act 1962 which addressed the activities connected with the development and use of atomic energy including safety and related matters.

2. Environmental radiological surveillance at sites of nuclear installations and related R&D programmes

Dr A K Ganguly, who joined Dr Bhabha in 1956 was working as a research associate in the Department of Radiation Chemistry in the University of Notre Dam, USA. The teams of young researchers led by him carried out studies in mostly new and unchartered territories. They prescribed limits for radioactive releases and radiation levels at occupied areas for various installations based on the results of these dedicated efforts. These ensured protection of workers, members of the public and the environment. The investigators used the best available experimental data and appropriate safety factors in line with the international norms. Dr. Ganguly's team including Shri T. Subbaratnam, Shri S. Somasundaram, Dr. D.V. Gopinath, Dr. M.R. Iyer, Dr. K.S.V. Nambi, Dr. V. Shirvaikar, Dr. P.R. Kamath, Dr. K. C. Pillai, Dr. L.V. Krishnan, Dr. P. Kotrappa, Dr. M.A.R. Iyengar, Shri S. Krishnamony, Dr. C.M Sunta among others made priceless contributions to the field of radiation safety, environmental monitoring, impact assessment, emergency preparedness among other topics.

The Indira Gandhi Centre for Atomic Research (IGCAR) issued the "Manual on Emergency Preparedness for Kalpakkam DAE Centre", written by Shri A.R.Sundararajan, Dr L.V.Krishnan and Dr.D.V.Gopinath in 1985. In preparing this first of a kind document, the authors had the cooperation and inputs from the District Collectors during the period. Such fruitful interaction with the civil authorities based on mutual respect is very vital in emergency management.

2.1 Environmental monitoring

In order to establish the normal background radioactivity, which provides the basis for all safety measures, scientists periodically surveyed the Trombay area to obtain data on the radioactivity in soil, vegetation and marine life. Scientists started these programmes before they set up the installations and updated and maintained relevant data for timely review if the need arose.

2.2 Dilution factors provided by tidal waters

One of the most notable investigations carried out by Dr Ganguly's team of about 60 young researchers during the late 50's was an experiment to estimate the dilution factors provided by tidal waters in Trombay bay. These studies provided objective inputs to prescribe the permissible limits for the discharge of various radioactive materials into the bay.

2.3 Indian Standard Man

Realizing that the body weight and density, the intake by volume of water and air of the average Indian adult differ considerably from those of the standard man on which the International Commission on Radiological Protection (ICRP) has based its recommendations for dose limit, a team of health physicists worked on Indian standard man during the 60s.They gathered data including total weights and organ weights of over 13,000 post mortem samples of subjects who suffered accidental deaths(1).

During the 90s, another group of BARC scientists collected additional data from 24 medical institutions located in 18 cities in India covering almost the entire country to obtain the organ weights for the adults and younger population. They critically evaluated relevant data from about 14,500 post mortem cases (about 10,000 males and 4,500 females) of accidental deaths. These data were representative as these subjects were healthy when the accidents occurred. This latter analysis generated physical, anatomical, physiological and metabolic data for reference Indian man (2).

2.4 Natural background radiation and radioactivity levels

Explaining the variation of natural background radiation and radioactivity is a pragmatic way to reduce the anxiety of public on the contribution of man-made radiation

Natural background radiation emerges from radioactivity in soil and air and cosmic rays. During mid-80s BARC scientists led by Dr.K.S.V.Nambi carried out a nationwide survey of the outdoor natural background radiation. They measured indoor radiation levels at 214 locations in India, continuously for over a year, on a quarterly basis by using special thermoluminescence dosimeters (3). They estimated the national average value of radiation level as 775 micro Gray/ year; the lowest recorded value was 230 µGy/year at Minicoy (Laccadive Islands) and the highest was 26,730 µGy/year at Chavara, Kerala. (Gray-Gy- is a unit for absorbed dose, when ionizing radiation energy imparted to a kg of material is one joule; since Gray is very large, one thousandth of a Gray-milligray –mGy- and one millionth of a gray-microgray-µGy- are commonly used).

2.5 Radiation map of India

The level of gamma radiation varies from place to place. It depends on the amounts of natural radioactivity (mainly thorium, uranium and their decay products and potassium 40) in soil and rocks. Their concentration depends on the type of rocks.

Dr. A V Sankaran and a few scientists from BARC considered the typical abundance of radioactive elements of rocks and soil in different parts of the country. Choosing such data from 4100 sites covering the entire country using base geological maps (scale 1:2,250,000) divided into 28 km interval grids, they generated computer 3D graphics, bringing out the fluctuating profile of radiation across the individual States and the country as a whole.

2.6 Radioactivity levels in foodstuffs

Every food item contains very small levels of radioactivity. Based on radioactivity, milk being more radioactive is less appealing than beer! Banana is so radioactive that a truckload of it can trigger radiation monitors kept at the gates of some nuclear installations. Dr B Y Lalit and his colleagues in BARC have measured the radioactivity content of almost every food item in India. India benefitted from these early dedicated efforts, when the Atomic Energy Regulatory Board (AERB) prescribed permissible limits of radionuclides in foodstuffs when it apprehended that dairy products and other food materials contaminated with fallout from the accident at the Chernobyl nuclear power station might appear in imports from European countries.

The Laboratories of BARC at Kalpakkam, Kolkata and Trombay started testing for radioactive substances in samples of imported food items and issuing certificates.

BARC team led by Dr.U.C Mishra gave inputs to the expert committee set up by the Bombay High Court to decide, "*Whether milk and dairy products and other food products containing man-made radionuclides within permissible levels prescribed by the AERB on 27th August 1987 are safe and/or harmless for human consumption*". Based on the recommendations of the committee the Supreme Court dismissed a Special Leave Petition on imported Irish Butter. (https://indiankanoon.org/doc/819058/)

2.7 Trace elements and radionuclides in terrestrial ecosystem

BARC scientists studied the impact of releases of radionuclides and trace elements emitted from stationary and mobile sources to the terrestrial and freshwater aquatic environments. In terrestrial ecosystem, a layer of a few metres of soil at the interface supplies most of the nutrients necessary for all forms of life. Scientists find out the effects of trace elements and radionuclide accumulation on soil and water in particular, living organisms, by estimating levels of environmental contamination, transfer (bioaccumulation) and its biological effects (bioindicators).

BARC scientists provided site specific Transfer Factors for different matrices of the terrestrial environment of India based on studies conducted by various Environmental Laboratories.

2.8 Environmental Survey Laboratories (ESL)

BARC established Environmental Survey Laboratories (ESL) in the townships, several km away from nuclear power plants (NPP) before they started operation. Shri P R Kamath was a pioneer in this task. ESLs are equipped with state-of -the- art radiation measuring systems, and are independent of the plant management. ESLs participate in the emergency preparedness programme of NPPs, On-Site and Off-Site emergency exercises and in the public awareness programs in the nearby region to promote awareness of nuclear energy and natural radiation in environment.

The ESLs regularly collect: *(a)* samples of air, drinking water, and local representative dietary items to estimate the dose received by the members of the public and (b) samples of weeds, sediment, soil, grass, etc., which have a tendency to accumulate specific radionuclides to monitor the uptake of radionuclides. Besides, the ESLs monitor the quality of drinking water and sewage effluents as required by the pollution control board.

The regular monitoring programs, by ESLs at NPP sites, have shown that the levels of radionuclides in samples such as soil, crop, vegetation, milk, meat, egg etc. are at global fallout levels and there is no observable increase due to power plant operations.

ESLs collect meteorological data continuously. These data together with sophisticated atmospheric dispersion models help to estimate the concentration of radionuclides and external and internal radiation dose to public around Nuclear Power Plant sites for releases including Ar-41 and Fission Product Noble Gases (FPNGs) from reactors. The average radiation dose received by the members of the public living around different nuclear facilities is far below the AERB limit of 1000 micro-Sv/year and is negligible compared to 2400 micro Sv/y received from natural sources present at any location in the absence of any radiation installation. The data for nuclear power stations are available in the Annual reports of AERB.

3. Radiological surveillance and radiation protection at all the nuclear and radiological facilities of DAE

BARC scientists carry out radiological surveillance and radiation protection at nuclear fuel cycle facilities of IREL, NFC and UCIL including BARC facilities at Tarapur and Kalpakkam and DAE accelerator facilities at BARC, TIFR, RRCAT and VECC, Kolkata. They evaluate shielding and criticality safety for nuclear fuel cycle facilities and radiological environmental impact assessment for upcoming nuclear fuel cycle facilities and power reactors.

Scientists carry out study on long-range transport of radioactive aerosols to estimate its radiological consequences to the members of public as part of strengthening the capabilities of Real-time Online Decision Support System for handling off-site emergencies in nuclear power plants. They also conduct studies in NPPs at different sites to develop protection strategy during severe accidents. Radiological safety analysis carried out for various nuclear fuel cycle facilities assesses the design adequacy, effectiveness of the safety provisions and, additionally, quantifies the margin of safety available.

4. Measures taken to reduce dose to the workers and collective dose in nuclear and radiological facilities

India has been one among the handful of countries, which enforced the latest dose limits for workers and public as soon as the International Commission on Radiological Protection (ICRP) recommended them. India could achieve this status because of proactive measures taken by the operating management with the dedicated assistance from associated Health Physics personnel

Adequate shielding, remote operation, radioactive source control and minimizing the exposure time reduced the external exposures to personnel; isolation, ventilation, cleanliness and the use of appropriate protective clothing and respiratory equipment controlled the internal exposure. The health physics staff continuously monitors areas for radiological parameters such as ambient dose rate, air and surface contamination levels. This increased surveillance has resulted in early detection of areas with exposure potential. The number of installed instruments for radiation monitoring has steadily increased in nuclear facilities resulting in improvement in overall monitoring for radiation protection.

The operating management and the health physics staff implemented multiple measures in reducing radiation exposure to radiation workers in nuclear and radiological facilities. The radiological measurements have provided vital information about the general health of the plant and the management initiated immediate corrective actions based on the data.

The health physics monitoring contributed substantially to reduce doses during maintenance jobs, unusual occurrences/ incidents; their corrective actions have reduced the radiological impacts. The collective dose budget remains lower than approved budget over the years. The radiation protection measures adopted over the years has resulted in avoiding radiation dose above the AERB prescribed limit for the last 15 years, and the average dose to occupational workers is less than one mSv/year for research reactor facilities.

The health and safety staff from BARC, helped to lower radiation exposures to workers in uranium mines and mills and thorium handling facilities. The steps included: segregating high radiation areas, reducing manual handling, stopping wind-table operations, replacing plate and frame filters in filtering mixed hydroxide slurry, thorium concentrates and radium-bearing mixed cake with rotary vacuum filters. In uranium mines, the Health and Safety Group introduced a radon badge for personnel monitoring based on Solid State Nuclear Track

Detectors (SSNTDs), after ensuring its acceptable performance in an inter-comparison programme.

Replacing radium with safer substitutes and consequent use of manual or remote after loading in brachytherapy led to substantial reduction of dose to technicians and radiation oncologists who apply the source to the patients. Previously, these workers were among the most highly exposed.

5. Radiation safety in the medical, industrial, agricultural and research applications of radiation

Medical x-ray units are the most widely used sources of ionizing radiation in any country including India.

"Surgeon Major Walter C. Bevoor of the British army brought the first x-ray unit to India in 1898 within three years of the discovery of x-rays. It was a very primitive portable x-ray unit. Bevoor used it successfully in the North East Frontier Province"(Eurasia Review, Nov 19, 2018)

Based on the experience the British Government equipped its base hospitals with x-ray units.

The number of medical x-ray installations in India grew rapidly. According to Eurasia Review, during the 60s and 70s and the earlier part of 80s, regulatory control of medical x-ray equipment and practices were on an advisory basis. Initially, scientists from the erstwhile Directorate of Radiation Protection (DRP) /BARC and later Division of Radiological Protection visited major hospitals and carried out radiation surveillance programs.

The Eurasia Review article recalled that BARC sent a few officers to Australia, Canada and the UK under various schemes for being trained in medical physics and radiological protection. They served as resource persons in training programmes and for nationwide radiation surveillance activities among others. BARC held several short-term training programmes for the users of radiation and continues to organize such training programmes in a big scale. Particularly notable is the postgraduate diploma course in radiological physics. The programme started during the sixties and it was the first such programme in the country to provide Medical Physicists and Radiological Safety Officers (RSO) to serve radiotherapy centres nationwide.

5.1 Medical X-ray registration programme.

Regulatory control of medical x-ray units and installations is a daunting task. The first major step was a nationwide registration programme. BARC scientists organized six short-term courses to train one hundred and twenty five middle level officers from DRDO and CSIR located in different parts of the country to visit medical x-ray installations nationwide to register them and to collect essential safety- related information from each installation. The registration covered over 30,000 units and provided very useful information for further action.

Permitting the use of only type approved of X-ray equipment ensures built-in-safety. BARC supported AERB in type approval and installation approval for diagnostic and therapeutic installations during early years until AERB took up the responsibility.

5.2 Replacement of Radium in India

Radium, the earliest and once the most widely used radioactive substance in hospitals successfully treated tens of millions of patients worldwide. Techniques developed in France, Sweden, United Kingdom and the USA provided invaluable clinical experience making radium therapy a most effective form of treatment for certain types of cancers.

The first stock of radium in India arrived at the Radium Institute in Patna in 1930. During a nationwide stock taking BARC officers found that over the decades, 65 hospitals owned about 20 gram of radium in the form of fine powder in hundreds of thin platinum - iridium tubes and needles. Many of them were in bad shape due to rough handling and uncontrolled heat sterilization.

Physicians and technicians used to receive high doses during normal handling of sources because of lack of protective accessories. In some hospitals, many sources remained stuck in storage safes and containers of archaic design. Taking into account the deplorable safety status of radium, it was decided to replace it with Cs-137. The AERB endorsed the decision. With the arrival of Cs-137, physicians started after-loading application in place of pre-loading application; occupational doses reduced substantially and the accuracy of patient doses improved significantly.

BARC scientists also fabricated special containers using leak tight stainless steel tubes filled with activated charcoal to carry the sources (some of them leaky) safely from the far-flung hospitals to the Waste Management Division in BARC or IGCAR as appropriate for final disposal.

5.4 Monitoring of workers handling radio-luminous paints

During the 90s, watch manufacturing industries, telephone and defence agencies were using radioluminous paints (containing tritium or promethium-147). The radio-luminous paint will glow in the dark so that those handling the dials of watches and other instruments can see them in the night.

BARC scientists estimated the intake of these radionuclides by workers by using sophisticated instruments and bioassay techniques (urine/fecal analysis) wherever appropriate. Survey team recommended measures to reduce a few needless exposures. The team also guided the institutions on safe practices in handling luminous compounds.

5.5 Regulatory compliance of thorium in gas mantles

Avoiding excess radioactive material is a measure of environmental protection and personnel protection. In 1994, there were about 70 manufacturing units in India, employing about 400 persons handling about 150 tons of thorium nitrate to produce about 200 million mantles annually. BARC scientists verified whether the thorium content in Indian gas mantles comply with the stipulated limits. Scientists analyzed the gamma spectrum of mantle samples from 18 manufacturers and used the ratio of Ac-228/ Th-228 to evaluate the age. Using the age, they determined the Th-232 content. The results showed that nearly $11\pm2\%$ by weight of the mantle accounts for the weight of thorium.

5.6 Radiation Standards and Traceability of Radiation Measurement in India

Dr Bhabha identified the availability of radiation standards as one of the important areas as it plays a key role in radiation protection practices. During 1957-58, a small group of scientists started to develop radioactivity standards. They established a $4\pi\beta$ coincidence system for activity measurement. The laboratory also participated in the first international inter-comparison of radioactivity measurements in 1961.

There was total or near total absence of radiation dosimetry in radiotherapy practice in India (IAEA Bulletin,21 No 5). Radiotherapists carried out radiotherapy on an ad hoc basis depending on their clinical experience. As a first step, BARC researchers designed and developed primary standards such as free air chambers, graphite chambers and calorimeters for fundamental radiation units and also established a calibration facility for calibration of dosimeters on a countrywide basis. (4) They fabricated radiation measuring devices and dosimeters from locally available components and materials to the extent possible. They trained young and enthusiastic physicists, in radiological physics, offered short-term courses on radiation safety aspects in the industrial, medical and research applications of radiation.

After setting up the radiation standards, BARC offered dosimeter calibration service to all hospitals in India as well as to those in neighboring countries. They calibrated against reference standards for soft X rays, Orthovoltage X rays and Co-60 gamma rays. They also issued certificates specifying the calibration factors, accuracies and other essential information. Recognition of the BARC lab in 1976 as an IAEA/WHO collaborating centre for secondary standards radiation dosimetry was a shot in the arm.

There are over 500 radiotherapy institutions in the country totally operating more than 230 tele-cobalt and 350 accelerator units. BARC conducts TLD quality audit for radiotherapy centres periodically to ensure that dosimetry practices of these facilities are within acceptable limits. The BARC service which assures accuracy of radiotherapy is beneficial to tens of thousands of patients treated daily nationwide.

6. Development of Aerial Gamma Spectrometry System (AGSS) and Aerial radiation monitoring methodology.

After any nuclear accident, information on ground contamination in particular due to iodine -131 is crucial in planning and executing an effective emergency plan. Identifying this requirement, in 1993, Aerial Gamma Spectrometry System was developed in BARC under the leadership of then Head, RSSD, Dr.M.R.Iyer. Later, a team led by Dr. D.N. Sharma upgraded the system by developing software and monitoring methodology. The team developed the capability to asses radioactive contamination over large area qualitatively and quantitatively and to locate and identify orphan sources. The modified system can transfer the processed data online to display the contaminated area on the digitized map at a ground control centre to enable the decision makers to take countermeasures in case of any nuclear emergency- without need for waiting for the aircraft to land.

After further refinements in calibration methodology, radiation monitoring system, capability to prepare the digitized map of the area which indicates the positional information, hotspots, radioactivity profiles etc, the BARC researchers carried out aerial monitoring campaigns around the emergency plan zones (EPZ) of nuclear power plants at Kalpakkam, Narora and some selected sites in Pune, Noida, Ayanagar etc. They successfully tested AGSS in different types of helicopters at different sites.

Fig.1: Aerial Gamma Spectrometry System (AGSS) developed and used by RSSD team in many aerial Gamma spectrometry surveys using helicopters and during mobile radiological surveys.

7. Indian Environmental Radiation Monitoring Network (IERMON)

BARC scientists set up Indian Environmental Radiation Monitoring Network (IERMON) to carry out radiation surveillance across the country. The network consists of 545 Environmental Radiation Monitors (ERMs) to detect any increase in atmospheric background gamma radiation levels either due to any radiological / nuclear emergency or trans-boundary migration of radioactivity. These stations transfer data online to ICCM/ BARC Emergency Response Centre, Mumbai. Following atmospheric releases from Fukushima nuclear accident, the IERMON online data played an important role and addressed the concerns on the possibility of the radioactive plume reaching India. BARC shared the data with IAEA during that period.

Fig.2: Environmental Radiation Monitor (ERM) of IERMON installed at one of the sites

8. Development of preparedness for response to nuclear and radiological Emergencies

The Site Emergency Control Centre (SECC) for BARC set up in 1987 assesses and responds to any radiation emergency in BARC. One of the most important features of SECC was the Radiation Early warning System for the site with radiation monitors installed around the Trombay site with online data transfer to SECC. The system has been subsequently upgraded with more radiation monitors and radiological impact prediction software to predict movement of radioactive plume by using atmospheric dispersion models.

In the year 2001, DAE decided to develop 8 DAE-Emergency Response Centres (ERCs). DAE also set up 25 DAE-ERCs within the next 17 years with 25th DAE-Emergency Response Centre established in 2018. These DAE-ERCs with BARC-ERC as the nodal ERC at Mumbai have Emergency Response Teams (ERTs), state of the art radiation monitoring systems, stock of protective equipment, potassium Iodate tablets, decontamination agents etc. They participated in many national level emergency preparedness/response activities including Mayapuri radiological emergency(2010), training of Emergency Response Teams (ERTs), first responders, security agencies and mobile radiation monitoring of major cities Emergency Plan Zones (EPZs) of NPPs.

BARC has also developed and installed two Mobile radiological Impact Assessment Laboratories (MRIALs) with state-of- the-art monitoring systems with data transfer capability to ICCM/BARC-ERC. They periodically carry out environmental radiation monitoring around BARC sites, Mumbai-Navi Mumbai area, and other sites as per requirement. The BARC-ERC also coordinates the support of experts in dosimetry, dispersion modelling, radioactive waste management and medical management of radiation emergencies etc.

In 2018, the Site Emergency Control Centre (SECC) of BARC was upgraded for responding to any type of emergencies including nuclear and radiological emergency within BARC, Trombay site with the development and commissioning of ICCM. Trained teams operate the ICCM 24x7. ICCM is attached with a facility to handle decontamination and medical management of contaminated/exposed persons. In addition to IERMON online data, ICCM also provided online data of 'Radiation early warning system' developed for BARC site's emergency preparedness. To ensure that radioactive contamination/radioactive sources will not reach public domain inadvertently, installed monitoring systems under the supervision of ICCM also monitors all scraps going out of BARC sites.

The national level nuclear and radiological emergency preparedness and response are coordinated under the guidance of the designated Emergency Response Director [ERD] (Director, Health Safety & Environment Group, BARC who is also the member of DAE's Crisis Management Group (CMG))

9. Responses to radiation emergencies by DAE Teams

The DAE-ERCs have effectively responded to radiation emergency at Mayapuri and many suspected emergencies from various parts of the county.

9.1 Mayapuri accident (INES,IAEA Level-4) caused by inadvertent release of Co-60 sources

DAE's Emergency Response Teams (from ERCs of BARC, AMD-DELHI and Narora (NAPP and ESL) and regulatory teams of AERB with support from NDRF and Delhi Police recovered major part of the Co-60 sources within 24 hours (8-9th April 2010) and safely transported them to Narora for disposal. The ERC teams supervised decontamination of area and transported safely the recovered contaminated soil and scrap and disposed them off at an authorized disposal site at Narora. Recovery and decontamination were challenging jobs accomplished efficiently without any one getting undue exposure.

9.2 Radioactive sources recovery from Cooum River in Chennai

In October 1993, AERB received information on the theft of three highly radioactive sources used by an oil-well logging company. A team of scientists from BARC and IGCAR assisted the source recovery team. The company under guidance from scientists recovered the sources lying in slush at a depth of several metres after several days after constructing a cofferdam at the site.

9.3 Other instances

There were many other instances of lost or allegedly stolen radioactive sources in the country over the years. Most cases are medical sources or sources used in industry. BARC teams recovered most of them. In a few cases, there were radiation injuries to the persons who handled them unknowingly.

9.4. Ensuring Radiological Security & Safety during Major Public Events

Based on the request from MHA/NDMA, during the Common Wealth Games (CWG-2010), dedicated teams from DAE ensured radiological security & safety at Delhi and all Commonwealth stadia in line with IAEA's document on preparedness for 'Major Public Events (MPEs). BARC-ERC team trained selected teams from DAE-ERCs, Delhi police and NDRF before the CWG. The teams carried out detailed radiation monitoring of all relevant sites and

Fig.3: (a)'Source search' using 'Back Pack' Radiation Detection System, (b) monitoring of one of the stadia of CWG, (c) mobile monitoring of access roads to stadia

stadia until the games were over. The monitoring team installed AGSS in two helicopters and kept them ready for any quick monitoring / response.

9.5 Training on radiological safety and response to nuclear and radiological emergencies and Capacity Building

BARC has conducted many training workshops and field exercises on radiological safety and emergency preparedness and response for training the plant workers, other staff of DAE, customs, security agencies, and staff of DRDO etc.

10. Indigenous Design and development of Instruments

Right from inception, DAE has placed emphasis on indigenous development of instruments and equipment for Department's programs. In line with this approach, BARC has developed a number of instruments and equipment for the monitoring of radiation.

10.1. Development of Radiation monitoring equipment

The instruments developed include

a) Radiation Monitoring Watch (RMW) for First Responders / Emergency Response Teams,

b) Mobile Radiological Assessment Laboratory (M-RAL) for emergency response,

c) Quad-rotor based Aerial Radiation Monitoring System (QARMS) for search of orphan sources and identification of contaminated area by remote controlled Aerial survey,

d) Battery operated Dose rate logging system for Long term unattended operation for deployment in any affected site,

e) Backpack Gamma Spectrometry System (BGSS) to search, detect and identify orphan/lost radioactive sources in public domain,

f) Quick Scan Whole Body Monitor (QS-WBM) for internal dosimetry and Portable Thyroid Monitor for measurement of thyroidal radioiodine content,

g) Limb monitor and Portal monitor to detect illicit/ inadvertent movement of radioactive materials and

h) Vehicle Monitoring System (VMS) to detect illicit shipment of Special Nuclear Material and radioactive material.

Fig.4: Radiation Monitoring Watch (RMW)

Fig.5: Mobile Radiological Assessment Laboratory with screen display during a survey

Fig.6: Quad-rotor based Aerial Radiation Monitoring System (QARMS)

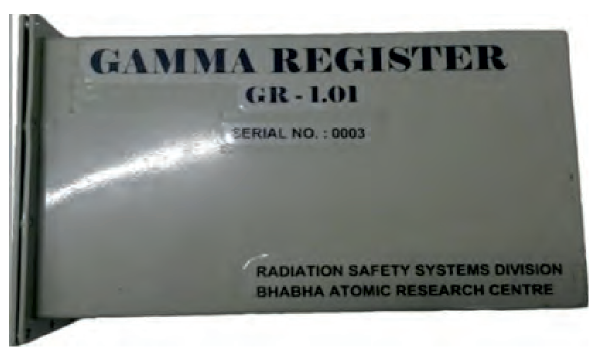

Fig.7: Battery operated Dose rate logging system

Fig.8: Backpack Gamma Spectrometry System

Fig.9: Quick Scan Whole Body Monitor (QS-WBM) and Portable Thyroid Monitor

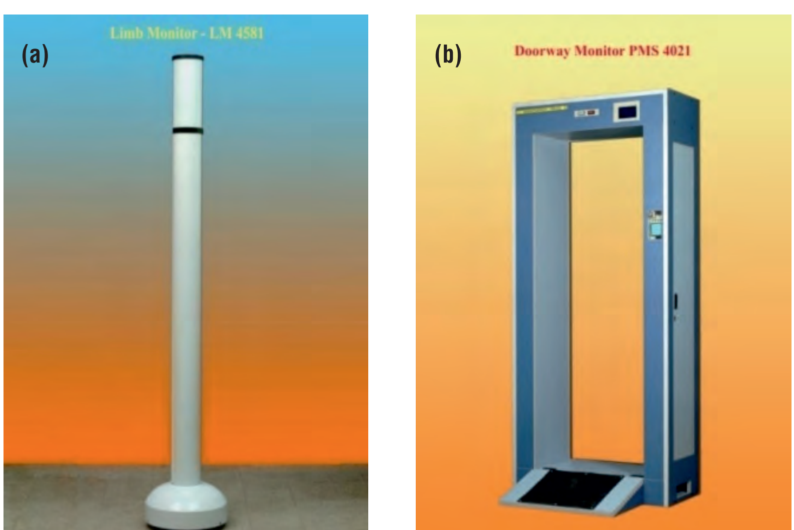

Fig.10: (a) Limb monitor (b) Portal Monitor

Fig.11: System developed for radiation monitoring of Vehicles and Cargos -VMS (ECIL has made many such VMS and installed them in the entrance and exit points of many facilities)

10.2 Indian Real-time Online Decision Support System (IRODOS)

BARC has developed IRODOS to provide Detection & Communication Network for Sensing and Assessment of Accidental Release. The IRODOS shows 72h weather & radiological forecast at any instant of time; through GIS shows the areas, villages, cities etc on which counter measures are to be implemented. It also provides State of Art Weather Prediction, Dispersion Modeling Techniques & Radiological Dose Calculation. IRODOS is currently modified to Decision Support System (DSS) for NPPs to handle an offsite nuclear emergency arising out of an unlikely event of a nuclear accident**.**

10.3 Indigenous Dosimeters

10.3.1 Thermoluminescence Dosimetry (TLD) system for research projects

During the 70s, Biomedical Group of BARC with the support of the Health Physics Division evaluated the long-term effects of high background radiation on selected population groups in Kerala coast. The scientists in the Health Physics Division developed a calcium fluoride TLD monitoring system to measure the radiation dose to a few thousand people residing in the area. They evaluated the doses to individuals with reasonable accuracy, reliability and reproducibility. The unique dosimetric survey covered about 20% of the households in each area in the region. The scientists distributed 12716 dosimeters and provided the needed personnel doses for the success of the project. The dosimeters were in the form of lockets ensuring ease of use. The study did not show any adverse health effect of radiation for the level of exposure they were subjected to.

10.3.2 TLD for Personnel Monitoring.

DAE started the official centralized Personnel Monitoring Service (PMS) for radiation workers in 1952 using Film Badges. Its limitations led to the indigenous development of a better dosimetry system, thermoluminescence dosimeter (TLD) by BARC.

TLDs are able to measure a greater range of doses in comparison with film badges. Staff can read TLDs on site instead of sending them away for developing and are easily reusable. An important part of the dosimeter is an indigenous technique to fabricate PTFE (PolyTetraFlouroEthylene) based $CaSO_4$: Dy TLD disc for dosimetry. This development led to replacement of Film Badge by TLD Badge in 1975 in a phased manner. Presently, 16 TLD Laboratories (Government and Private) located in various parts of the country provide PMS using the indigenously developed TLD Badge System.

Fig.12: (a) TLD Badge and TLD Card (b) TLD Badge Reader along with PC and other Accessories

10.3.3 Optically Stimulated Luminescence Dosimeters (OSLDs)

In TL, the heat energy acts as stimulation, while in the Optically Stimulated Luminescence (OSL) technique, light energy (generally blue or green) carries out the stimulation. The intensity of the emitted light is a function of dose, which forms the basis of dosimetry. OSL dosimetry system is popular because it is a simple system. It's other notable features are: (a) its optical nature (b) it can be used in a wide dynamic range of measured doses (c) It is easy to automate (d) it has re-read capability and (e) it has ability to perform imaging for determining the static or dynamic dose etc.

HSEG has indigenously synthesized Al_2O_3: C (Alumina), a standard OSL phosphor used worldwide for radiation dosimetry, on a large scale using the melt processing technique. This method is protected under the United States Patent granted to Muthe et al of BARC.

The OSL sensitivity and other properties of this phosphor are at par with the commercially available Al_2O_3:C. The complete dosimetry characterization of this phosphor is completed and new OSLD badge is designed and fabricated. A reader system is also developed indigenously to read out the OSLD badge. The rigorous testing and characterization of both the OSLD badge and the reader system is in progress. After successful completion of field trials it may replace TLD based personnel monitoring system.

10.3.4 Chemical dosimetry system

Division of Radiological Protection, BARC developed an accurate, simple, convenient and inexpensive spectrophotometric method or free radical dosimetry under an IAEA research contract. The Group has developed a dosimeter for low dose measurements. BARC has been using chemical dosimeters in very high dose rate areas for measuring dose. BARC developed an emulsion of PVC containing a pH sensitive dye that undergoes change in colour from yellow to red on irradiation. They are ideal to identify irradiated products.

10.3.5 Capability for internal dosimetry

The scientists of Internal Dosimetry Division/RSSD developed systems and methodology for in-vivo and in-vitro monitoring of suspected internal radioactive contamination (actinides, fission and activation products, radiopharmaceuticals) and assessment of internal radiation dose to radiation workers and members of the public; this include analysis and assessment of tritium, C-14, high energy beta and alpha emitters in biological and environmental samples; studies on biokinetic behaviour of radionuclides. The Scientists also developed an Automation System for radiochemical separation of radionuclides such as thorium, uranium, plutonium, americium, strontium etc. in bioassay samples.

11. National Occupational Dose Registry System

The dose received by radiation workers during their working life (occupational dose) is an important aspect in radiation protection. Maintenance of lifetime dose data of these radiation workers is also necessary to (i) ensure and review radiation safety of workers, (ii) certification and other legal purposes, and (iii) epidemiological studies. Indian Dose registry was networked for most of the DAE units in 2007 and later upgraded in 2013. The upgraded 'Networked National Occupational Dose Registry System (NODRS)' has main database and application servers at BARC. It is an integral part of DAE and countrywide personnel monitoring program, which plays a vital role in effective dose management. Its servers are connected to local servers of all Nuclear Power Plants as well as other DAE units through NPCNET/ANUNET. In addition to dose data and personal information, this system can store biometric information (photograph and finger print) of radiation workers. The system facilitates (i) online allotment of personal numbers to new radiation workers after incorporating personal and biometric data, (ii) online updating of dose data, (iii) identifying radiation workers with previous dose history, if any, using his/her fingerprint, (iv) tracking of radiation workers using fingerprint moving within DAE units, (v) linking of dose records, (vi) online availability of dose history of existing radiation workers.

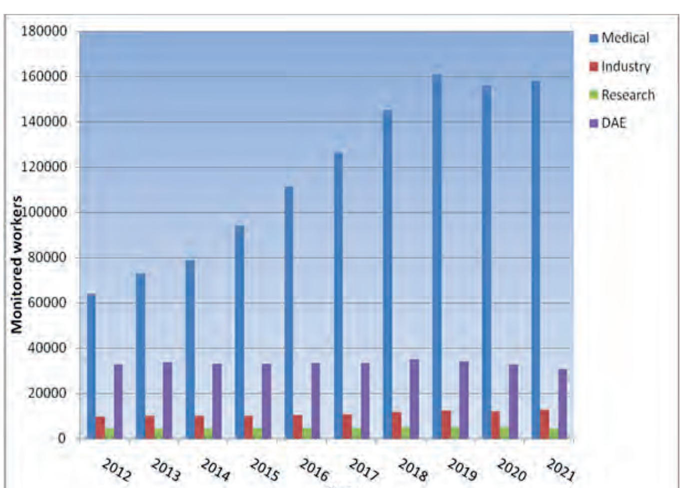

Fig.13: Monitored radiation workers in NODRS under various categories.

In 1954-55, when personnel monitoring service started in the Health Physics section under Dr Raja Ramanna, the section sent about 60 reports every week. Now the NODRS database has the record of 8,64,265 radiation workers and 42,439 institutions. Among them, 2,05,651 radiation workers and 20,434 institutions were active in 2021. It has linked data of 2,18,007-radiation workers, who had worked in more than one institution.

12. Manpower management and R&D needs

The Health & Safety activity in DAE has a rich tradition of research, which is essential for maintaining the vibrancy of the program. Dr A K Ganguly, former Director of Chemical Group mentored and trained dozens of health physicists and radiation protection specialists to provide the scholarly ambience and critical attitude essential for carrying out research in the field. One can see that over the years, the health and safety programmes contributed to many applied research projects, which addressed the needs of the Department by providing science-based answers to many vexing questions. If the "Ganguly school" thrives, health and safety programmes will thrive!

In this chapter, the authors have described some of the events and developments to reveal the humongous contributions of DAE in the field of health and safety since its inception. The health and safety professionals attempted to protect even the smallest sections of people who handled sources of ionizing radiation. They communicated safety aspects to public. While a few individuals carried on with the job exclusively on their own initiative, many others did it by actively participating in the programmes of professional associations such as the Indian Association for Radiation Protection and the Association(IARP) of Medical Physicists of India(AMPI).

Unbridled use of any technology is harmful. While remaining proactive, scientists in DAE Units and AERB have always strived to comply with what Dr Homi Bhabha advised. They handle radioactive material and sources of radiation "*in a manner, which not only ensures that no harm can come to workers or anyone else, but in an exemplary manner so as to set a standard which other organizations in the country may be asked to emulate."*

13. References

1. An evaluation of radiation protection standards for Indian populations, K Venkataraman, S. Somasundaram and S D Soman Health Physics Vol 9 pp 647-652
2. Studies of the anatomical, physiological and metabolic characteristics of the Indian population for setting up a reference man H S Dang, D D Jaiswal, M. Parameswaran and S.Krishnamony IAEA-TECDOC-1005 Vol 2, 1998
3. Natural Background Radiation and Population Dose Distribution in India, K S V Nambi, V N Bapat, M David, V K Sundaram, C M Sunta and S D Soman, Health Physics Division, Bhabha Atomic Research Centre 1986
4. The Development and Functions of the Indian Secondary Standards Dosimetry Laboratory, G , Division of Radiological Protection, BARC,IAEA Bulletin VOL 21, 5, 1979

Further Reading

“Anil Kumar Ganguly (1918-1988) And The Evolution of Health Physics Science in India: Collection of Memoirs”, Ed. M.R.Iyer, Special issue of Radiation Protection and Environment, Jan-Mar 2018.