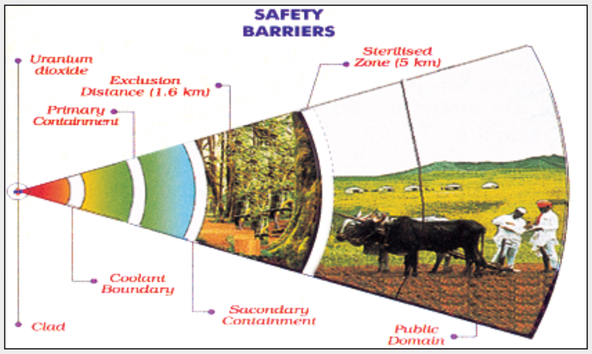

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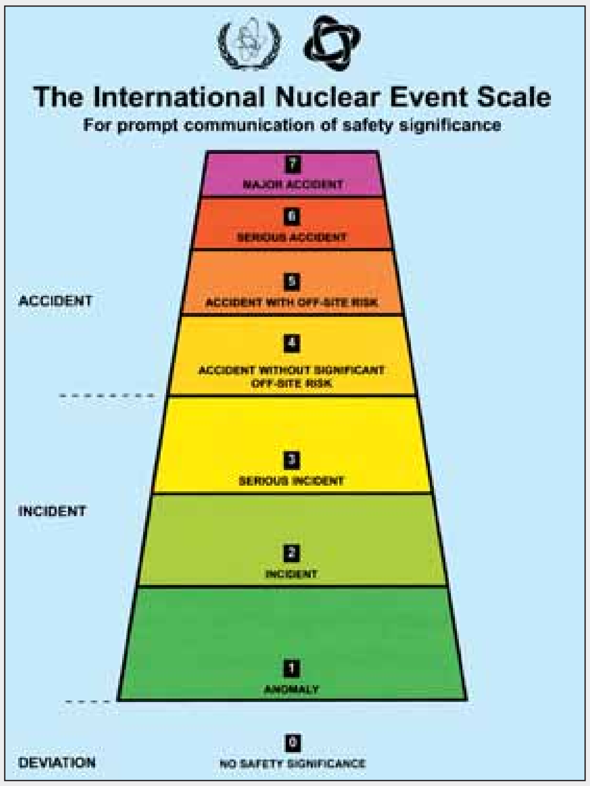
Chapter 7

Environmental Aspects – Radiation and Safety



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Department of Atomic Energy
Golden Jubilee Year
August 2003 - August 2004

Captions for Photo-Collage

1. *Illustration of defence in depth in a nuclear reactor. Several barriers exist between the fuel and the public domain.*

2. *Tritium sampling being carried out by Environmental Survey Laboratory (ESL) in the vicinity of PHWR plants.*

3. *Collection of water samples in the vicinity of the nuclear plant for radiation monitoring.*

4. *Sample of local vegetable being collected as part of the routine environmental monitoring programme around nuclear plants.*

5. *International Nuclear Event Scale (INES) was introduced in march 1990 to facilitate communication among the nuclear community, media and public on events occurring at civil nuclear installations. It is designed to provide prompt, clear and consistent information on nuclear events occurring at a nuclear installation. In a grade of 7, only events above 4 have public concerns and are classified as accidents.*

6. *Whole body counting of personnel working in nuclear plants to regulate the dose limits much below the international safety guidelines.*

Radiation and Safety

Nuclear power has established itself as a dependable, safe, economically viable and environmentally benign source of electricity. In India, the concern for safety has been deep rooted in DAE beginning right from planning, design and site selection to construction, operation and safety evaluation of nuclear power plants (NPP). The primary safety requirement of the nuclear power programme is protection of the operating personnel, public and the environment from potential hazards of radiation. Specifically, nuclear safety calls for prevention, by built-in design features, of accidents which are likely to lead to release of radioactivity, establishment of proper operating conditions through constant surveillance of all components and mitigation of consequences of any accident, should it occur, through implementation of emergency preparedness plans.

> "*Radioactive material and sources of radiation should be handled in Atomic Energy Establishment in Trombay in a manner which not only ensures that no harm can come to workers or anyone else, but should be done in an exemplary manner so as to set a standard, which other organizations in the country may be asked to emulate*".
>
> ***- Homi J. Bhabha***

There are continuous efforts for improving the economics and operational efficiency of nuclear installations. Here again, safety is accorded prime importance and this has influence on the design of the systems as well as their operational methodologies.

While the above are the objectives set for themselves by the designer/operator of nuclear installations, there are also criteria and standards prescribed by regulatory authorities to be followed uniformly by all design and operating groups. From 1948, to this date, the approach to safety has evolved in the country from a scheme of self-regulatory approach by the Department to the present status of institutionalisation and independent regulation by the Atomic Energy Regulatory Board (AERB).

Homi Bhabha often stressed the importance of a professional approach to achieve high level of safety. True to his vision, the Atomic Energy community in India has shown the path for a systematic and comprehensive approach in many areas of safety.

Siting of Nuclear Installations

Safety considerations for all nuclear installations begin with the process of site selection. Basic siting criteria are laid down to ensure that operations at the site do not introduce radiological or other risks of unacceptable magnitude. The first among these is the requirement to provide an exclusion zone immediately around the installation entirely in control of the installation. No public habitation is to be permitted in this exclusion zone. Also, suitable measures are taken to ensure that there is no large increase in population, beyond natural growth, in a region beyond the exclusion zone. This region is currently defined as the sterilised zone in India. According to the criteria prevailing at present, the exclusion zone extends to 1.5 km around a nuclear power reactor and the sterilised zone extends to a distance of 5 km from the reactor.

The second criterion prescribes limits for any radiation exposure to the general population that may arise, during normal operation as well as under specified accident situations. A comparison with other countries reveals that there is considerable conservatism built into the Indian criteria.

The siting process involves careful evaluation of the characteristics of the candidate sites, like population density, topography, geology, seismology and meteorology, accessibility, infrastructure availability, construction facilities, availability of power supply, transmission lines and cooling water availability.

Specifically, aspects examined in detail during site selection of nuclear installations are:

- Effect on the installation by external events (natural and man-induced) and its likely implication in radioactivity release
- Effect on site environment and population due to anticipated accidents in the installation
- Factors affecting implementation of emergency measures to mitigate risks to the general population

Data from geological, geophysical, seismological and geotechnical investigations are collected and analysed to

Environmental Radiation Dose (μSv/y); (AERB Dose limit 1000 μSv/y)

Distance (Km)	Tarapur (1990-2003)		Rawatbhata (1990-2003)		Kalpakkam (1990-2003)		Narora (1990-2003)		Kakrapar (1994-2003)		Kaiga (2000-2003)	
	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
1.6	15.6-54.4	31.3	0.7-134.9	51.96	7.2-59.4	30.9	0.79-3.85	1.83	0.96-6.09	3.37	2.39-4.39	3.22
1.6-4.8	4.2-18.5	7.25	0.5-65.8	25.65	3.8-22.7	12.84	0.78-2.09	1.20	0.96-4.28	2.30	3.14-3.75	3.44
4.8-8	1.74-7.9	4.62	0.5-25.1	10.34	1.8-9.3	5.23	0.73-1.18	0.86	0.96-2.92	1.97	2.39-2.53	2.46
8-16	0.9-3.5	1.74	0.4-10.5	4.73	1.1-3.1	2.17	0.59-0.95	0.75	0.86-2.71	1.83	1.92-1.99	1.95

assess hazards due to earthquakes. The site is also assessed for hazards due to extreme meteorological phenomena such as high winds, precipitation, snowfall and temperature, potential missile hazard associated with high winds and tropical cyclones and flooding hazards and potential for shoreline instability.

SAFETY IN DESIGN

Engineered Safety Features in Nuclear Reactors

Nuclear power is considered as an environment friendly energy resource largely on the merit of design and technology in construction, operation and maintenance of the reactors. The reactor design is based on the 'defence-in-depth' concept. The first level of defence is a high degree of conservatism in the design of all the components and systems. The second level of defence is provided by the highly reliable means to detect, intercept and control deviations in normal operation. Accordingly, safety sensors and control mechanisms are provided in multiple sets to achieve redundancy. A further measure of safety is introduction of diversity in the principles of their operation to avoid possibility of simultaneous failure of all safety systems due to the same cause. Likewise, independence and physical separation of safety sensors and control mechanisms is also insisted upon. The third level of defence is achieved through provision of multiple barriers to prevent release of radioactivity to the environment in the unlikely event of an accident. Over and above these, emergency preparedness plans for protection of the general public are formulated and tested for ready implementation in case of significant environmental release of radioactivity.

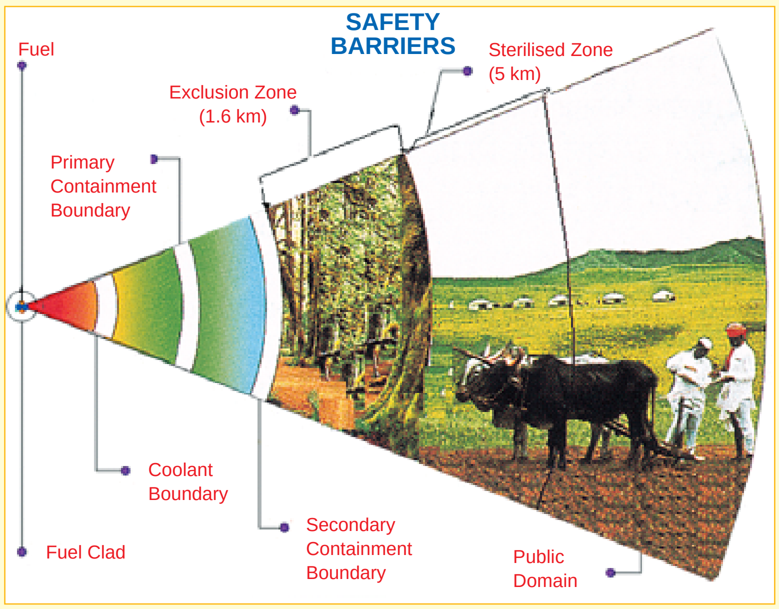


Illustration of defence in depth in a nuclear reactor. Several barriers exist between the fuel and the public domain. The fuel matrix prevents release of fission products to fuel element cladding. The fuel clad prevents its release to the coolant of the primary heat transport circuit. The primary circuit prevents the release of fission products to inner containment that does not allow its release to the outer containment. The outer containment is the final barrier to release fission products to the environment through an exclusion zone. The exclusion zone and sterilized zone act as additional protection

First Level of Defence

The course of events during operational transients and accidents in PHWR involves complex single-phase as well as two phase thermal hydraulic phenomena like flow coast down, thermo-syphon, blow down, reflux condensation, rewetting etc. To understand these complex phenomena, experimental facilities for integral system behavior experiments are set up, closely simulating the PHT systems and the associated components of secondary system of Indian PHWR. For avoiding catastrophic failures, a well considered material selection and design basis is essential. One phenomenon that might work against leak before break (LBB) is the reduction in fracture toughness due to cyclic loading experienced during an earthquake. The cyclic loading during earthquake can also lead to a phenomenon called ratcheting, in which, a pipe under the action of constant internal pressure and cyclic bending moment bulges and fails due to this incremental deformation. Detailed analytical as well as experimental studies are carried out to understand and account for the same in design of nuclear components.

Second Level of Defence

To assure safe shut down of the reactor under all conditions, two fast acting, independent and diverse shut down systems are provided. The diversity is ensured over the entire system covering sensors, logics, drive mechanisms and absorber rods to make the system fail-safe. Each system is designed to limit its unavailability to less than 10^{-3} years/year. The systems are designed to effectively shut down the reactor in a very short time.

A special feature of nuclear reactors is that they continue to produce heat, called decay heat, even after the plant is shutdown and fission chain reaction ceases. It is thus a very important design consideration to remove the decay heat effectively to prevent overheating of the fuel. In the Fast Breeder Reactor (FBR) being constructed at Kalpakkam, when off-site power is available, decay heat is removed by the normal heat transport path of primary and secondary coolant systems and operational grade decay heat removal system incorporated in the steam-water circuit. In case of non-availability of this path because of absence of off-site power, decay heat is removed by the class I safety grade decay heat removal system.

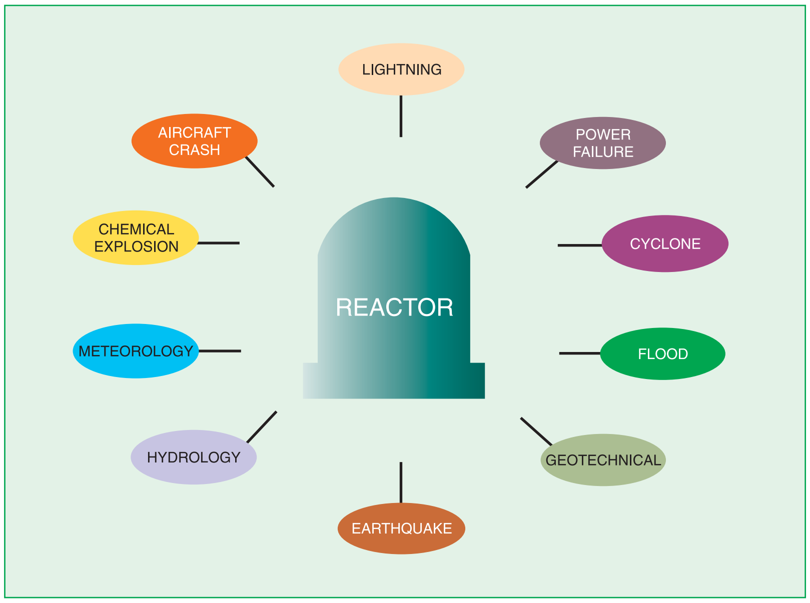
Technologies have been developed for periodic assessment by non-intrusive vibration diagnostic technique and in-service inspection of coolant channels in PHWR reactors using semi-automated BARCIS equipped with semi-automated ultrasonic or eddy current flaw detectors.

The dictionary meaning of “accident” is an unexpected event. A unique feature introduced by the nuclear industry, and later adopted by the chemical industry also, is to perform a detailed safety analysis in which a series of anticipated accidents, of graded severity, is identified and the consequences examined to lead to a suitable design of the system so as to avoid health effects to public and environment. It is customary to base the gradation on the estimated probability of occurrence of the accident. From among these accidents, those with a specified probability level are designated as Design Basis Accidents (DBA) and serve as a reference set for the purpose of meeting the exposure limits. Other accidents that may be more severe but have a much lower level of probability are defined as Beyond Design Basis Accidents (BDBA). These are also examined and serve as a basis for formulation of the emergency preparedness plans. The accident situations to be analysed are broadly classified as those arising from external causes like earthquakes, cyclones etc and others that could occur due to failure of equipment or operator error within the plant.

External Events

Earthquake Resistant Reactor Design

Earthquakes are among the more important natural hazards to be considered in the design of nuclear installations. There are siting criteria, relating to seismicity or earthquake proneness of the location, that have to be met in selecting a site for a nuclear power project. These criteria determine if a candidate site is suitable at all. For the sites eventually selected, these criteria stipulate a basis for design of the structures and components to withstand the earthquake of maximum severity to be expected at the site. Various international codes like ASME (American Society of Mechanical Engineers), IEEE (Institution of Electrical and Electronic Engineers), ASCE (American Society of Civil Engineers), ANSI (American National Standards Institute) etc., are used in the design of Nuclear Power Plants against earthquakes. All the reactors constructed in India since 1975 as well as those now under construction



Various external factors to be taken in to account for reactor design

(500 MWe PFBR and 1000 MWe VVER reactors) are designed to withstand the earthquake loads expected in the respective regions.

Seismic design requirements of nuclear power plants are more stringent compared to those for conventional structures. Nuclear power plants are designed to withstand two major levels of earthquake. The first level includes an earthquake that may be infrequent (once in 10,000 years) but severe enough in intensity. The reactor design should be so as to result in safe shutdown of the reactor, if such an earthquake occurs. This is referred as the Safe Shutdown Earthquake (SSE). The structures, systems and components required to shut down the reactor are to be so designed to remain functional in the event of an earthquake of a magnitude equivalent to the SSE occurs. Some damage and deformation beyond elastic limits may occur and subsequent operation may not be possible without repair or replacement of some components. But, even in such a scenario the reactor should be capable of being shutdown and to be maintained in a coolable geometry and to ensure that there is no radiation exposure to operating personnel as well as to public. For this, essential systems that perform the safety functions of shutdown, heat removal and plant monitoring should survive the earthquake.

The second level corresponds to more frequent, but less severe earthquakes. The components and structures of the reactor are to be designed to operate normally in the event of such earthquakes and so this category is known as the Operating Basis Earthquake (OBE). The design should be such that seismic vibrations due to this category of earthquake may result in deformation of structures but should be within elastic limits and functional maintainability for subsequent operation should be available. Reactor containment structure, reactor core etc., are designed for this category. The seismic event of this intensity can be reasonably expected to be experienced at the site once during operating life of this plant.

"… Going down memory lane, I recall the first interaction of Department of Earthquake Engineering, University of Roorkee, with the DAE, in a meeting held at DAE design office where Mr V.Ramachandran sketched a diagram with earthquake studies at the centre of various elements in relation to Narora atomic power plant design, while highlighting the critical importance of seismic safety for all the elements. That was a statement that made us proud that we are being put at such a high pedestal in the structural safety ladder. That day onwards, the Department of Earthquake Engineering became, so to say, a comrade-in-arm with DAE.......... It was a stage that in most cases we had to develop dedicated softwares ourselves in each case. There was a lot of brain storming and learning together, raising the knowledge base of both the organisations. During these discussions, there were many occasions of meeting with manufacturing industries personnel also, involved in complicated equipment design of calandria, end shields, boilers, etc., wherein seismic analysis was also needed. Such multi-purpose discussions greatly enriched our quest for deeper understanding of the linear elastic, non-linear elastic and inelastic dynamic analytical refinements.

On the whole, I may say that interaction of Department of Earthquake Engineering with DAE benefited greatly not only the two organisations, but also made the country self-reliant in earthquake engineering analysis and design of all structural systems from the simplest to the most complex one…"

- Prof A.S.Arya

National Seismic Advisor, Ministry of Home Affairs, The major effects of an earthquake are related to vibrations induced in the structures, systems and components of the reactor. The damage potential is due to excessive stresses and deformations in structures. It depends on the magnitude of the earthquake and the distance at which it occurs. The presence of fault lines, if any, close to the nuclear power plant also influences the probability and damage potential of the earthquake. It has been observed that earthquakes of magnitudes greater than 5 on Richter scale produce damaging ground motions. It is satisfying to observe that, in 2001, the two Kakrapar power stations in Gujarat continued to operate normally, when an earthquake of magnitude 7.9 struck Bhuj, 500 km away from the reactor. This earthquake was felt at two other nuclear power plants in India viz., Narora in Uttar Pradesh and Rawatbhata near Kota in Rajasthan. However, the level of vibration experienced at these locations was much below the level for which these plants are designed. The post-earthquake inspections of these plants indicated that the distress observed in plants is very minor in nature and that too in non-structural elements. This shows unambiguously that the earthquake resistant design and construction of NPPs are well established and have enough margins to ensure adequate safety.

Over the years, expertise has been developed at Nuclear Power Corporation of India Limited, Bhabha Atomic Research Centre, Indira Gandhi Centre for Atomic Research, and prominent educational institutes and research laboratories in the country in the area of seismic design and analysis. The civil structures are analysed by performing a response spectrum analysis using a finite element technique. However, many equipment are quite complex for application of an analytical approach, for example, the primary shutdown systems, reactor control systems, the electrical and instrumentation panels. The qualification of such complex mechanical, electrical and instrumentation devices may not be possible by analysis alone to demonstrate their functional operability during an earthquake. The problem is addressed by mounting and testing critical parts of these systems on a shake table to demonstrate functional operability of the active devices. Motion identical to acceleration time history at the base of equipment during an anticipated earthquake is given to the shake-table and functional performance is monitored during the table motion. If it fails to perform the intended function, the equipment is reviewed and strengthened accordingly. Developments are also underway to use passive seismic response control devices such as isolators, energy absorbers of elasto-plastic type, lead extrusion type, friction type, etc to achieve protection against earthquake induced damage at lower cost. The main purpose of the base isolation devices is to attenuate the horizontal acceleration transmitted to the superstructure. This may result in damage only to the isolation system, which can be replaced, if necessary. The passive devices can, in fact, be retrofitted in existing reactors.

Protection Against Floods

Nuclear power plants are generally located near rivers or on the sea coast. This warrants close examination of the likelihood and severity of flooding of the site and the resulting damage is yet another important external event design basis, which is examined in a detailed way. This calls for collection and careful examination of the parameters such as maximum rainfall rate upstream and flow in the rivers and also the consequences of a failure of a dam if present upstream. From the historical hydro-meteorological and hydrological data so compiled, the characteristics of a Design Basis Flood (DBF) are determined and the maximum water level in the vicinity of the site is estimated to provide a basis for design of the floor level of the buildings

At coastal sites, the potential for flooding by combination of high tides, surge level and the wave run-up is examined to arrive at the design basis flood level, resulting independently from cyclone and tsunami. The cyclone and tsunami events are completely independent events and each of these events has a low probability and combination of the two events will have extremely low probability. Design basis flood level from cyclone is based on probabilistic analysis, while the design basis flood level from tsunami is based on margin over historical information. All components important to safety are positioned above the design basis flood level or protection is achieved through construction of permanent external barriers such as levees or dikes.

Internal Event Analysis

Analyses of internal events in nuclear reactors requires visualisation of a very wide range of deviations from normal operations due to equipment failure and operator error, individually and in combination. This is a challenging task, but the safe operating record of nuclear power reactors in India, free from any major failures demonstrates that it is feasible.

The consequences of most of the off-normal operating conditions are limited to the plant, with some damage to equipment or radioactive releases well contained within plant buildings. The more significant of the events in the water-cooled reactors, in the context of the safety of the general population, is related to the Loss of Coolant Accident (LOCA). The situation can get compounded if there is a simultaneous failure of either the reactor shutdown system or the Emergency Core Cooling System (ECCS). It is such a dual failure event namely, LOCA with loss of ECCS, that is considered as a DBA for PHWR.

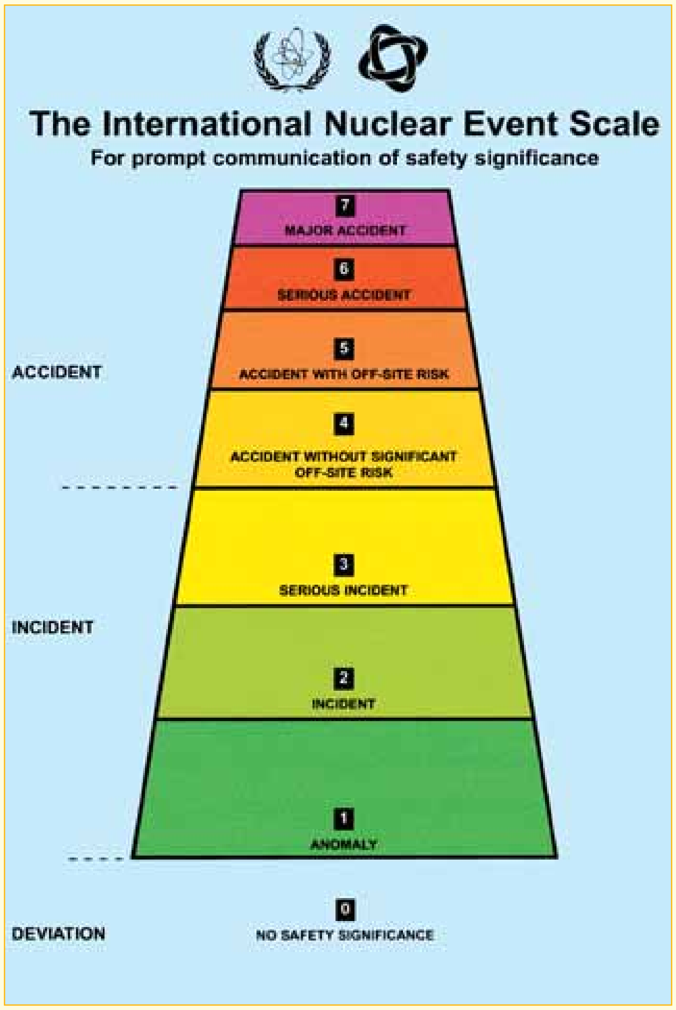
In the heavy water reactors, analysis of incidents involving LOCA also investigate hydrogen generation as a result of chemical reaction between zirconium and steam. This is important because if hydrogen finds its way into the containment, a hydrogen deflagration/detonation there, may affect containment integrity. Consequently hydrogen transport and distribution behaviour is studied with care. Incorporation of passive devices for catalytic recombination of hydrogen and oxygen is a solution that is being adopted.

Extensive use of computer codes, of which some are developed and tested by laboratories in other countries and some others developed in-house are used to analyse various failure conditions to establish a safety case for the reactors.

Fire Safety

A major incident occurred in Unit-1 of Narora Atomic Power Station in the year 1993, in which lubrication oil caught fire in the turbine hall. It did not involve any radioactive systems and there was thus no release of radioactivity as a result of the fire. The fire affected occupancy in the control room and disabled some instrumentation, but the well rehearsed emergency operating procedures were followed promptly to bring the reactor to a safe shutdown state. The incident nevertheless highlighted the importance of planning for fire protection, which now has become an integral part of the design right from the conceptual stage of the design. Redundant safety systems are now being incorporated in such a manner that in the event of any fire, safety systems would still be capable of performing

International Nuclear Event Scale (INES) was introduced in March 1990 to facilitate communication among the nuclear community, media and public on events occurring at civil nuclear installations. It is designed to provide prompt, clear and consistent information on nuclear events occurring at a nuclear installation. In a grade of 7, only events above 4 have public concerns and are classified as accidents. The Chernobyl accident during 1986 in erstwhile USSR (now in Ukraine) has been rated at the highest level of seven. The Three Mile Island (TMI) accident in USA in 1979 leading to severe core damage was rated at 5. The fire incident at Narora atomic power station has been rated at level 3 as it did not result in any release of radioactivity and radiation exposure. It is a matter of immense satisfaction and confidence booster to note that the nuclear power plants in India have not registered any accidental scenario in more than 200 reactor years of operation.



the required safety functions. Consequence of fire propagation and its impact on the plant safety are being studied by computer codes BRAN, FIRE and FDS including the in-house developed code PFIRE. A software package, 'risk monitor' has been developed to estimate the risk in the plant due to various configuration changes resulting from component failures or maintenance activities.

In fast reactors cooled by liquid sodium, due to the high chemical reactivity of sodium with oxygen, any exposure of sodium to air would lead to a highly exothermic reaction and produce dense opaque smoke reducing visibility. Based on extensive research, sensitive detectors were developed and deployed to detect the leak at the point of origin and the presence of sodium combustion products in the air, at a very early stage, the leak at the point of origin and the presence of sodium combustion products in the air at a very early stage.

Attention has also been focussed on pool fires of sodium that might result if the leaking sodium accumulates on the floor. Passive means are adopted to minimise the fire duration and the consequences are mitigated through ready application of effective extinguishing media. Sodium fires are in many respects less significant in comparison with conventional oil fires, because of the difference in their physical and chemical properties. For example, the burning rate of petrol is 4 times greater than that of sodium. The boiling point of sodium is 1155 K while that of petrol is 353 K. The latent heat of evaporation for sodium is 12 times more compared to that of petrol. The combustion heat of sodium is 4 times less than that of petrol. Thus, the energy release rate due to sodium combustion is approximately 15 times less than that of petrol. In case of sodium fires the flame height is very small due to the higher boiling point of sodium and the flame tips are close to sodium surface. In striking contrast, flames can reach as high as 4 m in petrol fires. The temperature even at 1 m height above the sodium fire surface is quite low being about 373 K, while for petrol fires, the temperature is more than 873 K at 2 m height above the burning surface.

The best way to extinguish sodium fire is by exclusion of the oxygen. A passive method adopted is to provide suitably designed collection trays in areas where a sodium leak is considered likely. The trays are in the form of closed boxes with slotted and sloped top covers. They serve to improve the sodium drainage, to reduce sodium temperature rapidly and to smother burning by starving the burning zone of oxygen. Alternative methods are also in use in which the leaked sodium is transferred to collection tanks. An inert gas like nitrogen may be already present in the tanks or can be injected when needed. Elaborate experiments have been carried out with large simulated sodium leaks and the optimum design parameters have been arrived at. During sodium fire fighting, oxygen is excluded from the burning surface by spreading suitable extinguisher on burning surface. For small sodium spillages, dry sand or dry sodium chloride can be used. The combination of sodium carbonate and sodium bicarbonate called dry chemical powder (DCP) is used successfully for sodium fire fighting. The ratio of weight of DCP required to weight of sodium in the fire to be extinguished is established by experiments.

The analyses of sodium fires also consider the spray mode of fire, arising from any sudden ejection of sodium into the air. When the quantity of sodium is large, some of the ejected sodium may collect as a pool on the floor below and result in a combined spray-pool fire. Spray fires are more dangerous than pool fires because of higher sodium burning rates due to greater exposed surface area in droplet form. In the study of the consequences of spray fires, parameters like oxygen concentration, sodium temperature, the efficiency of dispersion of sodium, sodium-to-air ratio, the non-adiabatic nature of the container and its contents are very important.

In a spray fire incident that took place in a solar plant at Almeria, Spain in August 1986, 14 tonnes of sodium spilled in a period of half an hour. Though the temperatures reached up to melting of metallic structures, the damages were limited to the fire zone itself and did not result in any large-scale destruction.

Another important consideration is the exothermic reaction of sodium if ever it comes in contact with concrete. It is well known that concrete is used in construction of the reactors. In the event of an accidental leak of sodium over concrete, the sodium-concrete reaction takes place leading to exothermic reaction of sodium with the water content in concrete and results in liberation of hydrogen. To avoid such a reaction, critical areas are lined with steel. Also experimental studies are in progress for development of concretes resistant to such reactions.

Safety of Reactor Structures

The containment building housing the reactor serves a very important function, being the last barrier between the plant and the environment to prevent radioactive release in the event of an accident. The design of containment structures for our reactors has evolved over the years from a single walled structure to a double walled one. In PHWRs, the inner containment is made of pre-stressed concrete and is designed to withstand the pressures generated in a DBA due to loss of coolant accident. Techniques adopted for minimising the pressures have been improved. The earlier scheme of dousing of steam in the building by water sprayed from above is replaced by a passive one in which a permanent pool of water in the basement of the containment building serves to condense the released steam.

The secondary containment is made of reinforced concrete and the space in between is maintained at a slight negative pressure with provision for evacuation of air contained in it through filters. The containment is also required to withstand earthquake loads. A computer code for ultimate load capacity assessment has been developed indigenously and has been extensively bench marked with experimental results and for the prediction of safety margins of Indian PHWRs. Also a containment thermal hydraulics computer code CONTRAN has been developed in-house and validated against data from open literature as well as from in-house tests conducted in a test facility built at MAPS, Kalpakkam. The code is currently being extensively used for carrying out containment analysis for the Indian PHWRs, AHWRs and the proposed VVERs.

The fast reactor is designed such that there is no high pressure water present inside the containment building. Nevertheless, a hypothetical situation in which a certain amount of sodium is ejected upwards from the primary pool is postulated and temperatures and pressures arising from burning of this sodium serve as the basis for containment design. The pressures are estimated to be far lower than in the case of heavy water reactors.

Environmental Radiological Surveillance at Nuclear Power Plants

Nuclear power is an environmentally benign source of energy, as it does not contribute either to global warming or acid rains. Nuclear power plants do produce radioactive gaseous and liquid effluents as well as solid wastes. Studies show that release of radioactivity to environment from nuclear power plants leads to population exposures far less than from thermal power stations. The importance of environmental survey was realized very early by DAE. Well-equipped Environment Survey Laboratories (ESL) are established at each power plant well before commissioning of the plant. The primary aim of the environmental monitoring programme is to establish and monitor the radiation level in environment due to the operation of reactors and to ensure its compliance with the radiation exposure limits set for members of public by AERB.

Sample of local vegetable being collected

As early as 1962, a proposal was made for the setting up of an ESL at Tarapur. At that point in time, this concept was totally unique and there was no such precedence anywhere else in the world in any of the nuclear or other conventional industries. In fact, after long deliberations for the need to establish ESL facilities, Bhabha, while deciding in favour of the proposal, emphasised the importance of ESL by recording that if there be no sanction for ESL, the reactors need not operate. In 1964, as the construction of Tarapur Atomic Power station had started, the functioning of the ESL commenced simultaneously at the Tarapur site for pre-operational survey. Taking the Indian concept of dedicated laboratories for environment monitoring around nuclear installations as a model, the World Health Organisation invited India, sometime in 1970, to prepare a guide lines for design, lay out, staff and equipment requirements for such laboratories.

In the pre-operational phase, ESLs generate baseline data on the levels of external radiation dose, due to both natural sources (uranium, thorium and their daughter products, potasium-40 etc) and also from global weapon fallout (strontium-90, cesium-137 etc.). A detailed survey of the 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 measurement is undertaken. The number and type of samples and sampling frequency are optimized for each site on the basis of the type of operating facilities, utilization of local natural resources, existence of population clusters and related demographic data. Three types of environmental samples are collected and analysed. The first category of samples (drinking water, air and locally produced dietary items consumed by the public.) are directly relevant to the estimation of dose received by members of the public. The second category of samples such as weeds, sediment, soil, grass etc. are "trend indicators" for build up of radionuclides in the environment, if any. The third category includes sensitive indicator organisms that accumulate specific radionuclides to a great extent and these serve as very sensitive detectors or markers. For example, goat thyroid is used for detection of low levels of fresh radioactive fallout of Iodine-131. Subsequent to the Chernobyl accident, iodine activity in goat thyroid sample as measured in all the ESLs in the country showed a perceptible increase, but well below the level of concern. This demonstrates the high sensitivity of this technique.

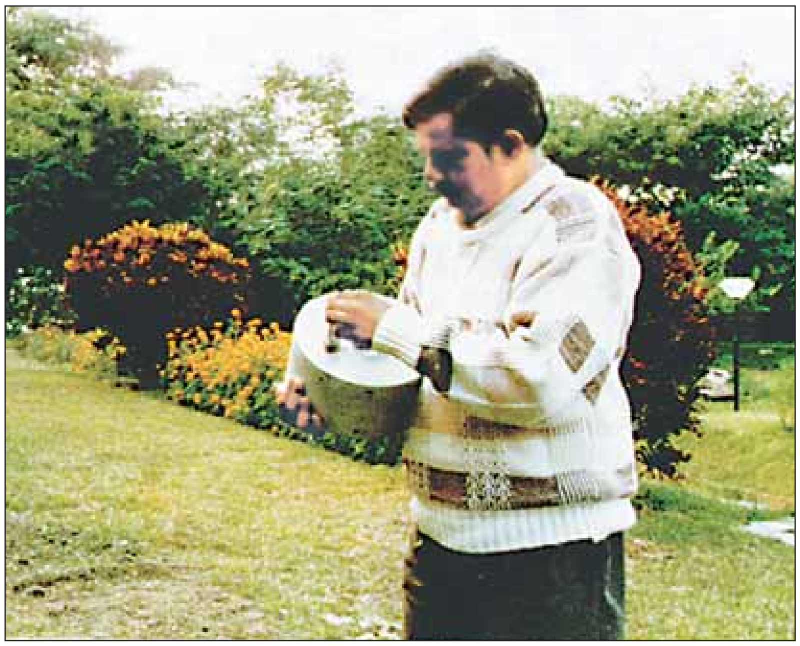
During the pre-operational period, another important activity of the ESL is the collection of meteorological data, like wind speed and wind direction on a continuous basis. The dispersion factor or dilution factor for gaseous effluents is derived on the basis of these data. The dispersion factors are used for arriving at release limits for radioactive gaseous effluents from the stack. These data are continuously collected during operational period also.

The natural radiation background in the vicinity of the nuclear site is estimated in the pre-operational phase using special Thermo Luminescent Dosimeter (TLD) sensitive to low levels of radiation. Subsequent to commencement of reactor operations, the ESL continues to monitor the external radiation exposure levels in the environment, to measure the meteorological parameters and to analyse the distribution and concentration of reactor related radionuclides in samples of different environmental matrices.

Sampling of tritium

This permits an assessment of the contribution, if any, from the plant releases. Tritium is an important radionuclide that could be released from the Pressurised Heavy Water Reactors (PHWRs). In the over-all sampling programme, therefore, considerable emphasis is given to the tritium measurement in the aquatic and atmospheric environment.

Data collected by the environmental survey laboratories have shown that, even after thirty years of operation of nuclear power plants, the levels of radionuclides in terrestrial samples such as soil, crop, vegetation, milk, meat, egg etc., are much below



Monitoring radon in the environment

internationally accepted threshold values. It has been established that the contribution from plant operations to radioactivity in terrestrial samples collected in the public domain is insignificant. Aquatic samples such as water, fish and sediments in the vicinity of discharge area show a small increase in the levels of tritium and cesium-137, but the levels are too low from the health point of view.

The maximum dose estimates for members of public situated at various distances around the nuclear power stations typically range from about 8% of dose limits (1mSv/y) at Tarapur, Rajasthan and Kalpakkam to less than 1% in the case of new generation plants like those at Narora, Kakrapar, Kaiga and the units 3 &4 in Rajasthan, the latter arising from improved design features. At all the reactor sites, any exposures to an individual member of the general public, attributable to the station releases, have remained well below the natural exposure levels. This provides confidence in the operation of the nuclear reactors. As a matter of general policy, the ESLs have always been open to the public, to visit, observe and have discussions. After the Chernobyl accident in 1986, the ESLs have been recognized as accredited laboratories for analysis and certification of the radioactivity levels in a wide variety of samples, including commodities for export.

A mobile radiological laboratory has been developed for off-site deployment to assess the radiological impact in the event of any nuclear accident. It is equipped with a whole body counter, a hyper pure germanium detector for low level counting of environmental samples, an automatic weather station, global positioning system and several other radiation survey meters with on line dose and dose rate recording facility for acquiring the data.

> *"…I have reasons to believe that the Nuclear Power is soon going to occupy, in the global context, a pivotal position as it is most benign from the point of view of CO_2 emissions as none exists in this mode of power generation. Nuclear industry unquestionably is the highest level science based enterprise. It is most satisfying that the power of the atom, in totality, is fully manifested in the multifarious activities of the Department ranging from agriculture, food security, health, non-invasive method of measuring flow parameters, maldistribution, etc. The Department epitomizes conversion of high level of scientific pursuits, across the entire spectrum from Biology to Chemistry, quite apart from Physics, Materials Science, Chemical Engineering, Mechanical Engineering, Electrical engineering and Electronics, etc., to the market place in a purposeful and cost effective way…"*
>
> ***- Prof M.M. Sharma,***
> *Emeritus Professor of Eminence*
> *Institute of Chemical Technology*
> *Mumbai University*

Development of Radiation Monitoring Instruments

In order to ensure that radioactive contamination and exposure of workers to radiation are effectively controlled, a number of radiological measurements broadly categorized as area monitoring, personnel monitoring and effluent monitoring are carried out in various nuclear installations. Different areas of the plant are regularly monitored for external radiation levels, radioactive contamination and radioactivity present as aerosol in the working environment. All radiation workers are subjected to personnel monitoring for assessment of radiation exposure. Internal exposure to radioactive materials is estimated based on bioassay measurements and whole body counting. A PC based dose data management programme, developed in house, exists at all the nuclear facilities. Monitoring services for all solid radioactive wastes generated during operation of the plant, their transport, handling and disposal are also provided. These measurements and the control measures, if necessary, ensure that the radioactive materials released to the environment are

Whole body counting

within the authorized limits.

The personnel monitoring programme in India started in the year 1952. A Film badge system based on imported radiation sensitive film packs was used for the purpose. Thermoluminescent dosimeters (TLDs) based on solid state dosimetric technique have emerged as a good alternative to provide required accuracy, reliability, ruggedness and possibility of automation for handling large number of dosimeters. Indigenous development of TLD badge system based on $CaSO_4$:Dy phosphor in the year 1975 was an important step for replacing imported photographic films by TLD badge system. Standardisation of production procedures of TLD badge system including TLD reader and dosimetric procedures, paved the way for the transfer of technologies for fabrication of component systems like TLD phosphor, TLD dosimeter and TLD reader. Subsequently carbon doped alumina phosphors were developed with sensitivity at least 40-60 times higher than TLD-100 a commonly used commercial phosphor. Carbon doped alumina is best known for its high optically stimulated luminescence (OSL) sensitivity. The OSL technique simplifies instrumentation and offers an efficient way of low level radiation dosimetry. In the event of a major nuclear reactor accident or a nuclear attack, radioactivity may be deposited over a large area, which has to be assessed quickly to initiate prompt counter measures, including evacuation of the public or restrictions on agricultural produce from the affected area. Aerial Gamma Spectrometric Survey (AGSS) can be used as a reliable and effective technique to assess ground contamination for demarcating the affected area. This technique can also be used for plume tracking, searching radioactive sources and for mapping the background radiation levels in emergency planning zone around a NPP periodically. The indigenously developed AGSS is vibration and shock proof and is compact, to enable its quick and easy deployment even in small aircrafts/helicopters.

"... In the recent years, a number of radioactive sources have been discovered in Georgia. We are happy that our indigenously developed and manufactured gamma radiation monitoring instruments have been useful to the agency in its operation in the Republic of Georgia. We have collaborated with the Agency to provide equipment including an aerial gamma survey system and services of our experts for conducting ground and aerial survey for the search of orphaned sources. We are gratified that both the Agency and the Government of Georgia have expressed appreciation for our experts and equipment ..."

- Dr. Anil Kakodkar,
46th General Conference, IAEA, 2002

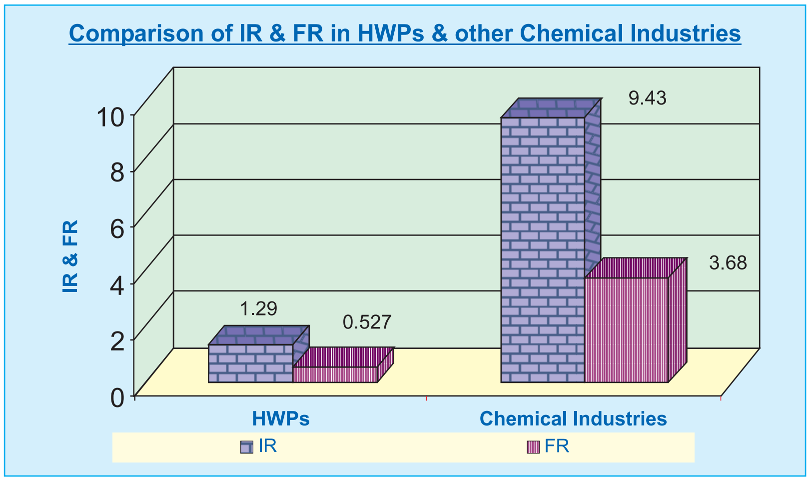
Several ultra sensitive, compact and/or portable devices have also been developed in the Department to detect clandestine removal of radioactive material, trafficking and for routine nuclear transport monitoring. Many special nuclear materials need to be properly safeguarded and accounted to prevent their unauthorized movement and illegal trafficking which necessitates monitoring of these materials even in very small quantities not only at the entry/exit gates of the nuclear facilities but also at entry and exit ports of the country. The portal monitor developed for this purpose checks any unauthorized carrying of radioactive materials by personnel at specific sites. Plastic scintillator coupled with a photo-multiplier tube offers a very simple and efficient detector system to detect gamma rays. Audio and visual alarms are provided with manual and auto-acknowledge features and are interfaced to a computer ensuring continuous monitoring with a low transit time of 2 sec. This system has a sensitivity of 200 milligrams for plutonium and can detect a few micro-curies of cesium-137 or cobalt-60. Also limb monitors have been developed that can be installed as radiation monitors at major transport routes and exit/entry points of various nuclear installations and elsewhere. These provide an effective method of monitoring of pedestrians, vehicles and environment without being noticed. They collect and analyse radiation data and activate a remote alarm to notify the authorities of possible movement of radioactive material. Such monitoring systems are very useful in taking measures for preventing/detecting nuclear/radiological proliferation and terrorism.

Clinical dosimeters have also been developed for medical applications. One such instrument measures exposure to the bladder and rectum of the patients undergoing gynecological cancer therapy to ensure that the doses to the adjoining tissues/ cavities do not exceed the prescribed limits. The technology for this dosimeter has been transferred to M/s Nucleonix systems Pvt. Ltd., Hyderabad and more than 30 dosimeters of this type are presently in operation in various radiotherapy centers in the country.

During normal operation of radiation facilities, it is ensured that radiation exposure to plant personnel and exposure to members of the public due to any release of radioactive material from the plant is kept As Low As Reasonably Achievable (ALARA) and well below the prescribed limits set by the Atomic Energy Regulatory Board (AERB). These limits are based on the recommendations of the International Commission for Radiation Protection (ICRP).

Environmental Friendly Technologies From Heavy Water Board (HWB)

There are significant achievements in Safety and Environment Management of Heavy Water Plants. All the plants



have implemented ISO 9001 (QMS) and ISO 14001 (EMS). The overall safety performance indices of Heavy Water Plant are far better as compared to the similar industries in the country.

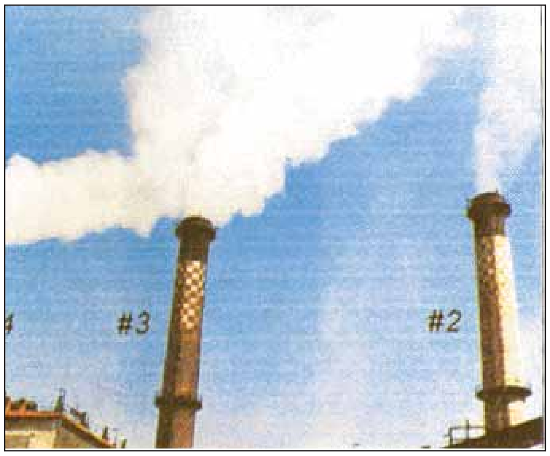
Modified Vapour Absorption System

Utilisation of low-grade heat is one of the most challenging problems especially in a tropical country like India. The discharge of gas and liquid effluents at temperatures above 370 K and 320 K, respectively creates thermal pollution, and wastes a large amount of energy. Heavy Water Board has developed a new technology consisting of modified vapour absorption system for utilization of low grade effluent energy and converting it into a useful cold energy in the form of sub-zero refrigeration effects.

Flue Gas Conditioning Technology for Reduction in Suspended Particulate Matter

Suspended Particulate Matter (SPM) constitutes one of the major air pollutants and cause many respiratory diseases including the dreaded silicosis. The flue gas from a coal fired thermal power station contains fine particles of ash with size

Stack 2 is with ammonia conditioning at Punjab State Electricity Board (PSED) plant, Bhatinda, Punjab



varying from 80 microns to less than 5 microns. Electrostatic precipitators (ESP) are used to knock down the ash particles from the hot flue gas through a high voltage charge creating a transverse motion of the particles and getting attached to the collecting electrode. However, in many power stations, concentration of the SPM exceeds the specified limits. This is where the flue gas conditioning technology developed in India for the first time, by DAE finds excellent application. This spin-off technology was developed when one of the heavy water plants having a coal fired captive co-generation plant had an excess of SPM emission levels during its initial days (500 – 600 mg/nm^3 compared to a limiting value of 115 mg/nm^3). The most appropriate solution was to externally alter resistivity of the ash particles in the charged flue gas medium through weak alkali conditioning agents. After a pilot level study with ammonia as a conditioning agent, a full-fledged technology demonstration plant was set up for the first time in 1999 in the captive power plant, which reduced the SPM levels from 500-600 mg/nm^3 to less than 70 mg/nm^3 making the stack exhaust almost invisible (smokeless stack). After successful commissioning of this system at HWP, Manuguru, this technology was demonstrated at the power plants of Punjab State Electricity Board, Bhatinda and the Gujarat Electricity Board, Ukai through technology transfer channel. M/s. Chemithon India Pvt. Ltd. to whom this technology has been transferred, is currently in the process of implementing this technology at number of power stations.

Safety Research

Safety research has also been given a prime place in the programmes of the Department. As early as 1971, an extensive programme of measurement of individual doses to people residing in monazite areas was undertaken. This involved as many as 14,000 measurements, and the accuracy of the measurements was in fact appreciated by experts from WHO. Presently a very large number of radiation workers all over the country (not only in DAE units but also in other institutions handling radioactivity) are covered by the dosimetry service of BARC, employing the indigenously developed TLD. These TLDs have been placed all over the country and the radiation map of India has been generated.

Independence of Regulation

The tradition of independent safety review of nuclear facilities dates back to the sixties, when the construction of CIRUS was undertaken. In fact, three chapters of the safety report on CIRUS, which were written by Indian scientists and engineers, were independently reviewed by a British expert. The first version of the Radiation Protection Rules was drafted in 1962 under the Atomic Energy Act. A Directorate of Radiation Protection was set up in 1963, to devote attention to radiation monitoring practices. In the seventies, the DAE Safety Review Committee was established to prescribe safety codes and guidelines. Furthening the cause of independence of regulation, in November 1983, Government of India constituted the Atomic Energy Regulatory Board (AERB) to carry out certain regulatory and safety functions envisaged under the Atomic Energy Act, 1962 and the Environmental Protection Act of 1986.

AERB is responsible for formulating and enforcing rules and regulations related to radiation safety under the Atomic Energy Act 1962 and under the Factories Act 1948 for industrial safety in the units operated by the Department of Atomic Energy. AERB is also entrusted with responsibility of ensuring the safety of all radiation sources used for medical and industrial applications. AERB develops safety codes, guides and standards for the siting, design, construction, commissioning, operation and decommissioning of various types of plants in the nuclear fuel cycle. It also develops regulatory documents on radiation and industrial safety. To promote and pursue research in selected areas of relevance to regulatory process, AERB has set up a Safety Research Institute at Kalpakkam in the year 1999. It also maintains liaison with national and international statutory bodies and keeps the public informed on major issues of radiological safety significance.

> *" ... In its enthusiasm for harnessing nuclear energy for vital developmental activities, India has never lost track of the need to assure the public of absolute safety in the nuclear installations. The Atomic Energy Regulatory Board, which has been installed and entrusted with overall responsibilities for the purpose, has set about its task in a systematic manner. the board has undertaken preparation of codes and guides in the nuclear, medical, industrial and transportation areas. Environmental surveys were conducted around all the nuclear plants and research centre sites…"*
>
> ***- M.R. Srinivasan,***
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> *31st General Conference, IAEA, 1986*