NUCLEAR SAFETY
CRITICAL FOR FUTURE NUCLEAR EXPANSION

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Safety is an important aspect of any activity or industry. But it is most critical for the nuclear industry that deals with materials that are radioactive and, hence, potentially dangerous, and with systems and technologies that are extremely complex. Moreover, nuclear accidents have widespread implications, not only in terms of the geographical expanse that may be affected, but more in terms of shaking public confidence worldwide in this source of energy. In no other industry does an accident in one plant have comparable impact on the international industry as a whole. The last major nuclear accident, Chernobyl in 1986, may have occurred two decades ago, but it still casts its shadow on the nuclear industry, and in the US, no new plant has been ordered since the Three Mile Island incident of 1979. Indeed, the future of the nuclear industry is greatly dependent on the assurance that such accidents will not recur.

Therefore, the safety performance of operating nuclear power plants (NPPs) and its periodic and stringent rule-based evaluation are of vital importance in order to minimise and possibly obviate any danger to plant workers or the public. In fact, for every nuclear plant that is built and operated, the society needs assurance that the facility will be safe mainly on four accounts:

(a) It would not suffer an accident leading to release of large amounts of radioactivity.

(b) It would not cause pollution to the environment during the conduct of its routine operations.

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(c) It would account for the long-term storage and safe disposal of its radioactive waste.

(d) And, more importantly in the context of today's threat perceptions, it would be safe against a possible strike by terrorists.

The guarantee of these assurances requires the establishment and maintenance of effective mechanisms and the deployment of requisite measures in the design, site selection, operation and decommissioning of a nuclear plant. At the same time, relevant regulatory bodies need to be instituted to oversee and assess the implementation of safety measures against a range of parameters so that the individual, the society and the environment can be protected against radiological hazards.

Generally speaking, three dimensions of nuclear safety preoccupy the public mind and future expansion of the nuclear power programme is dependent on perceptions of these safety issues. These relate to the personnel involved in the nuclear fuel cycle; reactor operations; and the environment. Given the Indian ambition of considerably augmenting the country's electricity generation with new nuclear plants, safety considerations related to all three aspects need to be taken into account.

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With this in view, this paper examines the safety philosophy of the Indian nuclear power programme. It also analyses the role of the regulatory bodies in this exercise; besides briefly highlighting the increasing focus on security of nuclear plants post-September 11. The paper argues that despite a good Indian record of nuclear safety over the last five decades or more, there can be no room for complacency. Rather, as more power plants are built along with the concomitant other fuel cycle activities, the safety concerns must be viewed with greater seriousness and urgency. Even a single untoward incident would be unacceptable since it would leave an indelible adverse impact on public opinion and mar the chances of widespread public acceptance for a long, long time.

NATURAL RADIATION

Any comprehension of the wider issues of nuclear safety must begin with the basic understanding that radiation is a natural phenomenon that man has cohabited with for centuries. It is over-dosage of radiation that is harmful to the human body and must be guarded against and, hence, the emphasis on nuclear safety. Nuclear power programmes and operations of atomic reactors are premised on this basic knowledge and need to take special care or safety measures to ensure no there is undue exposure of personnel and public to radiation in the course of the entire nuclear fuel cycle, from uranium mining to electricity generation and waste disposal.

Natural radiation exists in three forms — in the form of cosmic radiation from the sun and space; from naturally occurring radioactive materials such as uranium and thorium; and from radioactive elements present in our bodies such as potassium 40, carbon 14 or tritium. Estimated annual exposure of man to natural radiation sources in areas of normal background is 2.5 millisievert (mSv) of which two-third is from radioisotopes inside the human body. In some areas such as the Gangetic plains and the coastal areas of Kerala and Tamil Nadu, natural radiation levels are nearly 2-5 times higher than in others. It has been estimated that hundreds of thousands of people in countries like India, Brazil and Sudan receive up to 40 mSv/yr and some in Iran receive many times more, all without apparent ill effects. The cosmic radiation dose varies with altitude and latitude. Air crew can receive up to about 5 mSv/yr from their hours in the air, and frequent flyers may score a similar increment, but people subjected to such exposure have shown no adverse effects.

Apart from the radiation from natural sources, certain man-made sources such as X-ray machines, nuclear reactors and radioisotopes also provide radiation. This radiation is usefully employed in fields such as medicine, industry, hydrology, power generation and agriculture. However, the operative clause in all these uses is the avoidance of excessive exposure to radiation to the workers employed in the activity, and to the general public.

Accordingly, radiation protection is based on the understanding that small increases over natural levels of exposure are not likely to be harmful but that they should be kept to a minimum. To put this into practice, the International Commission for Radiological Protection (ICRP) has established recommended standards of protection based on three basic principles:

- **Justification**. No practice involving exposure to radiation should be adopted unless it produces a net benefit to those exposed or to society generally.
- **Optimisation**. Radiation doses and risks should be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- **Limitation**. The exposure of individuals should be subject to dose or risk limits above which the radiation risk would be deemed unacceptable.

These principles apply not only to routine operations but also to the potential for accidental exposures. The ICRP recommends that the additional dose above natural background and excluding medical exposure should be limited to prescribed levels which are established as: one mSv per year for members of the public, and 20 mSv per year averaged over five years for radiation workers who are also to remain under closely-monitored conditions. However, the weight of scientific evidence does not indicate any cancer risk or immediate effects at doses below 50 mSv in a short time or about 100 mSv per year.[1]

PERSONNEL SAFETY

The data mentioned in the above paragraphs forms the premise for the formulation of rules and regulations of personnel safety. Radiation protection or health physics is concerned with the protection of individuals employed in the nuclear industry at every and any stage of the fuel cycle. The guiding principle of this safety is to ensure that radiation doses to the occupational workers do not exceed prescribed limits as laid down by the ICRP at ALARA levels. The Atomic Energy Regulation Board (AERB) in the case of India has made these stipulations even more stringent. The Bhabha Atomic Research Centre (BARC), as also other laboratories accredited by it,

1. These figures are derived from studies about incidences of high radiation doses to populations such as from the Japanese bomb survivors. For more on this, see World Nuclear Association website at http://www.wna-org.

conduct countrywide personnel monitoring in nearly 3,000 industrial, medical, and research and development organisations that are involved in any way with the nuclear programme.

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Importantly, the nuclear industry is the only one where every single employee is subjected to periodic monitoring. This is because the harm caused by radiation can be both somatic and genetic, and, hence, is completely unacceptable. The effects of over-exposure may show up in the individual himself in his lifetime, or perhaps only later in his children. Accordingly, the workers wear monitoring 'badges' while at work, and their exposure is carefully monitored. However, health records of these occupationally exposed groups have shown that they have lower rates of mortality from cancer, the disease most associated with radiation exposure, than the general public and, in some cases, significantly lower rates than other workers who do similar work without being exposed to radiation.[2] At the low levels of exposure and dose rates involved in the nuclear industry, the effects are, in fact, probabilistic rather than measurable.[3]

Health risks to occupational workers in the nuclear industry need to be considered at mainly three stages of the nuclear fuel cycle: front end, reactor operations and back end or waste disposal. In uranium mining or in other activities related to the front end of the nuclear fuel cycle, the risks are largely internal and, hence, more dangerous. Past exposure of miners to radon gas, with

2. Cancer is normally the disease associated with radiation over-exposure. Also, since cancer is a common disease in older people there have been, and will continue to be, cancer cases among radiation workers. This does not, however, automatically imply that they are radiation-induced. However, this question has been studied closely in a number of areas and work is continuing. So far, no conclusive evidence has emerged to indicate that cancers is more frequent in radiation workers than in other people of similar ages in Western countries, where cancer accounts for a quarter of all deaths.
3. About sixty years ago, it was discovered that ionising radiation such as that which continually forms part of our environment could induce genetic mutations in fruit flies. Intensive study since then has shown that radiation can similarly induce mutations in plants and test animals. However, evidence of genetic damage to humans from radiation, even as a result of the large doses received by atomic bomb survivors in Japan has not shown any such effects. Some 75,000 children born of parents who survived high radiation doses at Hiroshima and Nagasaki in 1945 have been the subject of intensive examination. This study confirms that no increase in genetic abnormalities in human populations is likely as a result of even quite high doses of radiation. For more on this, see World Nuclear Association website at http://www.wna-org.

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a consequent higher incidence of lung cancer, is historically the most palpable evidence of this. However, with greater knowledge and understanding of this, safety precautions have since been in use and exposure to high levels of radon in uranium mines has not been an issue of concern for over thirty years now. Nevertheless, the presence of some radon around a uranium mine in operation and some dust bearing radioactive decay products must be recognised.

However, when compared with the hazards of inhaled coal dust in a coalmine, the health hazards to uranium miners are considered to be small and less than the risks of industrial accidents. In fact, the contrast between air quality effects from coal burning for electricity and increased radiation from nuclear power is very marked: a person living next to a nuclear power plant receives less radiation from it than from a few hours flying each year. On the other hand, anyone living in an area that receives wind blowing from over a coal-fired power plant can expect it to have an effect on the air quality, possibly even to the extent of affecting health. In some areas, coal contains enough radium and thorium to cause coal-fired power stations to release far more radioactivity to the environment than a nuclear power station, though today this is mostly retained in fly ash![4]

In the case of routine operations, the dangers of radiation to reactor operators are comparatively much lower than in the case of the front end workers since in a plant, operators are handling sealed sources. Of course, in the event of an accident in the plant, the risk rises manifold, but as is discussed in the following section, several inherent and engineered plant features guard against this risk. Certainly, nuclear power generation is not completely free of hazards in the occupational sense, but it does appear to be

4. World Nuclear Association at http://www.wna-org.

no more dangerous than other forms of energy conversion. This is well illustrated in Table 1.

Table 1: Comparison of Accident Statistics in Primary Energy Production
(Electricity generation accounts for about 40% of total primary energy)

Fuel	Immediate fatalities 1970-92	Who?	Deaths per TWy electricity
Coal	6,400	workers	342
Natural gas	1,200	workers & public	85
Hydro	4,000	public	883
Nuclear	31	workers	8

Source: Ball, Roberts & Simpson, *Research Report #20,* Centre for Environmental & Risk Management, University of East Anglia, 1994.

Workers employed in the back-end of the nuclear fuel cycle deal with the most dangerous open sources, particularly plutonium that is separated from spent fuel by reprocessing and has been called the most toxic element known to man. However, it would be instructive to compare its toxicity with that of some other materials. For instance, if swallowed, plutonium is much less toxic than cyanide or lead arsenate and about twice as toxic as the concentrate of caffeine from coffee![5] It is, however, the most dangerous if inhaled as fine dust and absorbed through the lungs since this increases the likelihood of cancer 15 or more years afterwards, and there has been one documented fatality from plutonium-induced cancer.

In conclusion, it may be said that since the health effects of exposure to radiation are well known, this knowledge allows the personnel to arm themselves with requisite safety measures too. For instance, the personnel are provided with proper radiation shielding. The plants follow a zoning system with regular contamination checks of personnel and equipment. The ventilation systems are so designed as to minimise airborne radioactivity. Plant personnel use protective clothing and respirators while entering hazardous areas and radiation levels in various plant areas are also continuously monitored. Given

5. Ibid.

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such precautions, it may be said that the dangers in the nuclear fuel cycle are not any more than in other industries. The essential task for those in government and in the nuclear industry is to prevent excessive amounts of such toxins harming people, now or in the future. ALARA must remain the guiding principle of radiation safety.

PLANT SAFETY

The Three Mile Island (TMI) incident in the USA in 1979 and the Chernobyl accident in 1986 are the only two major nuclear mishaps that have occurred ever since nuclear power came to be used for commercial electricity generation. The situation to date is that in over 10,500 reactor-years of civil operation, these are the only accidents in commercial reactors that could not be substantially contained within the design and structure of the reactor. And only the latter one, exemplifying the "worst case" disaster scenario, resulted in the loss of life of 31 staff and firefighters, 28 of them from acute radiation exposure. There have been also 800 cases of thyroid cancer in children, most of which were curable, though about ten have been fatal. About 130,000 people received significant radiation doses (i.e. above ICRP limits), and are still being closely monitored by the World Health Organisation. Radioactive pollution drifted across a wide area of Europe and Scandinavia, causing disruption to agricultural production and some exposure (small doses) to a large population.[6] But, in the case of TMI, the total radioactivity release from the accident was small, and the maximum dose to individuals living near the power plant was well below internationally accepted limits. Nevertheless, both these accidents had a pronounced psychological effect and proved to be a severe blow to the nuclear industry in the two countries and beyond.

The Chernobyl accident resulted from a combination of design deficiencies, the violation of operating procedures and the absence of a safety culture. In fact,

6. *Chernobyl Ten Years On* (OECD NEA 1996).

the post-accident analysis served as a sort of a wake-up call, and since then, plant operators and governments worldwide have become acutely conscious of the dangers involved and of the need to religiously follow safety precautions. Over the last two decades, the international safety record of NPPs has been remarkable given that the complex nuclear technology is today employed in about 40 countries, with some forty-year-old reactors still in operation. Yet, there have been no major safety lapses.

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While it should be emphasised that a commercial reactor cannot under any circumstances explode like a nuclear bomb, reactor safety, however, needs to be premised on the assumption that the problems are complex not only because of the inherent characteristics of the nuclear materials involved, but also because the process of fission could be affected by such extraneous factors as high temperature creep, irradiation induced creep, high temperature gradient, transient thermal stresses, propensity to fatigue damage, flow induced vibration, shock loading, earthquakes, etc. Therefore, in the case of nuclear plants, special precautions need to be taken at every stage — design, siting, operation and decommissioning.

The safety philosophy and principles being followed in India are examined in the following paragraphs. In the case of the Indian reactors that are mostly pressurised heavy water reactors (PHWRs), the safety principles begin to be applied from the time of selection of site to its designing and stringent quality control during construction itself in order to obviate chances of malfunction. The Indian NPPs are based on the principle of defence-in-depth, physical and functional separation between processes and safety systems, redundancy to meet single failure criteria, and accident analysis based on postulation of design basis events. In fact, in addition to the deterministic safety analysis, probabilistic safety assessment (PSA) techniques are also being used as are now being encouraged by the International Atomic Energy Agency (IAEA) worldwide. PSA allows the operators to model the design and operation aspects of the plant having a bearing on safety in a systematic and integrated framework of event trees in such a way that the contribution of any basic event such as component failure or human error to the overall plant safety can be determined. The results of such assessment can put the safety issue in perspective and can be used in risk-informed decision-making in design and in operation.

Site Selection and Construction

Correct choice of site for NPPs is critical. Detailed investigations are required to ensure that the location of the plant will not pose undue radiological hazard to the public and the environment during normal operation and following an accident. This involves the assessment of the seismic history and geological characteristics of the region, possibility of natural events such as floods based on the precipitation patterns, high tides, wind effects, etc. At the same time, and more so after the September 11 attacks, there is a need to assess the possibility of man-induced external events such as aircraft crash, chemical explosion blasting operation, etc. in the vicinity of the plant.

For minimising radiological impact on the surrounding areas and for facilitating effective emergency measures for the population in the event of an accident, certain zoning requirements are established. These include:

(a.) An exclusion area of minimum 1.5 km from the reactor centre to be established around the reactor with entry here restricted only to personnel.

(b.) A sterilised area of upto 5 km around the plant where growth of population is restricted for emergency measures.

(c.) A radial distance of 16 km from the plant is established for emergency planning wherein availability of transportation networks and means of communication are checked for adequacy.

Safety during construction is also critical. This is achieved through stringent quality assurance during material selection, testing, component fabrication, civil construction, site erection, assembly and commissioning. Special care is particularly necessary to ensure the leak-tightness of the containment structure.

Defence-in-Depth

As became evident in 1986, not all Soviet-designed reactors followed the "defence-in-depth" protection. The accident drew public attention to the lack of an adequate containment structure. An important safety feature that today guides NPPs worldwide is that of defence-in-depth. This implies a safety philosophy wherein several lines of defence are created, one after another. The chief aim of reactor safety is to ensure that the radioactive fission products generated in the reactor are contained under all circumstances. Therefore, several barriers are created so that the failure of one barrier or level of defence does not lead to a catastrophe.

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There are four primary barriers to contain the release of radioactive fission products. As the first level, the fuel itself being of high density retains most fission products within itself. Secondly, the fuel is sealed inside a clad. Then, the fuel with the clad is placed inside a high-pressure heat transport system. And, fourthly, a massive double walled containment building surrounds the entire reactor.

The double containment in PHWRs is the critical barrier between the plant and the environment. While certain inherent safety features in PHWRs and engineered systems for reactivity control[7] reduce the chance of an accident, the containment building surrounding the reactor provides an added level of safety. The inner containment of the PHWR is made of pre-stressed concrete and is designed to withstand design basis accidents (DBA) such as LOCA (loss of coolant accident) or main steam line break, etc. The outer wall is made of reinforced concrete and the annulus between the two containment walls is maintained under negative pressure with a provision for continuous monitoring of radioactivity. The double containment ensures almost zero release to the

7. For more on these features, see V.K. Sharma, "PHWR Safety: Design, Siting and Construction," in Satish K. Gupta, *Nuclear Reactor Safety*, A Compilation of Talks and Abstracts of the First National Conference on Nuclear Reactor Technology, organised by BARC on November 25-27, 2002, Mumbai, pp.78-82.

environment and it can even withstand external and internal missile or aircraft impact load effectively.

Amongst the most common disaster scenarios is one involving a loss of coolant. This may lead to overheating of the fuel in the reactor core and the release of fission products. Hence, emergency core cooling systems need to be constantly maintained on standby. In case these should fail, a further protective barrier comes into play: the reactor core is normally enclosed in structures designed to prevent radioactive releases to the environment.

Besides, the physical barriers that layer the defence-in-depth, it is also possible to establish certain action-based levels of defence and the means adopted to enhance reactor safety. These include:

- Prevention of deviation from normal operations or failures through emphasis on conservative design and high quality construction.
- Quick detection and interception of failures through control, limiting and protective systems and use of surveillance techniques.
- Control of consequences in the rare event of an accident through engineered safety features and accident procedures.

Maintaining Structural Integrity of Components and Processes

Reactor safety hinges on the structural integrity of its components and systems, and the safety of the power plant can be assessed by considering the safety of individual systems that constitute the whole. Therefore, the ultimate goal for safe reactor operations is to ensure that the structural integrity of reactor components is maintained not only under normal operating conditions but also in case of a nuclear accident. This is done through adoption of the latest software tools for analysis and design, stringent specifications of used materials, comprehensive quality assurance during fabrication, installation and operation, regular in-service

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inspections and simulated component failure to see how the process and other components withstand.

The first step towards ensuring structural integrity is at the design stage. While designing nuclear components, three main tasks are undertaken:

(a) Identification of various failure modes of each material and component used. For instance, a pressure tube undergoes corrosion and hydrogen/deuterium concentration from the primary coolant from the inside and carbon dioxide (CO_2) from the outside. This can lower the fracture toughness of the tube. Moreover, the hydrogen migration towards stress concentration, particularly the tip of growing cracks, can lead to severe degradation of mechanical properties.

(b) Identification of parameters such as stress, hydrogen concentration on materials, etc., that might cause failure

(c) Incorporation of relevant safety features based on the above.

One of the most important objectives of safety to nuclear plants is to ensure that the radioactive fission products stay contained within the fuel. This requires that the integrity of the fuel and fuel claddings be maintained by ensuring that the fuel does not get overheated beyond certain limits. Safety assessment, therefore, requires an analysis of possible system or component failures that could lead to such overheating. However, by following the principle of physical and functional separation between processes and safety systems, it is ensured that a single local event such as fire, or a pipe failure, does not result in multiple component or system failure.

Accident Analysis

Accident analysis of nuclear reactors is an important safety mechanism. The first category of accidents, called the DBA are those which have a low, yet significant probability of occurrence (rated at one on one million) and design provisions are made to mitigate their consequences. An example of such accident is the LOCA. The emergency core cooling system is provided as an engineered safety feature to mitigate the consequences of LOCA.

The second category of accidents is known as the beyond design basis accidents or severe accidents. These have an extremely low probability of occurrence of one in a hundred or in a thousand million and could be the consequence of a combination of failures where a postulated DBA is accompanied by simultaneous failure of engineered safety systems, leading to spillover of consequences to the public domain.

G.R. Srinivasan, vice chairman of the AERB has listed ten rules of nuclear reactor safety[8]:

1. Operate conservatively
2. Do not relax rules in times of crisis.
3. Maintain defence-in-depth.
4. Verify actions affecting reactor safety.
5. If in doubt, stop, think and ask.
6. Ensure all actions stand up to critical scrutiny.
7. Understand the implication of a change.
8. Do not live with problems.
9. Determine and correct underlying reasons for problems.
10. Keep it simple.

As is evident, seriously following certain basic rules of safety is most essential for the safe running of an NPP. This has been proven in the retrospective analysis of every accident. For instance, an accident at a plant in Tokaimura in Japan, in 1999, was caused by workers trying to save time by mixing excessive amounts of uranium in buckets. This killed two people and injured hundreds, and led to the temporary suspension of all 17 plants of the Tokyo Electric Power Co (Tepco) plants in April 2003 after it admitted to falsifying safety records. This naturally prompted considerable alarm amongst the Japanese public, already very sensitive to nuclear issues, given their historical experience, and was reflected in the views of the Citizens' Nuclear Information Centre (CNIC) in Tokyo, which was created in 1975 to monitor nuclear safety. CNIC concluded that the roots of the problems were two-fold: inadequacy in government regulations and a culture within the industry's management of covering up mistakes. It said the Japanese safety appraisal process, which takes place before a power plant is even built, was extremely lax, while inspections carried out afterwards were "very

8. G.R. Srinivasan, "Regulatory Strategy and Key Issues in Safety Evaluation of Operating Plants," in Ibid., p.70.

haphazard." Such an approach is unacceptable for nuclear plants and the contemporary emphasis on nuclear safety must obviate this.

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ENVIRONMENTAL SAFETY

The environmental safety aspects of nuclear energy are formulated on the basis of well-established international radiation protection standards. Acts and rules have been formulated to achieve effective control of release of radionuclides into the environment. The Department of Atomic Energy (DAE) itself has laid down an Environmental Protection Policy as the first step to regulate environmental releases from nuclear facilities. This establishes that:

(a) The operation of the nuclear installation shall not interfere in any manner with proper utilisation of environmental resources in the area outside its control.

(b) No deleterious effects shall accrue from the nuclear operations and disturb the ecological balance of life.

(c) Radioactive and non-radioactive pollutants released into the environment shall be at such concentration levels and quantities that the resultant accumulation of radioactivity and other toxins in any component of the environment will not cause detriment to the ecosystem.

The basic concepts for discharge control are based on current radiation protection principles of the International Commission on Radiological Protection (ICRP) and are expected to be consistently maintained at all NPPs. While safe radioactive waste disposal and safe decommissioning of plants are also critical for maintaining the sanctity of the environment, these issues will be dealt with separately in another paper. This one, meanwhile, retains focus on the safety of the environment during the operation of the plant.

Environmental radiological surveillance and protection was initiated in India at the very inception of the nuclear programme. Presently, under the Global Environmental Radiation Monitoring Network (GERMON), 25 stations spread all over India continuously measure levels of radioactivity in the environment. Also, an aerial surveillance facility for quick assessment of large area contamination and locating lost/misplaced radiation sources has been in operation for the last eight years. This Compact Aerial Monitoring System (CARMS) is used for estimation of large area contamination using unmanned aerial vehicles.

Environmental monitoring at various NPP sites is initiated by setting up environmental survey laboratories (ESL) at least two-three years prior to commissioning of the plant for conducting pre-operational monitoring that would provide a base line for natural and fallout radioactivity in the environment. The ESL operates as an independent monitoring agency set up by BARC and estimates radiation exposure to the general public through detailed sampling and analysis of environmental matrices like water, milk, air, vegetation, soil, etc.

The monitoring programme continues throughout the operational phase of the installation. The State Pollution Control Boards ensure compliance of pollution prevention measures. NPPs take the consent from these boards to discharge their water and air effluents. It is worth mentioning that the environment around nuclear sites in India is well conserved. In fact, nearly all NPPs and heavy water plants have the Environmental Management System Certification under the ISO 14001 and have bagged the AERB Green Site Award.

REGULATORY STRATEGY

Well-established regulations are critical for nuclear safety. It is the responsibility of the regulatory bodies to stipulate the safety levels while simultaneously achieving a balance between a conservative approach that calls for frequent shutdowns and one that shows greater propensity for high production at low cost. In India, the AERB, the Ministry of Forests and Environment and the State Pollution Control Boards lay down

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the requirements with respect to environmental protection, pollution control, radiological safety, industrial safety and emergency preparedness.

The AERB is the main regulatory body governing nuclear operations in India. Given the importance of the tasks it is expected to perform, it is important for the AERB to have the requisite mechanism and methodology to obtain an integrated safety performance evaluation of each unit throughout the life cycle of the plant, from its siting to its decommissioning. Its regulatory strategy is based on the principle that the responsibility of the safe operation of the plant lies with the licensee. Calculating that its regulatory burden is inversely proportional to the safety efforts put in by the licensee[9], it promotes an effective safety management system by ensuring self-assessment and self-regulation. This is quite in contrast to the US Nuclear Regulatory Commission (NRC) regime that is based on prescriptive regulation, accompanied by inspection and enforcement of rules. But in the case of India, the AERB maintains that induced safety cannot be more effective than inherent safety. It encourages the NPPs to evolve a good safety culture so that safety is ingrained in every aspect of the plant, its people, procedures and systems. There are strong internal review processes within the operating organisations and multi-tier review committees. The AERB uses several tools and processes for continuous safety evaluation such as inspections, study of reports, periodic safety reviews and licence renewal, etc.

In India, licences are issued by the AERB after the successful commissioning of an NPP. These are given for the design life of the plant, which is generally estimated at 30-40 years for PHWRs. During the process of this licensing, all aspects related to safety at various stages such as siting, design, construction, commissioning and operation and even management of waste and decommissioning are reviewed. Within the operating licence, the AERB grants initial authorisation for a specified period and renewal of authorisation for further specified periods after assessment of the safety performance of the plant.

One of the important responsibilities of the AERB is to prepare concise and comprehensive safety standards, codes, guides and manuals to address the following requirements:

9. Ibid., p. 60.

(a) To simplify, accelerate and standardise the complex licensing process.

(b) To ensure that siting, design, construction, operation and decommissioning of the nuclear facilities happen on a uniformly high safety level and in accordance with the latest technological advances made in the industry.

(c) To take into account public concern and improve public acceptance.

(d) To protect the site personnel, public and environment from undue radiological hazards.

Towards this end, safety codes and guides are prepared on the basis of international recommendations as made by the International Atomic Energy Agency (IAEA), the International Nuclear Safety Group (INSAG) and the Nuclear Safety Group (NUSAG). Formulated as a result of multi-tier reviews along with expert opinions, the codes and guides reflect a consensus on safety principles and are also subject to periodic reviews and updates to take into account natural and technological evolutions and to implement enhanced safety requirements.

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AERB aims to ensure the safety of the public, environment, plant operators and plants. However, it must not only do so but also must be seen to be doing so. Therefore, the regulatory strategy must also envelop transparency, openness and public information. In fact, it would aid the future expansion of the nuclear power programme if the government would, as part of its near-term R&D programme, develop more fully the capabilities to analyse life cycle health and safety impacts of fuel cycle facilities and focus reactor development on options that can achieve enhanced safety standards. The MIT study conducted in the US on the "Future of Nuclear Power" proposes nothing less than a whopping $50 million per year for this purpose.[10] India must take a cue from this and realise the import of nuclear safety.

10. MIT study, *The Future of Nuclear Power*.

COST IMPLICATIONS OF SAFETY

Often, it has been argued that the high cost of nuclear power plants is because of the criticality of having advanced safety features in place. About one-third of the capital cost of reactors is normally due to engineering designed to enhance the safety of people—both operators and the public. However, given the nature of the material and processes that the nuclear industry deals with, there can be no cost high enough to ensure safety. Rather, as has been proven, safety and production are not mutually exclusive — where safety performance is high, production too has been high. Delays, even if for reasons of construction accidents as occurred in the case of the Kaiga unit 1 dome delamination, or due to some other aspect of industrial safety as in the case of the electrical fire in the NAPS unit 1 that led to the disruption of normal operations, inevitably result in financial losses. Therefore, safety and production are inseparable.

Nevertheless, a contemporary debate on nuclear safety focusses on whether nuclear reactor safety goals would be compromised with a transition to competitive electricity markets. Some observers suggest that private nuclear electricity generators, whenever they are allowed to participate in this activity, will be more concerned with maximising plant output and less willing to close plants for safety inspections and corrective actions where necessary. On the other hand, owners groups have long stated that nuclear plant operation conducted to ensure a high level of safety is also economically beneficial.

In any case, the public's views on safety and costs are critical to their judgment about the future deployment of this technology. Technological improvements that lower cost while improving safety can increase public support for this energy source.

SECURITY OF NUCLEAR INSTALLATIONS AGAINST TERRORIST ATTACK

After the September 11 attacks in New York, there is greater understanding worldwide that terrorists have the ability to inflict catastrophic damage. Nuclear facilities as potential targets (of terrorist attacks) have not escaped notice. However, nuclear experts contend that civil works and security provisions make nuclear plants hard targets.

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In fact, nuclear plant safety itself is a good starting point for the evaluation of security risks. As a matter of routine, nuclear plant safety has considered natural external events, such as earthquakes, tornadoes, floods, and hurricanes. Terrorist attacks by fire or explosion are analogous to external natural events in the implication for damage and release of radioactivity. The strength of containment buildings and structures presents a major obstacle and the power plant is actually a hardened target for attack. However, a broad survey and evaluation of hazards and protective actions is in order to make decisions on adequate protection. Such an analysis must begin by identifying possible modes of attack and vulnerabilities associated with designs and locations. It must also identify the cost-effectiveness of a range of security options for new designs, old plants near decommissioning, and plants in mid-life. There is also a need for sharing information with governments of other countries and supporting institutions that will undertake nuclear power programmes in order to provide effective intelligence and security.

CONCLUSION

Adequate supply of energy is essential for continued industrial and socio-economic development, especially for a developing country like India with increasing population and urbanisation. Nuclear power is an important source suited for meeting energy demands and it will be increasingly necessary to expand this source of energy in the national energy mix. Although nuclear power involves handling and generation of radioactive materials, it is a technology whose hazardous effects are well understood and controlled. Moreover, it is a technology that has developed with strict regulatory control and realises that it is always under public scrutiny. Hence, the industry itself realises the need for emphasis on safety at every stage.

While there can be no nuclear activity or nuclear plant design that is totally risk-free, with the benefit of experience and improvements in reactor designs and adoption of enhanced safety features, plant performance has improved over time to unit capacity factors of 90 per cent and higher, even as the incidence of major mishaps in nuclear power generating units has drastically reduced. Indeed, over five decades of experience have taught the nuclear community a number of lessons, including the introduction of inherent safety features, defence-in-depth, and better emergency planning, conduct of independent peer reviews and feedback of operating experience at reactors worldwide, so that operators share information and there is the evolution among plant owners and managements of a safety culture. Actions and initiatives in training and qualification of reactor operators that have been implemented by organisations are major factors in the performance improvements and are manifest in the fact that a number of events at reactors that could have been headed for an accident were stopped short. Above all, there is a tacit understanding worldwide that safe operations require effective regulation, a management committed to safety and a skilled workforce.

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Evidently then, if used safely, the benefits of the use of radiation and radioactive materials under controlled conditions greatly outweigh the risks. Hence, it would be foolish to give up the use of fission because of fear of radioactivity contamination. As has been said earlier, the chances of this are less than one in a million. In fact, risk is an inevitable part of life and its many activities, even such banal ones as walking or driving down the street. Table 2 is demonstrative in this regard.

Table 2

Activity	Chance of Death per year
Smoking 20 cigarettes a day	1 in 200
Deep sea fishing accidents	1 in 400
Death due to natural causes 40 years old	1 in 500
Road accidents	1 in 5,000
Accidents at home	1 in 10,000
Accidents at work	1 in 20,000
Radiation work (2 mSv an year)	1 in 20,000

Source: Indian Association for Radiation Protection (IARP), "Natural and Man-Made Radiations Around Us", pamphlet issued as part of Public Awareness Programme, IARP, Mumbai.

Therefore, what is important is that the dangers of dealing with nuclear power are adequately understood and safety measures stringently employed to minimise, if not obviate the chance of accidents. Highest priority needs to be assigned to undertake reactor safety related research and development not only in areas of existing PHWR systems, but also for new concepts of reactors like the advanced heavy water reactors (AHWRs), prototype fast breeder reactors (PFBR), etc. which will soon be inducted into the Indian nuclear power programme. The goal of such R&D work should be to develop progressively improved mathematical models to represent components/sub-systems closer to reality. In the case of PFBRs, standard safety principles have been followed in the design, choice of materials, concepts and feedback from the operating experience of 300 reactor years of fast reactors.[11] Increased nuclear power will mean more safety concerns and a greater need for training and qualification of people competent to manage and operate NPPs safely, including the supporting infrastructure necessary for the maintenance, repair, refuelling and spent fuel management.

Achieving unimpeachable safety standards should be treated as a continuous journey and not as a destination. While the safety performance of India's

11. For more on detailed safety features incorporated into PFBRs see Om Pal Singh, S.C. Chetal and S.B. Bhoje, "Safety Design of Prototype Fast Breeder Reactor," in Gupta, n.7, pp. 38-59.

operating units is more than satisfactory, there is no room for complacency. Given the widespread impact that safety can have on the fate of nuclear power worldwide, the relevant procedures and their regular improvement need to be imbibed as an organisational culture so that safety that results is not induced but inherent. Improvements, or a constant update of safety procedures, is particularly important based on advanced R&D, worldwide operational experience, assessment of incidents and accidents, and changes in public opinion. At the same time, intangible parameters for safety excellence such as dedication, safety thinking, a questioning attitude, good communication, discipline and a methodical approach also need to be periodically stressed and rewarded. For nuclear safety there can be no goal less than AHARA or As High As Reasonably Achievable.

While the safety performance of India's operating units is more than satisfactory, there is no room for complacency.

APPENDIX 1

The International Nuclear Event Scale

For prompt communication of safety significance

Level Descriptor	**Off-Site Impact**	**On-Site Impact**	**Defence -in-Depth Degradation**	**Examples**
7 **Major Accident**	*Major Release:* Widespread health and environmental effects			Chernobyl, Ukraine, 1986
6 **Serious Accident**	*Significant Release:* Full implementation of local emergency plans			
5 **Accident with Off-Site Risks**	*Limited Release:* Partial implementation of local emergency plans	Severe core damage		Windscale, UK, 1957 (military). Three Mile Island, USA, 1979.
4 **Accident Mainly in Installation** either of:	*Minor Release:* Public exposure of the order of prescribed limits	Partial core damage. Acute health effects to workers		Saint-Laurent, France, 1980 (fuel rupture in reactor). Tokaimura, Japan 1999 (criticality in fuel plant for an experimental reactor).
3 **Serious Incidentany of:**	*Very Small Release:* Public exposure at a fraction of prescribed limits	Major contamination, Over-exposure of workers	Near Accident. Loss of Defence-in-Depth provisions	Vandellos, Spain, 1989 (turbine fire, no radioactive contamination). Davis-Besse, USA, 2002 (severe corosion)
2 **Incident**	nil	nil	Incidents with potential safety consequences	
1 **Anomaly**	nil	nil	Deviations from authorised functional domains	
0 Below Scale	nil	nil	No safety significance	

Source: International Atomic Energy Agency.

APPENDIX 2

Some Energy-Related Accidents 1977 - 2002

Place	Year	Number Killed	Comments
Machhu II, India	1979	2,500	hydro-electric dam failure
Hirakud, India	1980	1,000	hydro-electric dam failure
Ortuella, Spain	1980	70	gas explosion
Donbass, Ukraine	1980	68	coal mine methane explosion
Israel	1982	89	gas explosion
Guavio, Colombia	1983	160	hydro-electric dam failure
Nile R, Egypt	1983	317	LPG explosion
Cubatao, Brazil	1984	508	oil fire
Mexico City	1984	498	LPG explosion
Tbilisi, Russia	1984	100	gas explosion
northern Taiwan	1984	314	3 coal mine accidents
Chernobyl, Ukraine	1986	31+	nuclear reactor accident
Piper Alpha, North Sea	1988	167	explosion of offshore oil platform
Asha-ufa, Siberia	1989	600	LPG pipeline leak and fire
Dobrnja, Yugoslavia	1990	178	coal mine
Hongton, Shanxi, China	1991	147	coal mine
Belci, Romania	1991	116	hydro-electric dam failure
Kozlu, Turkey	1992	272	coal mine methane explosion
Cuenca, Equador	1993	200	coal mine
Durunkha, Egypt	1994	580	fuel depot hit by lightning
Seoul, S.Korea	1994	500	oil fire
Minanao, Philippines	1994	90	coal mine
Dhanbad, India	1995	70	coal mine
Taegu, S.Korea	1995	100	oil & gas explosion
Spitsbergen, Russia	1996	141	coal mine
Henan, China	1996	84	coal mine methane explosion
Datong, China	1996	114	coal mine methane explosion
Henan, China	1997	89	coal mine methane explosion
Fushun, China	1997	68	coal mine methane explosion
Kuzbass, Siberia	1997	67	coal mine methane explosion
Huainan, China	1997	89	coal mine methane explosion
Huainan, China	1997	45	coal mine methane explosion
Guizhou, China	1997	43	coal mine methane explosion
Donbass, Ukraine	1998	63	coal mine methane explosion

Liaoning, China	1998	71	coal mine methane explosion
Warri, Nigeria	1998	500+	oil pipeline leak and fire
Donbass, Ukraine	1999	50+	coal mine methane explosion
Donbass, Ukraine	2000	80	coal mine methane explosion
Shanxi, China	2000	40	coal mine methane explosion
Guizhou, China	2000	150	coal mine methane explosion
Shanxi, China	2001	38	coal mine methane explosion
Sichuan, China	2002	23	coal mine methane explosion
Jixi, China	2002	115	coal mine methane explosion

Source: World Nuclear Association.