Radiological Safety

Chapter 6

Ensuring Safety of Professionals, Public and Environment

Over the last few centuries, man has learned to develop and use complex technologies to meet his increasing needs. And with all the new technologies, be it air travel, operating a large petrochemical industry, a chemical factory manufacturing pesticides or a large dam for generating electricity, a certain amount of risk is associated with the use of technology. The challenge lies in minimizing this risk and utilizing the enormous technological potential for achieving a better quality of life for humankind. Nuclear technology is no different. In fact, the three key words in utilizing any nuclear technique are safety, safety and safety! It is safety of personnel, safety of installation and safety of environment. The Safety First criterion is fundamental in nuclear industry the world over, and India is no exception. Since the formative years of DAE, utmost importance has been attached to achieving the highest safety standards in all the operations. This necessitated development of trained manpower to implement the safety requirements, establishing the required facilities as well as developing suitable instruments indigenously. India's atomic energy programme covers almost all aspects of nuclear technology including mining of uranium, fuel fabrication, electricity generation, radioisotope production, waste management and so on. In order to meet various challenges of these activities, specialized safety measures had to be evolved. This Chapter enumerates the philosophy behind the safety aspects and the present status of radiological safety being implemented in the Indian nuclear industry.

SODAR equipment at Environmental Survey Laboratory, Kaiga, Karnataka

RADIOLOGICAL SAFETY
Ensuring Safety of Professionals, Public and Environment

Historical Perspective

Ionising radiation and radioactive materials have always been features of our environment; but owing to their lack of impact on our senses, mankind became aware of them only at the end of the nineteenth century. Since the ushering in of atomic era, radiation sources are increasingly being used for various applications in agriculture, industry, `medicine and research. Radiological protection is concerned with protecting man against harmful effects of radiation. The primary aim of radiological protection is to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure. Ionising radiations need to be treated with care rather than fear and their risks should be kept in perspective with other risks.

Operational health physics activities and research and development programmes in radiation protection started in the mid fifties along with the other programmes in nuclear science, engineering and technology. The mandate for radiation protection was clearly spelt out by Dr. Bhabha himself,. This delineated DAE's concern for the safety of workers in particular and the members of the public and the environment in general.

> *"Radioactive materials and sources of radiation should be handled in the Atomic Energy Establishment in a manner which not only ensures that no harm can come to workers in the Establishment or anyone else, but also in an exemplary manner, so as to set a standard which other organisations in the country may be asked to emulate".*
>
> ***H.J. Bhabha***
>
> *Feb.27,1960* *Director*

The programme of atomic energy in India had started taking shape by the year 1953 and small amounts of radioactive samples were being handled at that time. It was envisaged that in the near future reactor facilities might be built and more intense radiation sources would have to be handled by a large number of workers. Realizing this, AEC formed a new division called the Medical and Health Division (MHD) in 1953. The mandate of this division was to safeguard the health of persons exposed to radiation and to establish monitoring facilities for personnel. During early 1954, US carried out atmospheric testing of nuclear weapons and severe radioactive contamination of some Japanese fishermen generated serious concern about adverse effects of the fall out. Scientists at the Institute of Physics (now Saha Institute of Nuclear Physics) analyzed samples of oil and grease from exposed surfaces of passenger aircrafts landing at Dum Dum Airport, Calcutta and attributed radioactivity in the samples to debris from nuclear tests. A new division called Air Monitoring Division was created in DAE in 1954 which organized an extensive study to assess the fall out levels over India through analysis of air, water, milk and desposited dust. Detailed studies were carried out to determine strontium-90 (^{90}Sr) and cesium-137 (^{137}Cs) especially in milk samples. The sampling stations were set up at eight locations namely, Bombay, Bangalore, Calcutta, Delhi, Gangtok, Nagpur, Uthagamandalam and Srinagar. Special radiation measuring equipments were developed for detecting and studying very low levels of radioactive materials.

The processing of the monazite sands for recovery of thorium and rare earths had begun by that time and hence measurement of natural radiation levels in terrestial environment became a subject of considerable attention. The first surveys of radiation levels in monazite area were undertaken in the month of July 1956. The commissioning of APSARA reactor and setting up of Radiochemical Laboratories in 1956, demanded more systematic radiation surveillance activities on a round the clock basis. Since the scale of activities was yet not very large, the approach followed during the period was of self regulation. The early programmes on Radiation Protection and Health Physics Instrumentation were initiated for effective self-reliant safety surveillance activities to meet the growing needs of the nuclear programme of the country.

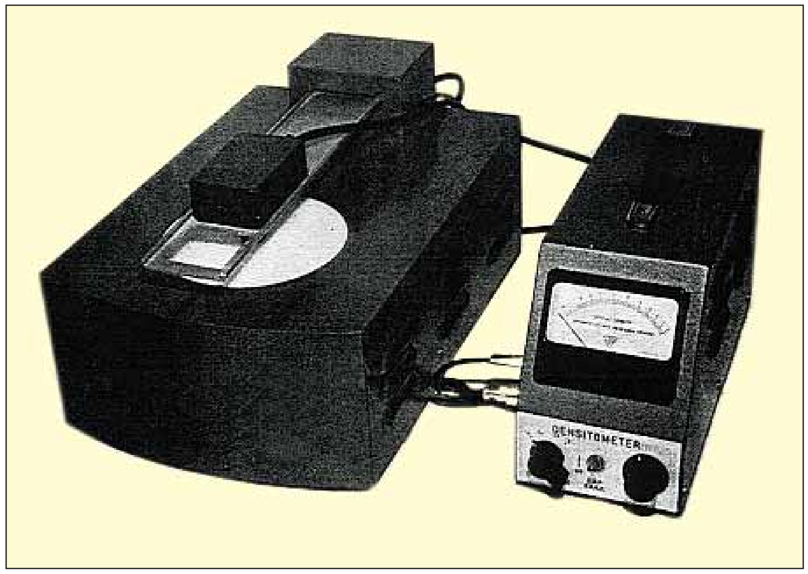
Setting up of Canada India Reactor (CIR), later named CIRUS, in 1957 at Trombay, necessitated a study of the dynamics of the harbour bay for assessing the suitability of

Low level counting equipment used in the early days for measuring small quantities of the fallout of isotope strontium-90 in milk and other food samples

site for effluent discharge. A detailed study was carried out and even before CIRUS became operational, the limits to be followed for radioactive liquid effluent discharge into the bay were established. A meteorological station was set up at Trombay site for providing data for determining the required height of stack for release of gaseous activity into the atmosphere.

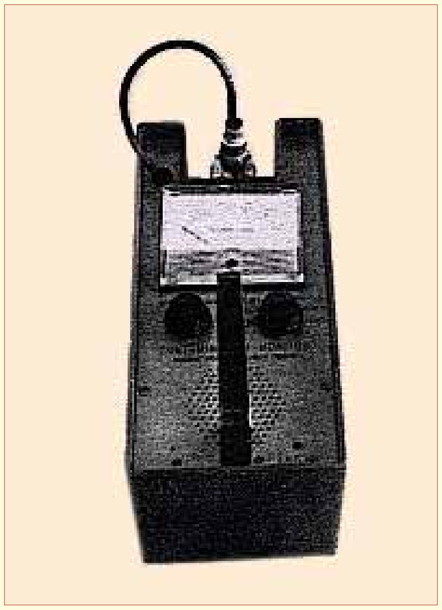
Safety requirements of a bigger reactor like CIRUS needed many more developments such as protective equipment for the safety of crew, development of new instruments for detection and measurement of tritium formed during reactor operation and a whole body counter to scan and assess the amount of radioactive material present in the body. Many of these equipments were developed in-house.

Over the years the emphasis on the type of R&D activities undertaken changed with the demands of the DAE programmes. In the year 1960, after taking into consideration various factors such as seismic activity, population, water supply source, Tarapur was selected as the site for the first atomic power station. For identifying future power plant locations, a Committee was set up in 1961. Meanwhile, Health Physics Divison evolved safety criteria for site selection that recommended a buffer zone of 1.6 km radius as exclusion zone and an outer zone extending upto 5 km radius as sterilization area. It was further recommended that there should not be a town having population exceeding 10,000 within aerial distance of 16 km from power reactors. These recommendations were more exacting than those adopted by other countries.



Densitometer developed at BARC for measurement of optical densities of films used in radiation measurement

The availability of reactors such as APSARA and CIRUS also enhanced use of radioisotopes and radiation technology in areas such as medicine and industry. This necessitated adequate attention for ensuring safety of personnel handling radioactive sources. Following the passage of the Atomic Energy Act in 1962, formulation of rules and regulations for ensuring proper implementation of the provisions for protection from radiation was initiated A Directorate of Radiological Protection (DRP) was set up in 1963 with the responsibility of ensuring safety aspects of facilities outside DAE in the country where radiation was involved. The various tasks undertaken by the Directorate included (a) organization of a countrywide personnel monitoring programme for radiation workers and maintenance of appropriate individual dose records; (b) initiation of appropriate measures in case of excessive exposure to individuals; (c) organization and conduct of radiological protection surveys of institutions using radiation sources; (d) formulation and promulgation of rules and regulations relating to radiation protection; (e) education of radiation workers in the safe use of radiation sources; (f) design and development of radiological instruments and protective devices; (g) setting



Contamination monitor. This portable battery powered monitor was made entirely of indigenous components in 1960's

up of safety standards and publication of radiation safety manuals; (h) research and development on various aspects of radiation measurements and radiological hazards; (i) advising institutions on the layout of radiation installations such as X-ray and teletherapy installations and radioisotope laboratories and on problems relating to transport, storage and use of radiation sources; (j) advising on civil defence measures to be initiated against nuclear attacks; and (k) formulation of appropriate measures in cases of radiation emergencies. One of the notable programmes started by the Directorate in cooperation with World Health Organization was a one year post-graduate course in Radiological Physics aimed at training personnel in the use of radioactive sources in medicine, industry and research and implementing attendant safety measures. This course has ensured availability of a large number of trained personnel in the country for radiation safety requirements. The President of India, exercising the powers conferred by the Atomic Energy Act of 1962, constituted Atomic Energy Regulatory Board on November 15, 1983 to carry out regulatory and safety functions.

Safety-related studies demanded extremely sensitive and sophisticated nuclear electronic instruments for various activities. A variety of such equipments were developed indigenously for meeting the specific needs. These included air monitoring systems, multichannel analyzers, low level counting systems, a microbarograph for detection of nuclear weapon tests and whole body counters. Besides these, research and development activities have remained an integral part of the safety program at DAE for providing a firm basis for setting safety limits as well as providing necessary measurement techniques. One of the important programmes in this direction was development of thermoluminescence (TL) technique for radiation monitoring. The first report on this technique was presented in an international conference on luminescence in 1964 and soon thereafter an indigenous instrument based on this technique was developed.

The first indigeneously developed Thermoluminesence instrument at BARC

Today, the mandate of DAE encompasses the full nuclear fuel cycle ranging from mining to waste disposal. Developments in safety have kept pace with the latest and relevant developments in the associated fields the world over. It is heartening to note that quite often some of the pioneering studies and the programmes initiated at BARC in this field as well as in associated fields became the forerunner for several research activities in other parts of the world. The health, safety and environment programmes covered several topics such as operational health physics, radiation protection services and instrumentation, theoretical and experimental dosimetric studies, radiation shielding calculations, protective equipment, occupational dose monitoring, studies on natural background radiation, global fall-out, micrometeorology, oceanography, aerosol studies, bioassay procedures, biokinetics and internal dosimetric programmes, standardization and quality assurance of instruments and methodologies, tritium monitoring and liquid scintillation spectrometry, solid state nuclear track detection, radon studies, environmental dosimetry, environmental chemistry, radioecology, accident dosimetry, emergency preparedness and epidemiological studies. The Department has also developed a vast reserve of trained manpower to meet the growing demand for radiation safety personnel in the country for the various programmes.

An Overview

Almost all phases of any atomic energy programme require application of stringent radiation safety measures. Extraction and beneficiation of uranium ore, processing and production of nuclear pure uranium, fabrication of fuel elements for use in nuclear reactors, construction and operation of nuclear reactors, handling and reprocessing of irradiated fuel elements, preparation and processing of radioisotopes, use of radioisotopes in a wide variety of applications, and safe disposal of solid, liquid and gaseous wastes that are radioactive, are all operations requiring radiation safety measures.

Safety aspects of radiation are addressed right from the project study stage itself. Radiation hazards that would normally arise in the operation of the project, the worst imaginable hazards that can come about in the unlikely event of an accident, various measures that need to be taken to prevent such accidents, the need for facilities in the neighbourhood for safe disposal of solid and liquid radioactive wastes, the geographical and micrometeorological factors of the proposed site for the project, and the population density and other socio-economic factors in relation to areas immediately adjoining the proposed site for the project are but some of the many factors that are studied in great detail before the site for a proposed atomic energy installation is finalized.

The next phase of a project in which safety experts are called upon to play a crucial role is in the design features of the facility. In this phase of operations, the basic philosophy is to build in as much safety as possible into the structure itself. The design provides many engineered safety features such as shielding, ventilation, amenability for remote operations and while deciding equipment and area layout, radiation safety aspects are also considered for achieving the aim of maximum built-in safety. Health physicists are posted even at the time of cold commissioning of the facility.

Once the construction is complete and the project goes into operation, required number of health physicist are always posted at the facility. All operations involving potential radiation hazards are carefully planned in consultation with the health physicist. The health physicist further ensures that during the operations in question, no situation is allowed to arise which could give rise to internal or external radiation exposure. Furthermore, in order to face the extremely unlikely event of a radiation emergency, emergency procedures are drawn up and practised by the personnel involved down to the minutest detail.

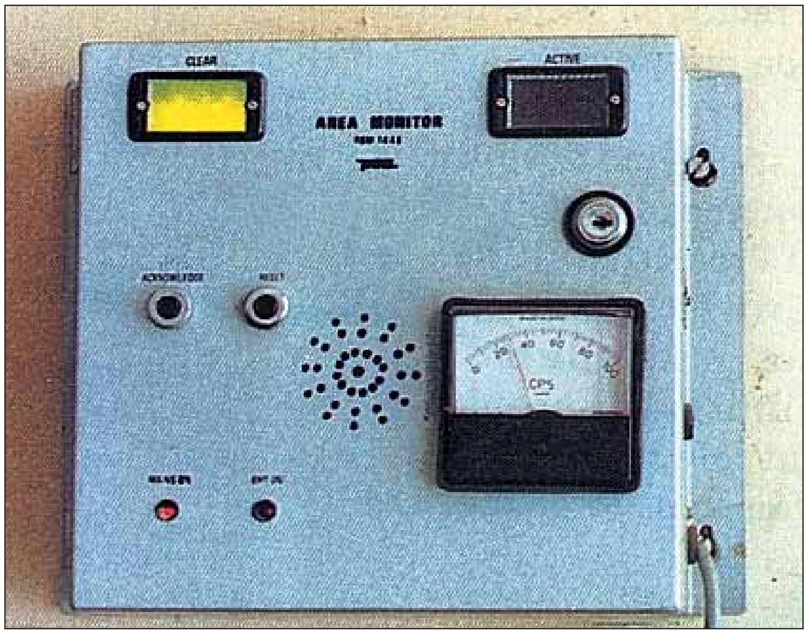
A typical Nuclear Fuel Cycle constitutes,

- Mining and processing of uranium ore
- Fuel Fabrication
- Reactor Operation
- Fuel Reprocessing
- Radioactive Waste Management

A pictorial representation of Nuclear Fuel Cycle having a Pressurized Heavy Water Reactor (PHWR) for power generation (shown as NPP)

At DAE, a comprehensive radiological surveillance programme that takes into account nature of radiological hazards in the facility, has been prepared and is implemented for each facility. The programme includes:

- Assessment of radiological conditions such as radiation level and airborne activity in the plants using area gamma monitors, continuous air monitors and portable survey instruments.
- Prescription of appropriate measures towards effective radiation exposure control of occupational workers.
- Estimation of external and internal dose received by occupational workers.
- Monitoring of radioactive effluents (both liquid & gaseous) released to the environment from the facility.
- Providing technical advice on the implementation of the prescribed measures, control and limit on effluent release (both liquid and gaseous) to the environment and the management of solid radioactive waste.



Area gamma monitor

Ensuring Safety of the Occupational Workers

Safety of the radiation worker is the prime consideration in all operations related to working with radiation sources. This is ensured through the following steps:

- Reduction in radiation levels in working areas
- Prevention of radioactive contamination
- Reduction in individual doses and collective doses
- Use of specific protective gears


Continuous Air Monitor

Individual Dose Assessment

Individual dose can be of two types :

- External dose
- Internal dose

External dose is received by an individual when the source of radiation (e.g. x-rays, ß or neutrons) is outside the body. Following devices are used for measuring external dose:

1. Quartz -fibre direct reading dosemeter (for x,γ-rays and ß radiation) for day to day control of dose.

2. Thermoluminesecent dosemeter (TLD) that uses $CaSO_4$: Dy as the thermoluminesent material for measurement of dose due to x, γ-rays and ß radiation.

3. Semiconductor diode detector for x and γ radiation for day to day control of dose.

4. Solid State Nuclear Track Detector (SSNTD) for fast neutrons.

TLD was introduced for personnel monitoring in BARC, Trombay and TAPS, Tarapur in the year 1975. Slowly other units of DAE were also covered. At present TLD is used for personnel monitoring of external exposure in all units of DAE and in all

Personnel Dose Assessment with TLD in a TLD Laboratory

TLD Badge (left) and Direct Reading Quartz-Fibre Dosimeter (right)

the medical, industrial and research institutions handling radiation sources and radioisotopes in India.

Internal Dose Assessment

Internal dose is received when the source of radiation is inside the body. The techniques for internal dose assessment are:

(i) Whole body counting and Lung counting.

(ii) Bioassay.

i) **Whole body counting**

Whole body counter, incorporating a NaI(Tl) detector housed inside a steel room of 60 tons weight (for reducing background) for detection of various internally deposited gamma emitters, was commissioned in the year 1962.

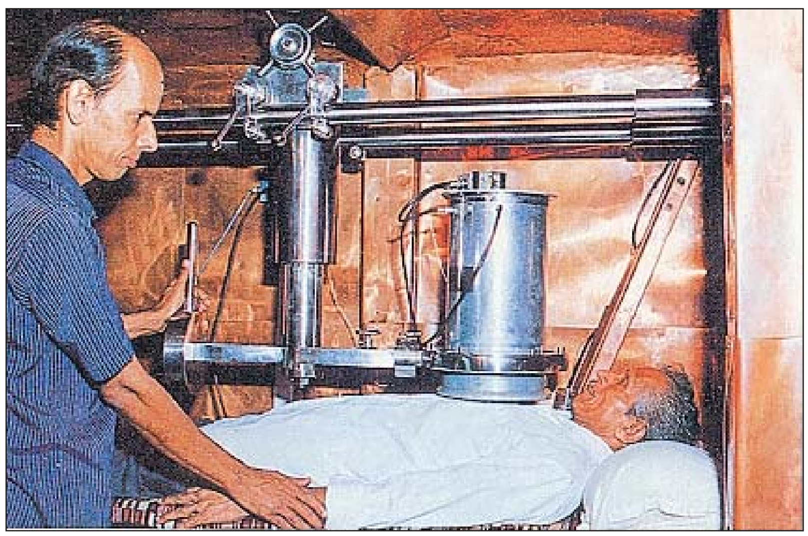
A shadow-shield bed whole body counter having a shielding of about 5 tons of steel and NaI (Tl) detector was commissioned in the year 1967. In this system, linear scanning of the body is carried out by moving the subject along his/her body length below the detector.

- Minimun. detectable activity: 100-200 Bq (for ^{137}Cs, ^{134}Cs, ^{131}I, ^{58}Co, ^{60}Co)
- Measurement time is about 15 minutes

Shadow-shield bed whole body counter

Lung Counting

For assessment of low level actinide deposition (U,Pu, Am) in the lungs highly sensitive detection system having a phoswich or hyper pure germanium detector placed in a 20 cm thick steel room and provided with lining of lead, cadmium and copper is used.



Lung counter

ii) **Bioassay**

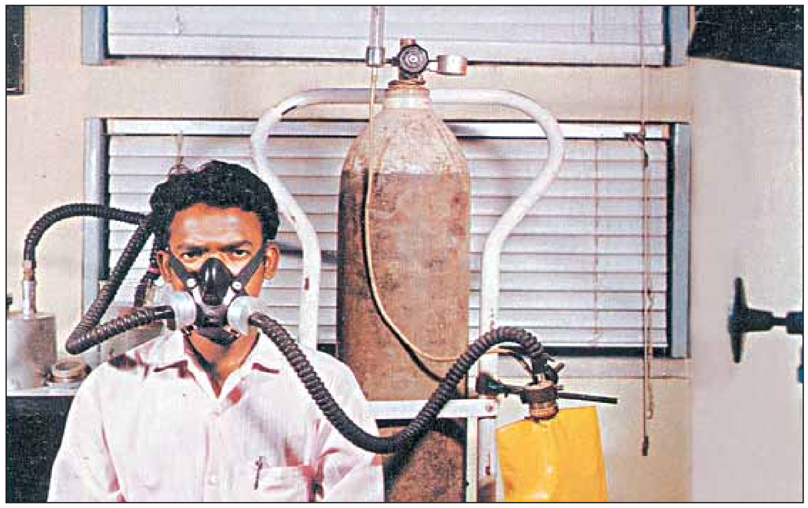
In this technique the daily excretion rate of a radionuclide from the human body through urine or faeces is measured using radiochemical methods. Internal dose is assessed using the measured excretion rate of the radionuclide and biokinetic model for the radionuclide. This technique is generally used for assessing the internal dose resulting from actinides (uranium, plutonium, americium etc.) and pure beta emitters such as ^{3}H and ^{90}Sr.

A view of the Radiochemical Laboratory

Counting room for bioassay samples

Breath Analyser

This technique is used for evaluation of low levels of Th and Ra body burden through Thoron and Radon measurements in breath.



Measurement of radon/thoron in exhaled breath

Radon Monitoring Instrument for Uranium mines/mills

Personal Protective Equipment

While doing work in radioactive areas protective clothing is worn to prevent uptake of radioactive material, skin contamination and spread of contamination to clean areas. A wide variety of protective clothing is available ranging from ordinary laboratory coats to complete vapour proof suits with self-contained breathing apparatus. The degree of protection required depends on the severity of contamination and the nature of the work being done. For work in areas where transferable contamination levels are very high, in wet conditions or in atmosphere containing tritium, plastic suits are used.

Persons working for long periods of time in an atmosphere containing radioactive aerosols wear respirators or air masks. Respirators remove the aerosol from the air, whereas air masks supply clean air either at a positive pressure or as per demand. The air to the mask is obtained from an air manifold, which supplies compressed fresh, filtered air through a regulator. The air mask and some other type of respirator are fabricated indigenously.

A worker with air mask which provides clean air

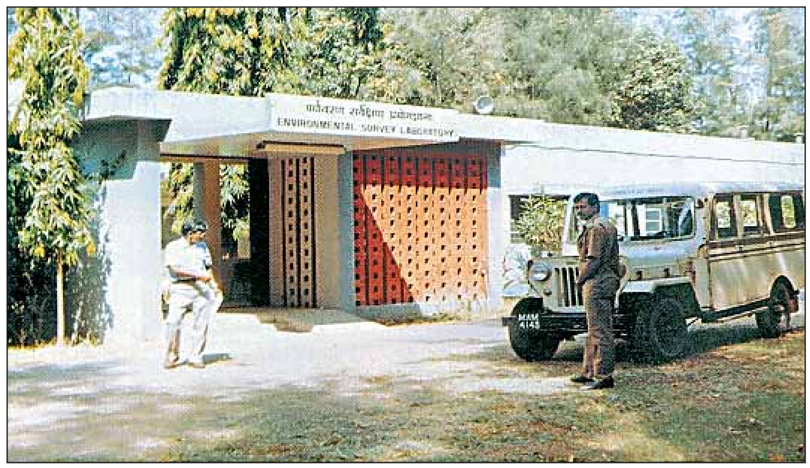
Pressurized plastic suit (frog suit) with hood for use in wet or tritium atmosphere

Ensuring Safety of the Environment Near Radiation Facilities

A well equipped Environment Survey Laboratory (ESL) is established at each nuclear facility site well before the commissioning of the plants. The primary aim of the environmental monitoring programme is to demonstrate compliance with the radiation exposure limits set for members of public. The first ESL was established at Tarapur in December 1964 In pre-operational phase, ESLs generate baseline data on naturally occuring radioactivity in the area, radiation level and radionuclides concentration due to global weapon fallout (Sr-90, Cs-137 etc.). This requires a detailed measurement of these radionuclides in different environmental matrices (air, water, fish, silt, sediment, soil, vegetation, goat thyroid, vegetable, milk, grass, crops, fruits, meat and other dietary items) covering a 30 km radial distance around the plant. The number and type of samples and sampling frequency is optimised for each site depending on the nature of operating facilities, utilization of local natural resources, existence of population clusters and related demographic data. In the operational phase, the ESL continuously monitors the external radiation exposure levels in the environment, measures meteorological parameters and analyses the distribution and concentration of relevant radionuclides in samples of different environmental matrices to assess the contribution, if any, from the plant releases.

Environmental survey laboratories are established at:

- BARC, Trombay
- UCIL, Jaduguda
- TAPS, Tarapur
- RAPS, Rawatbhata
- MAPS, Kalpakkam
- NAPS, Narora
- KAPS, Kakrapar
- KGS, Kaiga
- KK Power Project, Kudankulam



First Environmental Survey Laboratory, Tarapur set up in 1964

Meteorological measurements are made using either a tower on which instruments are installed or using Sound Detection And Ranging (SODAR), a ground based remote sensing technique that:

- Probes the atmosphere upto a height of about one kilometer.

- Provides basic meteorological data at user selected heights and time intervals.

SODAR data coupled with numerical modelling can be used for:

- Realistic predictions of environmental concentration doses of pollutants from routine or postulated accident atmospheric releases,
- Dispersion over complex terrain sites, and
- Evolving effective site emergency plan during accident scenario

Experience of extensive environmental monitoring has shown that even a hypothetical individual staying at plant exclusion boundary (1.6 km) will receive only about 8% of dose limits (1 mSv/y) for members of public, in case of Tarapur Atomic Power Station and Rajasthan Atomic Power Station. This would be even lower and less than 1 % in case of Narora Atomic Power Station, Kakrapar Atomic Power Station, Kaiga Generating Station, and RAPS 3 & 4 due to improved design features. At distances greater than 1.6 km, the doses to the members of public continuously get reduced and are insignificant compared to doses received from natural sources.

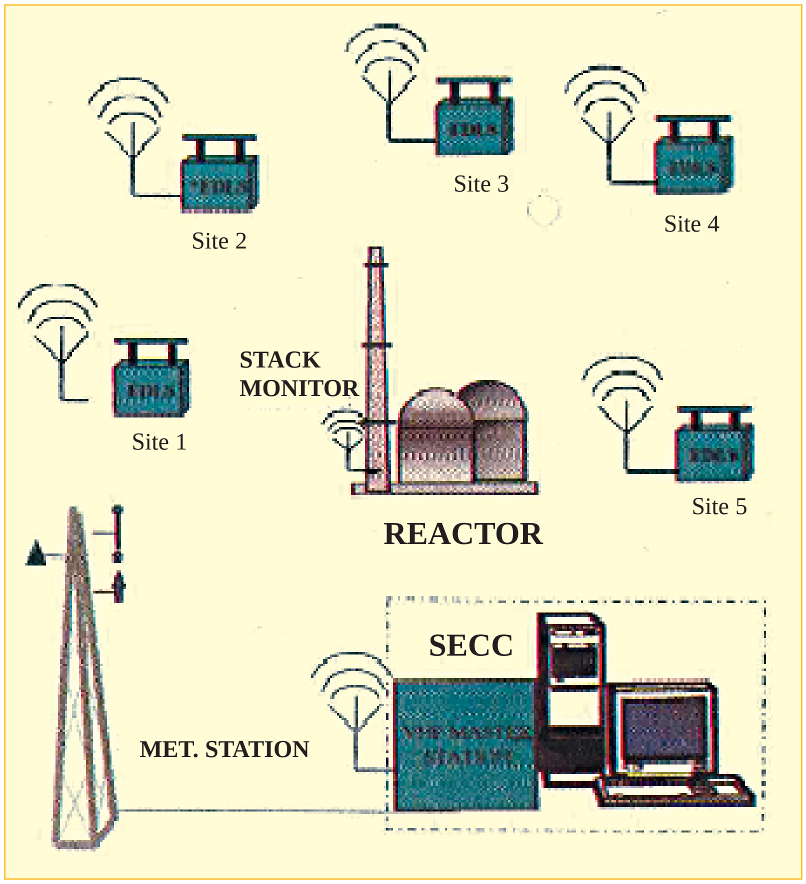
Emergency Preparedness for Nuclear Installations

Site Emergency Control Centre (SECC) is the nodal point for all decisions / actions during radiation emergency. Following facilities are available at the SECC:

- Radiation emergency warning system,
- Online computation and prediction of affected area and progress of radioactive plume using atmospheric dispersion models to initiate appropriate countermeasures,
- Radiation monitoring instruments, protective equipments and KI/ KIO_3 tablets,
- Mobile radiological monitoring vehicle, and
- Medical decontamination centre (attached with hospital/ dispensary).

Radiation Emergency Early Warning System

- A network of environmental radiation monitors is deployed around a nuclear site e.g. a nuclear power plant and linked to the SECC with VHF telemetry
- Data transmitted to SECC is processed on-line along with site meteorological data to project graphically the radiological status of the site.
- It provides sufficient technical inputs to the authorities for planning effective strategies to combat radiological emergencies.
- Analysis of the data can provide insight into the possible source term



Environmental Dose Logging System

Regulatory Framework

DAE has a strong regulatory framework to ensure safety. Earlier , in addition to providing radiological safety services and surveillance to various facilities in the Department, Health Physics Division of BARC was entrusted with the responsibility of carrying out regulatory functions also. After the formation of DAE Safety Review Committee (DAE-SRC) in September 1973, the regulatory functions were entrusted to DAE-SRC. Subsequent to that, Atomic Energy Regulatory Board (AERB) was constituted on November 15, 1983. The mission of the Regulatory Board is to ensure that the use of ionising radiation and nuclear energy in India dose not cause undue risk to health and environment.

The functions of AERB are to :

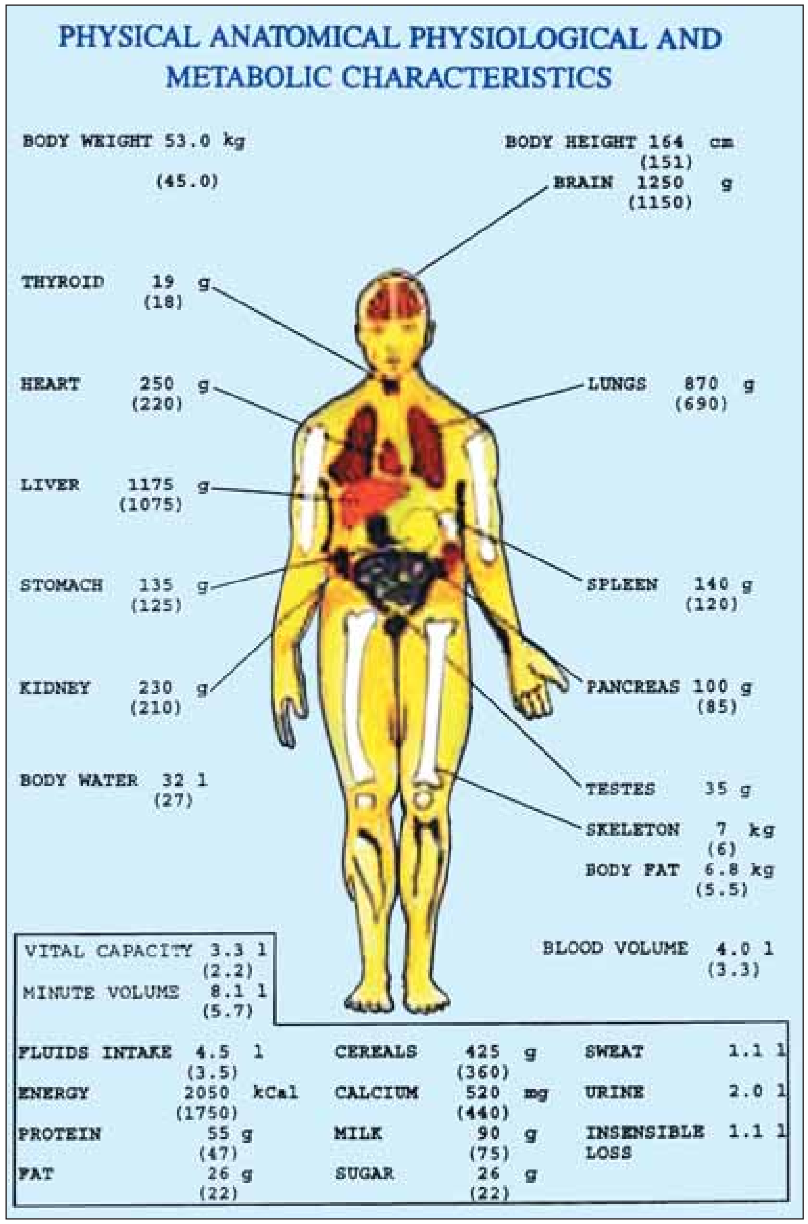
- Enforce rules and regulations promulgated under the Atomic Energy Act, 1962, for radiation safety in the country and under the factories Act, 1948 for industrial safety in the units under the control of DAE,
- Develop safety codes , guides and standards,
- Ensure compliance by DAE and non-DAE installations of safety codes and standards,
- Review, from the safety angle, for the purpose of authorising, commissioning or operation of DAE projects and plants,
- Review operational experience in the light of radiological and other safety criteria,
- Prescribe acceptable limits of radiation exposure to occupational worker and the members of the public and acceptable limits of environmental releases of radioactive substances,
- Carry out safety related research at AERB Safety Research Institute based at Kalpakkam and promote R&D efforts at other academic and research institutions through award of safety related research projects,
- Review the training programme, qualification and licensing policies for personnel of the projects and plants,
- Prescribe the syllabi for training of personnel in safety aspects at all levels,
- Maintain liaison with statutory bodies in the country as well as abroad regarding safety matters, and
- Keep the public informed on major issues of radiological safety significance.

There are Project Design Safety Committees (PDSC) to review the projects from the angle of safety. Also, there are safety committees at various levels for operating plants and the safety issue are reviewed by appropriate safety committee depending upon safety significance of the issue.

Special Studies and Systems

Bio-Kinetics of radionuclides and Reference Indian Man

On the basis of weighted mean data representative of the Indian population, physical, physiological anatomical and metabolic parameters are determined. These data are useful in determining the secondary or derived radiation protection standards for an Indian Reference Man (Male & Female).

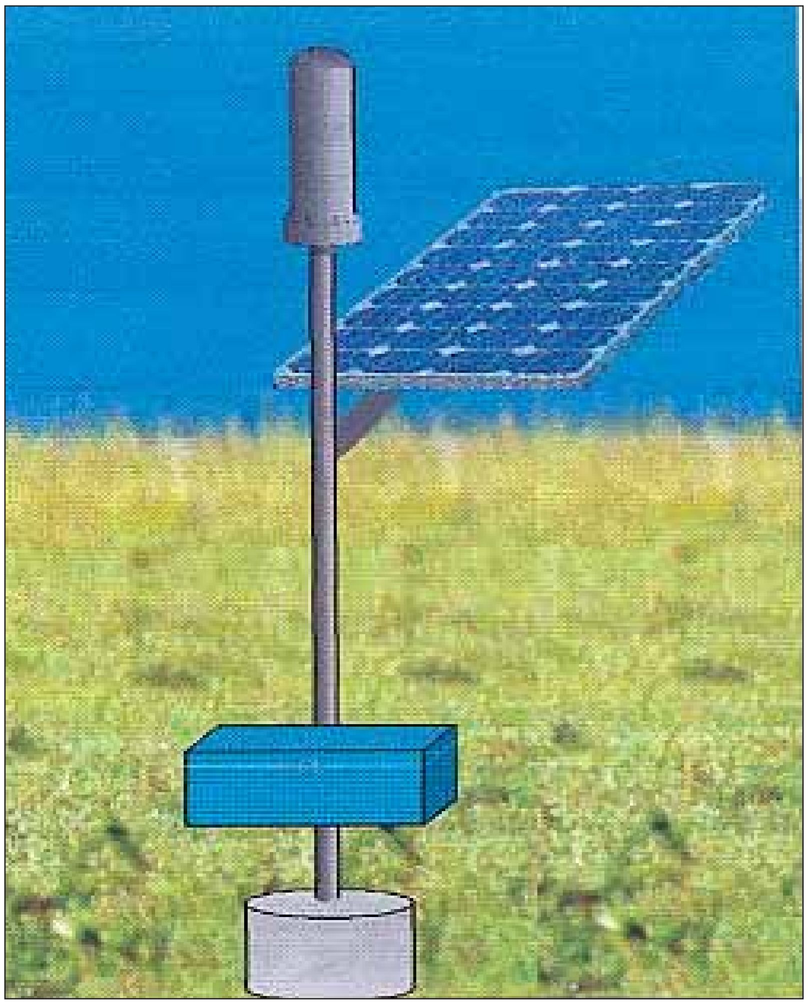


Indian Reference Man Data (Numbers in parentheses are for female)

Environmental Radiation Monitoring

Indian Environmental Radiation Monitoring Network (IERMON)

The first station was setup in the year 1956 in Mumbai and by 1969 the network was extended to 18 stations for regular measurements of radioactivity in air borne particulates, surface deposition and milk. WHO and UNEP jointly promoted the Global Environmental Radiation Monitoring Network (GERMON) programme. India was a member country and a member of scientific advisory committee of GERMON. The Indian GERMON was renamed as IERMON with effect from April, 2002. The IERMON network presently consists of 37 monitoring stations.The Environmental Radiation Monitor (ERM) was developed and manufactured at Environmental Assessment Division, BARC. The minimum detection level of ERM is about 5 μR/hr (50 nGy/hr) and its sensitivity is adequate to detect small changes in environmental radiation levels.



Solar-powered Environmental Radiation Monitor with wireless data communication

Objectives of IERMON

The objectives of IERMON network are to provide on-line information about radiation levels at various stations to the emergency control rooms of DAE to facilitate environmental impact assessment of nuclear emergencies and to demonstrate compliance with regulations on environment . Another important aspect that would be established through IERMON is the background environmental radiation levels across the country and to create a new radiation atlas of the country at district level. This programme is helpful in studying diurnal and seasonal variations of radon across the country and to explore various applications of radon research. Some of the other objectives of the programme are:

- To monitor the long term shift in the background radiation levels,
- To study redistribution of natural and man made radionuclides in the environment,
- To provide knowledge based environmental awareness to the public through participation of universities and other educational institutions,
- To facilitate R&D on new techniques and methods for environmental monitoring, and
- To develop and validate mathematical models for atmospheric dispersion of radioactive pollutants for short, medium and long ranges.

Average Individual Annual Radiation Exposure from Natural Sources (in μSv)	
Cosmic Rays	390
Gamma Rays (Earth's Crust)	460
Radon and Thoron	1300
Internal (Mainly Potassium)	230
Total (rounded)	2400

Aerial Gamma Spectrometry System

This system was commissioned in the year 1992 for quick assessment of radioactive contamination over a large area. It is an essential tool for emergency preparedness to quickly assess the contamination and decide on counter and control measures that can be quickly deployable in any vehicle and air craft. An integrated multi-input mobile spectrometer with simultaneous acquisition of 3D positional provides inputs through global positioning system (GPS). It maps the level of contamination on digitised maps of the area being surveyed. The data can be transmitted on-line to a ground control centre and minimum detection limit for ^{131}I is 40 kBq/ m^2 and for ^{137}Cs it is 24 kBq/m^2 from an altitude of 80 metres.

Environmental Radiation Monitor with Navigational Aid

An environmental radiation monitor deployable in a vehicle or railway coach for radiation background mapping has been developed. It simultaneously acquires environmental dose with 3 D positional coordinates using GPS and off line processing of data provides radiation dose levels mapped in colour codes on route map of the surveyed area. The system can be utilised to search lost radioactive sources.

Radon/Thoron Monitoring and Calibration Facility

It consists of a twin-cup dosimeter based on Solid-State Nuclear Track Detectors (SSNTDs) developed for the measurement of environmental radon/ thoron exposure to general population. The system is passive, non-intrusive and rugged. Alpha tracks recorded on the SSNTDs provide information on radon gas, thoron gas and progeny concentrations. Calibration facility has been set up with provisions for on-line monitoring of radon/thoron concentrations for the calibration of the dosimeters.

Optically Stimulated Luminescence Studies

Infra-Red Stimulated Luminescence studies in samples containing quartz and feldspar are being conducted for accident dosimetry, geological dating (e.g. for sand samples from Thar desert) and surface dose mapping.

Aerosols

Aerosols studies are important for development of instrumentation for aerosol measurements, characterising environmental and workplace aerosols and basic studies on the underlying physical processes. Nebuliser based aerosol generators have been developed for use in diagnostic and therapeutic applications such as radio lung imaging. The studies also include nucleation in binary systems as H_2O-H_2SO_4 formation of radiolytic nuclei, simulation of aerosol behaviour and transport in reactor containments under postulated accidental conditions in a test facility and special effects of electrical charge on particles in radiation environments.

Monazite Survey Project

Dosimetric measurements are being carried out as a part of the ongoing epidemiological studies in the Natural High Background Radiation Areas (NHBRAs) of Kerala. The project involves estimation of external gamma (using TLDs) and inhalation doses (using twin-cup radon/thoron dosemeters) in the dwellings and outdoor regions. The survey is being carried out in quarterly cycles for 100 houses in a year.

Environmental Modelling

In order to assess the effect of radionuclides form nuclear reactor on the environment, atmospheric and hydrogical modelling studies are regularly undertaken.

Atmospheric Modelling-Studies

- Three dimensional complex terrain model for environmental impact assessment with respect to routine releases of radioactivity into the atmosphere from nuclear reactors.
- Particle trajectory model-for computing the concentration of radio nuclides and corresponding gamma dose on a spatial and temporal scale.
- Land Sea Breeze Model-for obtaining the sea breeze/land breeze circulation over plain terrains.
- Gaussian Plume Model- for evaluation of atmospheric dilution capacity in and around nuclear reactors, stack height and radiological impact due to routine and unplanned radioactivity releases.

Hydrological Modelling

- For long-term safety assessment of radioactive disposal facilities as well as radioactive liquid effluent release practices over the hydrological domain.
- The Continuous River Release Model and the Continuous Coastal Release Model- for evaluating the impacts of routine releases of radioactive liquid effluents and sewage.
- Shallow Land Burial Model and Risk Evaluation Model for Safety Assessment- for assessing the safety performance of near surface radioactive disposal mode taking into account the type of disposal facility and geohydrology of the site.
- Deep Geological Repository Model- migration of radio nuclides from vitrified high level radioactive waste disposal in geological repositories.

Radiation Standards

The measurement of radiation-- its type, energy and intensity-- is of utmost importance to provide protection to the radiation workers and members of public.The Radiation Standards Section, Radiation Safety Systems Division, BARC endeavours to fulfill these objectives. The Section is the apex centre of the national measurement network. It maintains number of national standards and continuously updates them to achieve better accuracy. These standards include primary standards like 4 π-$\beta\gamma$ coincidence system, free air ionisation chamber, manganese sulphate bath assesmbly and reference standard such as Fricke dosimeter. Using these standards various types of dosimeters, radiation monitors, radiation sources etc. are calibrated. BARC provides standard radiation fields and calibration services for users in the fields of medicine, industry, agriculture and research. It caters to various requirements of defence establishments also. It also co-ordinates to standardize the radiation measurement facilities of different laboratories/hospitals in the country and ensures the traceability of these measurements to the National Standards.The availability of radiation standards plays a pivotal role in ensuring accurate radiation measurement as per the international health, safety and regulatory requirements.

4π-β,γ Coincidence counting system

Radiation Monitor Calibration Facility

Human Resources Development for Radiological Protection

Training perhaps constitutes the most important aspect of the radiation safety programme as the success of the country wide radiation safety programme can only be ensured through the trained manpower committed to implement all aspects related to the safety. To achieve this important need, a number of training courses of various duration are conducted to meet the different requirements. These include:

- Diploma in Radiological Physics
- Training Course on Radiation Protection
- Training Course on Food Irradiation Facilities

- Diploma in Radiation Medicine
- Diploma in Medical Radio-Isotopes Technology
- Training Programme on Planning and Preparedness for Radiological Emergencies
- RIA Training Course
- IAEA & IAEA/RCA Courses
- Radiation Safety in Diagnostic X-ray
- Radiation Safety on Quality Assurance in Diagnostic Radiology
- Radiation Safety Aspects in Servicing of Radiotherapy Equipment
- Radiation Safety for Radiation Therapy Technologists
- Safety Aspects in the Application of Radioisotopes in Research
- Industrial Radiological Safety Officer
- Refresher Course for Industrial Radiography Site-in-charge
- Radiography Techniques Level –1&2
- Radiation Safety Aspects for High Intensity Irradiator Safety-in-charge
- Radiation Safety Aspects on Nucleonic Gauges
- Radiation Safety in Gaseous Tritium Light Sources
- Radiation Safety in Radio luminous Paints
- Radiation Safety for Transport Carriers of Radioactive Material.

Summary

Radiation safety has been one of the most important aspects of the work at DAE since its inception. While expanding India's atomic energy programme and use of radiation sources all over the country, it has been ensured that stringent radiation safety requirements that go with such a programme, are fully met. In DAE, compliance with the dose limits given by the Atomic Energy Regulatory Board is carried out in letter and spirit. This,along with specially trained manpower to provide safety related services, surveillence and necessary research and development support, has ensured very high standard of safety in DAE installations in the country as envisaged by Dr. Bhabha in his order dated February 27,1960. India is at the second stage of its three stage nuclear energy programme. Prototype Fast Breeder Reactor (PFBR) for power generation, Advanced Heavy Water Reactor (AHWR), and Accelerator Driven System (ADS) will come in future. These facilities will pose new challgenges to the radiation protection professionals. Having excellent track record and committment to the profession, they are confident of meeting the challenges succesfully.