CONTOURS OF INDIA'S NUCLEAR SAFETY

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An objective study on the 'safety' of high-technological systems is a difficult enterprise and more so of the nuclear industry. Inadequate social science theories exist to help understand the causes of 'reliability' in this hazardous and complex organisation. Also, important pieces of evidence about past events remain classified; thereby empirical analysis on nuclear safety organisational designs and strategies is circumscribed. One possibility is to assume, on the basis of 14,000 cumulative reactor years of commercial operation in 32 countries, that the danger from nuclear activity is minimal and nuclear energy can be harnessed in a safe and secure manner.[1] This assessment can also be challenged on the basis of nuclear history that has witnessed three severe nuclear disasters – Three Mile Island, Chernobyl and Fukushima Daiichi – in the most advanced nuclear-capable countries.[2] As a case in point, India has more than 260 reactor years of experience in the operation of nuclear reactors and various other applications.[3] Its nuclear plants are claimed to have survived the tsunami and earthquake, though of lesser degree. On the other hand, incidents of fire, construction

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1. "Safety of Nuclear Power Reactors", World Nuclear Association, January 2011, http://www.world-nuclear.org/info/inf06.html.
2. Meltdown of the Three Mile Island reactor (USA) in 1979 and Chernobyl accident (USSR) in 1986 and the recent one in Fukushima (Japan), March 2011.
3. *National Report* to the Convention on Nuclear Safety, September 2007, Government of India, p. 3, http://www.dae.gov.in/press/cnsrpt.pdf.

'Nuclear safety', therefore, is understood as "the creation and application of excellent management, design and operation to protect people and the environment from accidents, plant malfunctions and human error."

mismanagement, and radiation scare have also been reported, thereby the question often raised is: what organisational strategies and safety culture has India devised to prevent nuclear accidents and enhance the security of its nuclear infrastructure?

The sections that follow look into the mores of India's nuclear safe-keeping and operation within the context of a two-front dynamic change in vogue: (1) introduction of new nuclear power plants or rapid expansion of the existing nuclear power programme; and (2) wider use of radioactive sources and ionising radiation. Basically, what organisational model and practice has India evolved over the years in handling nuclear operations? Is it the trial and error method mixed with sheer luck that helped India to manage the nuclear operations or a conscious strategy of nuclear governance that characterises India's atomic energy discourse?

CONCEPTUALISING 'NUCLEAR SAFETY'

Nuclear technology issues are associated with long time commitment for safe possession, handling and security of nuclear material after the decision to embark on a nuclear power programme has been made. The reason being the enormous hazard that a nuclear operation would result in if not handled safely. 'Nuclear safety', therefore, is understood as "the creation and application of excellent management, design and operation to protect people and the environment from accidents, plant malfunctions and human error."[4]

These objectives are generally sub-divided into three categories.[5] (1) The *general nuclear safety objective* is to protect individuals, society and the environment from radiation harm by establishing and maintaining effective defences. (2) The *radiation protection objective* is to ensure that radiation

4. World Institute for Nuclear Security, "An Integrated Approach to Nuclear Safety and Nuclear Security", A WINS International Best Practice Guide, Revision 1.0, 2010, p. 3.
5. Gianni Petrangeli, *Nuclear Safety* (Butterworth-Heinemann, 2006), p. 1.

exposure within the installation or due to any planned release of radioactive material from the installation is kept below the prescribed limits and as low as reasonably achievable and to ensure mitigation of the radiological consequences of any accident. (3) The *technical safety objective* is to take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences; and to ensure, with a high level of confidence that all possible accidents are taken into account in the design of the installation to zeroing on the likelihood of accidents with serious radiological consequences. Consistent with the technical safety objective, the International Safety Advisory Group prescribes the target for power plants, to minimise the occurrence of severe core damage, to below about 10^{-4} event per Plant Operating Year (POY).[6] And, stringent implementation of all safety principles should lead to the achievement of an improved goal of not more than about 10^{-5} such events per POY.[7] The objective is to ensure siting and plant conditions complying with adequate health, safety and radio-protection principles. These involve broadly two interconnected aspects of "nuclear governance"[8] – nuclear safety and nuclear security, which also constitute the basis of a strong "nuclear safety culture".[9] As India is envisaging an ambitious nuclear energy expansion programme, it is pertinent to evaluate what general, radiation and technical safety measures India has nurtured and how entrenched the nuclear safety culture in the country is.

THE DYADIC DISCOURSE

Within the organisation theory literature, the debate over the reliability of complex technological systems is dyadic. The optimistic view represented

6. Ibid.
7. Ibid.
8. Nuclear governance comprises the civilian or non-civilian oversight and control mechanisms that encompass the state executive, specialised civilian and parliamentary institutions, the civil society, etc. Hans Born, "National Governance of Nuclear Weapons: Opportunities and Constraints", Policy Paper – No. 15, Geneva Centre for the Democratic Control of Armed Forces (DCAF), 2007.
9. Nuclear safety culture as a generic term is associated with three major factors: viable nuclear management system; widely shared awareness of nuclear hazards; and self-controlled behavioural norms and values regarding nuclear safety. Giovanni Verlini, "The Mindset of Nuclear Safety", http://www.iaea.org/Publications/Magazines/Bulletin/Bull501/NS_Mindset.html

by the "high reliability theory" revolves on the possibility of extremely safe operation of complex technology; on the other hand, the pessimistic view represented by the "normal accident theory" asserts the inevitability of serious accidents with complex high technology systems.[10] Both assertions seem to bear logic; therefore, it is difficult to judge which assertion wins the test.

The High Reliability Organisation Theory

The high reliability organisation approach asserts that extremely safe operation of highly hazardous technologies can be possible if appropriate organisational design and management techniques are followed. According to Joseph Marone and Edward Woodhouse, "Given the challenge posed by modern technologies, the record is surprisingly good" because of the "systematic product of human actions" in the management of toxic chemicals, nuclear power, recombinant DNA research, ozone layer depletion, etc.[11] Aaron Wildavsky, the author of *Searching for Safety*, asserts that the increase in safety occurs due to entrepreneurial activity in complex systems as it shifts the focus from "passive prevention of harm to a more active search for safety".[12] These assertions are based not on the belief that human beings are perfectly rational; rather, on the belief that organisations, properly designed and managed, can be significantly more rational and effective than individuals.[13]

However, the preconditions for ensuring such reliability depend mainly upon four factors as the route of extremely reliable operations: (1) prioritisation of safety and reliability as a goal by the leadership; (2) high levels of redundancy in personnel and technical safety measures; (3) development of a high reliability culture continually practised in decentralised operations; and (4) sophisticated forms of trial and error

10. Scott D. Sagan, *The Limits of Safety: Organisations, Accidents, and Nuclear Weapons* (New Jersey: Princeton University Press, 1993).
11. Joseph G. Marone and Edward J. Woodhouse, *Averting Catastrophe: Strategies for Regulating Risky Technologies* (Berkeley: University of California Press, 1986), p. 5.
12. Aaron Wildavsky, *Searching for Safety* (New Brunswick, N.J.: Transaction Books, 1988).
13. Sagan, n. 10, p. 16.

organisational learning.[14]

When high reliability propositions are examined in the Indian context, obvious questions crop up as to where do India's nuclear related organisations fit in? What are the contours of India's nuclear safety culture? What system does India's nuclear establishment follow in safe-keeping and safe-operation of the technology and resources, starting from the exploration to the safe disposal of waste products? Are redundancy features of Indian nuclear facilities adequate and reliable to withstand unexpected and unforeseen contingencies?

The Normal Accidents Theory

Another set of scholars, by considering the nature and functioning of complex organisations, argue that one may work hard to maintain safety and reliability, but serious accidents are nonetheless a "normal" result or an integral characteristic of the system. According to Charles Perrow, the author of *Normal Accidents: Living with High-Risk Technologies*, "Serious accidents are inevitable, no matter how hard we try to avoid them."[15] He identifies two specific structural characteristics of organisations operating hazardous technologies – (1) interactive complexity; and (2) tight-coupling – which make them highly accident prone regardless of the intent of their operators.

The normal accidents theorists' view is that the nuclear industry as an extremely complex and nuclear energy production process, is not a set of independent and serial steps, rather, it requires many coordinated actions by numerous mechanical components and operators. In this set-up, critical components are kept, by necessity, in close proximity within a containment building, increasing the possibility of 'unplanned interactions'. For example, on the question of whether the zirconium and water outside the fuel rods could interact under extreme heat and produce dangerous hydrogen bubbles, the accident at Three Mile Island (TMI) proved that this was possible.[16] Also, power plant operators cannot directly observe all the

14. Ibid.
15. Charles Perrow, "Accidents in High Risk Systems", *Technology Studies 1*, no. 1, 1992; also *Normal Accidents: Living with High-Risk Technologies* (New York: Basic Books, 1984), p. 3.
16. Sagan, n. 10, p. 33.

Keeping both the theoretical arguments in mind, one may enquire about the extent to which the Indian nuclear industry is susceptible to accidents and equipped to mitigate them.

components involved in the production process—they rely on numerous warning devices, control panel lights, and redundant monitoring systems to manage operations which can be fallible. Such "freakish incidents are inevitable" in organisations with high interactive complexity as per the normal accident theorists.

"Tight coupling", is the second structural condition in the hazardous industries like nuclear energy and is subject to accidents that may escalate a minor accident to a complete disaster. The normal accident theory views nuclear energy production as a highly time-dependent and precise process where planned and unplanned interactions of different parts of the system occur quickly. Because of invariant production sequences and lack of slack in these systems, there is limited opportunity to improvise when things go wrong.

However, the two schools have a common estimate about the probability of dangerous accidents despite the difference in the tone of their conclusions.[17] The current global trend in the nuclear safety discourse seems to be guided by the conclusion of the high reliability logic that rests on the belief that "isolation away from society, intense socialisation, and strict discipline of organisation members," as in the ideal military model, can enhance reliability and safety. The trend in India certainly leaned towards the high reliability logic. In consonance, India has evolved its nuclear safety culture which seems struggling within a vicious circle of misinformation and misinterpretation owing to lopsided management of nuclear information.

PERSPECTIVES ON INDIA'S NUCLEAR SAFETY

Keeping both the theoretical arguments in mind, one may enquire about the extent to which the Indian nuclear industry is susceptible to accidents and equipped to mitigate them. Besides some minor incidents

17. Ibid., p. 48.

of mismanagement, the Indian nuclear infrastructure has not experienced any horrendous accidents beyond Level-3 in the International Nuclear Event Scale (INES).[18] Can one assume that the normal accident theoretical assumptions are inapplicable to the Indian nuclear organisational culture? Then, what is the decision-making and management of the interactive complexity system in India's nuclear energy production process? What model does the Indian nuclear establishment adhere to, to enhance intense socialisation of the operators, strict discipline of the organisation and its members, and warning systems, to early visualise any malfunctioning?

Besides use of radioactive materials in numerous civilian uses across the country, India has currently 20 operational reactors [18 Pressurised Heavy Water Reactors (PHWRs) and 2 Boiling Water Reactors (BWRs)], 8 are under construction [5 PHWRs, 1 Prototype Fast Breeder Reactor (PFBR), and 2 VVERs], and 36 more [6 PHWRs, 2 Fast Breeder Reactor (FBRs), and 28 Light Water Reactors (LWRs)] have been proposed.[19] Whatever may be the pace of these projects at present, India is going to experience increasing nuclear activities in the decades ahead. The strategy is to diversify nuclear energy production by involving several public sector undertakings and private partners, therefore, the safety of reactors, nuclear materials and their operation would be an overriding concern.

The safety record of India's nuclear establishment, though viewed by the majority with pride and respect, is often criticised by a few as "false claims."[20] The second group, like the normal accident theorists, comprises mainly the anti-nuclear activists (some of them with left-leanings) who reject India's exploration of nuclear energy on the grounds of both safety

18. The Narora fire incident of March 31, 1993, was rated by the INES scale at Level-3 (serious incident) mainly on account of the degradation of defence-in-depth of engineered safety features during the incident. The KAPS-1 incident of March 10, 2004, involving failure of the reactor regulating system during preventive maintenance on Power UPS-1 was rated by the AERB at Level-2 (incident) as per INES. Other two Level-2 incidents took place in 1998 and 2002. Many other "anomalies" or "deviations" have occurred during the past decades from which Indian scientists have, in fact, drawn lessons for improving the safety mechanisms in place.
19. Anil Kakodkar, "India's Nuclear Challenges 2010-2020", paper presented at CAPS seminar held on September 29, 2010, at IIC, New Delhi.
20. Buddhi Kota Subbarao, "India's Nuclear Prowess: False Claims and Tragic Truths", *MANUSHI*, no 109. pp. 20-34.

and environmental concerns. For example, Praful Bidwai is of the view, "Nuclear accidents happen because of the nature of nuclear technology. Natural calamities only make them more likely. All reactor designs are vulnerable to core-meltdown accidents."[21] The second category, comprising mainly the former members of the nuclear establishment and academics/researchers and scientists,[22] highlights India's nuclear organisational loopholes and the regulatory framework as "a total farce". For example, A.H. Nayyar, M.V. Ramanna and others argue that "spending more money on safety cannot stop small failures combining to produce a disaster, and may cause new problems…. nuclear reactors and people don't mix. People can cause accidents and accidents affect people. Operator error contributed to the accidents… ."[23] These cynics claim that India's nuclear power stations are "mismanaged", and that innumerable violations of minimal safety standards have been "covered up"; the regulatory body, the Atomic Energy Regulatory Board (AERB), has "no autonomy"; and, "a veil of secrecy" covers the nuclear power programme which "comes in handy to hide from public scrutiny the vast sums that are being wastefully spent to produce a tiny amount of our power requirements."[24]

The third group, resembling the high reliability theorists, consists of the scientific community, government officials, retired military personnel, journalists and some research scholars, who consider nuclear energy as a viable source for meeting India's future energy demands and feel that

21. Praful Bidwai, "Learning from Fukushima: India Must Put Nuclear Power on Hold," http://www.tni.org/article/learning-fukushima-india-must-put-nuclear-power-hold, April 2011.
22. Former AERB Chairman Dr A. Gopalakrishnan claims that he has documentary evidence to prove that "all is not well" with India's nuclear installations. Reportedly, AERB, under his chairmanship, had compiled a list of more than 130 nuclear issues affecting the safety of the Indian nuclear establishment. *The Times of India* (Mumbai) June 18, 1996; M.V. Ramanna, a physicist at the Programme on Science and Global Security, Princeton University (US), argues that the breeder reactors that India is resting its nuclear energy vision on, should be given up. According to him, the history of poor operations, lapses of safety at the many facilities run by DAE and its sister organisations, indicate that the safety of the country's nuclear facilities is indeed a matter of concern. "Safety First? Kaiga and Other Nuclear Stories", *Economic & Political Weekly*, vol. xlv, no. 7, February 13, 2010, pp. 47-54.
23. Zia Mian, A.H. Nayyar, M.V. Ramana, "South Asia's Misplaced Confidence in Nuclear Technology", http://www.tni.org/article/south-asias-misplaced-confidence-nuclear-technology, April 2011.
24. Subbarao, n. 20, p. 20.

India's nuclear establishment is capable of delivering it efficiently and cheaply. This trend is a continuity of the legacy established by India's early political leaders like Nehru and scientists like Bhabha and their succeeding generation, who have always viewed nuclear energy as a remedy for India's energy ailment. This group has been able to tout throughout India's history that nuclear power is a superior solution to India's growing appetite for energy. Responding to the allegation of nuclear accidents and disasters, they assert that disasters occur in all industries but the nuclear industry gets unprecedented attention owing to the negative popular perception of anything nuclear. The reports by the Nuclear Power Corporation of India Limited [NPCIL – which is responsible for the design, construction, commissioning and operation of Nuclear Power Plants (NPPs)] and Atomic Energy Regulatory Board (AERB – which monitors and lays down the safety regulations of NPPs) assert that "safety is accorded overriding priority" in the entire gamut of activities. While the NPCIL official "profile" claims that "no nuclear *accident* as defined by INES of IAEA has occurred so far in about 298 reactor years of operation of Indian nuclear power stations,"[25] the AERB report, "25 Years of Safety Regulation" (2008), reveals a number of nuclear safety *incidents*, the lessons learnt and the corrective measures undertaken.[26]

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However, a realistic evaluation on the claim that "India's safety record

25. "Profile", Nuclear Power Corporation of India Limited, http://www.npcil.nic.in/pdf/NPCIL%20Profile%20English.pdf, p. 5.
26. A. R. Sundararajan, K. S. Parthasarathy and S. Sinha, *25 Years of Safety Regulation*, AERB, Government of India, November 2008.

has been excellent"[27] needs to be undertaken keeping the Plant Load Factor (PLF)[28] in mind as all Indian reactors have not run up to their full capacity yet.[29] The gross life-time capacity utilisation factor of Indian reactors varies between 37 to 60 percent.[30] When more imported uranium reaches India, and more reactors from different operators come online, more safety related issues would emerge, thereby stringent safety measures would be required. To ensure fool-proof safety of nuclear operations, adequate technical expertise and stringent regulatory mechanisms are the preconditions. The question is: how capable is our nuclear regulatory body to identify the loopholes beforehand? The AERB, as viewed by many, "has no autonomy as it depends on DAE (Department of Atomic Energy) for funds, manpower, technical expertise and material resources." It is also expressed that there is a "vacuum of nuclear expertise outside the DAE" for independent criticism for its functioning.[31] Therefore, to assess the safety culture of India's nuclear establishment, one needs to examine mainly the nature of the organisational functioning of the Indian nuclear establishment, the technical capabilities of the regulatory body and the safety principles it adheres to.

NATURE AND FUNCTIONING OF REGULATORY AUTHORITY

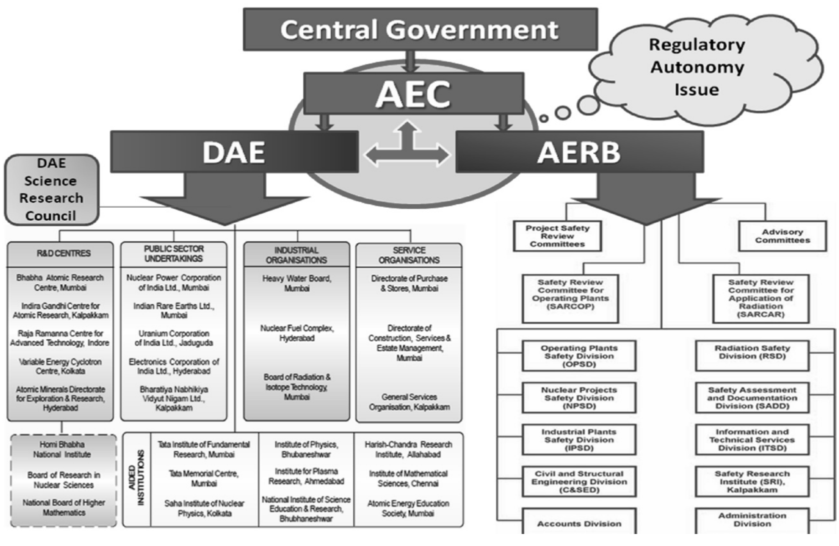
Under the provisions of the Atomic Energy Act (1948), the Atomic Energy Commission (AEC) was constituted in 1948 to frame national policies on nuclear energy production. The DAE, established in 1954, is responsible for the execution of the policies laid down by the AEC. For review and verification of safety related issues, the AERB was constituted on November

27. n.3, p. 3.
28. Plant load factor is the amount of power produced by a generator divided by the engineering capacity of the unit. Usually, load factors are stated for a year. The calculation, then, is the total kilowatt hours of power generated by the unit divided by the capacity of the unit in kilowatts times the number of hours in the year.
29. Five reactors (960 MW) use imported uranium and are being operated at high PLFs. Fourteen reactors are fuelled by domestic uranium which is not available in the required quantity. These reactors are being operated at lower power levels to match the fuel availability, resulting in lower average PLF. The government has taken a series of measures to augment fuel supply from domestic and import sources which have resulted in increase in average annual PLF from 50 percent in 2008-09 to 61 percent in 2009-10. http://indiacurrentaffairs.org, May 6, 2010.
30. A. Gopalakrishnan, "Issues of Nuclear Safety", *Frontline*, vol. 16, no. 6, March 13-26, 1999.
31. Subbarao, n. 20, p. 20.

15, 1983, directly under the AEC as an "independent regulatory authority", "totally independent of the DAE".[32] While the DAE is mainly responsible and coordinates the production and Research and Development (R&D) through its four sectors, the AERB is a unique organisation with great social responsibility that derives its authority from the Atomic Energy Act (1962) and the Environment Protection Act (1986) to ensure that any atomic activity does not cause undue harm to the health of the workers, the public and the environment. The AERB also administers the provisions of the Factory Act 1948 in the units of the DAE under its jurisdiction.[33]

The DAE is the promotional agency and the AERB is the regulatory body.

Fig 1: Position of the Regulatory Body in Government Set-Up



The Issue of Regulatory Autonomy

As per international practice, the regulatory and operational functions of national nuclear energy matters must be separated. Section 8.2 of the

32. *National Report to the Convention of Nuclear Safety*, AERB, September 2007, http://www.dae.gov.in/press/cnsrpt.pdf, p. 6.
33. "Code of Ethics", AERB, Government of India, http://www.aerb.gov.in/t/publications/ethics.pdf, p. 1.

Both the DAE and NPCIL exercise administrative powers over the AERB. Therefore, it is viewed that there are institutional limits on the AERB's effectiveness.

Convention on Nuclear Safety, which India ratified in 2005, says that a member-state should have a nuclear regulatory agency totally independent from the promotional agency.[34] In India's case, the DAE is the promotional agency and the AERB is the regulatory body. Though the AERB proclaims functioning independently and has performed so, the organisational patterns, compositions, and functions of the three units – the AEC, the DAE and AERB – give an impression that this body is a "captive". The mandate of AERB is to put down and monitor the observance of safety standards for siting, design, construction, operation and decommissioning of nuclear and radiological facilities in the country independently. It comprises, and is supported by, eight technical divisions and a number of committees that help oversee implementation of the mandate. However, for most of its overseeing activities, it draws its personnel from the AEC and reports also to the AEC whose Chairman is the DAE Secretary. The Chairman of the NPCIL is also a member of the AEC.

The issue here has been the composition of the AEC. The Managing Director of the NPCIL and the Director of the Bhabha Atomic Research Centre (BARC) are members of the AEC, but the Chairman of the AERB is not a member of the same. Thus, both the DAE and NPCIL exercise administrative powers over the AERB. Therefore, it is viewed that there are institutional limits on the AERB's effectiveness. Normally, both the DAE and the NPCIL are under the regulatory authority of the AERB. The major factors that make the regulatory body subservient to the other bodies are its lack of technical staff and testing facilities. According to A. Gopalakrishnan:

> … 95 percent of the members of the AERB's evaluation committees are scientists and engineers on the payrolls of the DAE. This dependency is deliberately exploited by the DAE management to influence, directly and indirectly, the

34. "Convention on Nuclear Safety", INFCIRC/449, IAEA, July 5, 1994, http://www.iaea.org/Publications/Documents/Infcircs/Others/inf449.shtml.

> AERB's safety evaluations and decisions. The interference has manifested itself in the AERB toning down the seriousness of safety concerns, agreeing to the postponement of essential repairs to suit the DAE's time schedules, and allowing continued operation of installations when public safety considerations would warrant their immediate shutdown and repair.[35]

It is also alleged that all radiation measurements and exposure evaluations are done by the health physics personnel employed by the DAE. These personnel, stationed at the facility, carry out the measurements and the DAE then provides the data to the AERB. These DAE physicists receive a monthly bonus from the NPCIL in proportion to the quantum of energy produced. If a reactor is shut down on the recommendation of a station health physicist, the bonus is lost.[36]

Therefore, the issue of the autonomy of the AERB has been raised, as it depends heavily on the support of, and reports to, the bodies whose modalities it is supposed to oversee. A small committee was set up by Dr Ramanna, Dr Abdul Kalam and others to consider this issue, but they concluded that there was no need for any change.[37] According to G. D. Mittal, a former BARC scientist, "It hardly matters whether the AERB reports to DAE or to the Prime Minister. This is because the people who will head or manage the AERB will be the same. So, the AERB in the present format is quite independent in its functioning."[38]

The merit of the issue should be judged not from the allegations but from any instance of safety compromise that the AERB may ever have committed. The current AERB Chairman S. S. Bajaj says, "We have never compromised on the safety of the plants and the workers, and even went to the extent of shutting down the operating plants till the required safety measures were implemented by the operators on several occasions…. We can quote several occasions when we had suspended the operations of the

35. Gopalakrishnan, n. 30.
36. Ibid.
37. "Complete Independence of AERB and Full Transparency, an Imperative – Interview with A. Gopalakrishnan", http://newsclick.in, March 25, 2011.
38. "Is India's Nuclear Regulator Independent Enough", http://news.in.msn.com, March 21, 2011.

Ensuring safety is a coordinated effort and utilising the expertise of the other wing of the organisation is prudent. Safety in the nuclear industry is paramount and the regulatory body should not be callous about it but too much emphasis on procedural issues can sometimes drive the organisation away from substantive issues.

plant or construction work for not following safety norms at different sites of NPCIL."[39] The AERB has full power to operate its budget which is allocated by the central government in the separate account head of the AERB. The regulatory body has also its own Safety Research Institute at Kalpakkam, Chennai.

It is easy to point fingers instead of understanding the compelling reasons why the AERB has remained associated with the DAE since its inception. For many decades, India was under a technology embargo, therefore all domestic resources and expertise had to be mobilised. A watertight compartmentalisation between two wings of the same establishment could have fractioned our nuclear ambition by generating an unnecessary tussle. Also, safety issues involve a lot advanced research and experiments which the DAE institutions can provide. Ensuring safety is a coordinated effort and utilising the expertise of the other wing of the organisation is prudent. Safety in the nuclear industry is paramount and the regulatory body should not be callous about it but too much emphasis on procedural issues can sometimes drive the organisation away from substantive issues and the integrity gets diluted. The idea of making the AERB independent is mooted in comparison to the procedures of the Railway Safety Commission which does not report to the Railway Board but to the Department of Civil Aviation. The same is the case with the mine safety organisation whose Chief Inspector is part of the Department of Labour. But the question is: should nuclear safety oversight reports and findings be placed in front of a non-nuclear expertise organisation?

The bottom line rather is to strengthen the current power and position of

39. "Legislation can Strengthen AERB's Autonomous Status," http://ibnlive.in.com/generalnewsfeed/news/legislation-can-strengthen-aerbs-autonomous-status/626417.html, March 28, 2011.

the AERB by providing it statutory status through suitable legislation and amending the Atomic Energy Act. The rationale being that when the NPCIL is joining hands with large public sector companies and more power plants are on the cards, the responsibility and functioning of the regulatory body needs to be revamped. Environment Minister Jairam Ramesh has recently proposed the conversion of the AERB into an independent statutory body—something on the lines of the Nuclear Regulatory Commission of the USA—completely delinking it from the DAE and AEC.[40] However, ensuring nuclear safety should not come about by squeezing the progress of nuclear technology and overemphasising the procedural aspects. It needs to be kept in mind that technology misunderstood and mismanaged is development missed. However, the decision to transfer the regulatory and safety review functions related to BARC from the AERB to an internal safety committee structure of BARC in June 2000 is bound to trigger scepticism about the integrity of the nuclear regulatory provisions.

The *Annual Report* of the AERB, the half-yearly newsletter, provides minute details of the activities of the body, and various monographs and guides provide ample perspectives on its functioning.

The Issue of Transparency

As complete opacity prevails around nuclear plants and the functioning of the nuclear establishment, many critics reject the results of the safety audit and oversight by the regulatory body.[41] Secondly, the public is unaware of the safety issues and what the nuclear establishment is doing, the problems they face and the solutions that are applied. However, these allegations do not seem to be based on firm ground for two reasons. First, public perception on anything nuclear is negative; therefore, gradual and controlled information dissemination is prudent, to avoid spreading unnecessary panic and chaos among the public. The government and the scientific community is extra careful to retain the confidence of the public. Second, how transparently the

40. "Jairam: Time for Independent AERB", *The Indian Express*, March 28, 2011.
41. "Need for Independent Review of Indian Nuclear Plants", Roger Reports, http://rogeralexander.worldpress.com, March 30, 2011.

AERB functions and conducts its oversight function can be perceived from the numerous reports and studies it brings out. The *Annual Report* of AERB, the half-yearly newsletter, provides minute details of the activities of the body, and various monographs and guides provide ample perspectives on its functioning. All reports and activities are promptly available on its official website. Especially, the "25 Years of Safety Regulation" (2008), a silver jubilee publication of the AERB, places in the public domain, in great detail, the safety-related issues of the last 25 years of its existence, the challenges faced and the way they were resolved.

In fact, during the last 25 years, the AERB has grown from a handful of scientists and engineers to a vibrant institution of more than 200 personnel now.[42] Its professional strength and quality management system are vindicated by the fact that in 2006 it secured the ISO-9001:2000 certification from the Bureau of Indian Standards. The AERB uses the accredited system for formulating and enforcing its rigorous safety norms, for carrying out in-depth safety review and conducting elaborate and effective regulatory inspections of the nuclear and radiation facilities. All Indian NPPs have been awarded the ISO-14001 and ISO-18001 for their Environment Management System.[43] Similarly, the Quality Assurance (QA) Directorate and Engineering Directorate of NPCIL have been awarded the ISO-9001 for quality assurance and design respectively.[44] As part of this international standardisation, both these directorates have issued policies which have a strong bearing on the safety of NPPs.

At the international level, the AERB has been actively involved in many forums like the CANDU Senior Regulators Group, VVER Regulators Forum, Nuclear Regulatory Commission of the USA, Nuclear Safety Authority of France, Federal Nuclear and Radiation Safety Authority of Russia, World Association of Nuclear Operators (WANO), and International Nuclear Event Scale (INES). However, the issue of transparency and the domestic nuclear safety debate need to be viewed in the overall discourse of the nuclear

42. n. 3.
43. R. Deolalikar, "Safety in Nuclear Power Plants in India", *Indian Journal of Occupational and Environmental Medicine*, vol. 12, no. 3, September-December, 2008, pp. 122-127.
44. *21st Annual Report 2007-08*, NPCIL, http://www.npcil.nic.in/pdf/annual_report07_08.pdf, p. 38.

safety culture that India follows. Perceptibly, India's nuclear establishment has adhered to a limited and selective nuclear information management system which has resulted in gross misunderstanding and confusion.

INDIA'S NUCLEAR SAFETY FRAMEWORK

Right from the early days, a distinguishing feature of the Indian scientific community has been their realisation and consciousness of the utility of atomic energy for national development and, at the same time, they were equally conscious of the hazards of the nuclear industry. When the Indian atomic energy programme was initiated with the formation of the atomic energy establishment in 1954 and the Apsara research reactor was commissioned in 1956, the safety of the plant was ensured through self-regulation. The directive which Bhabha issued on February 27, 1960, considered as the safety mission statement, reads:

> Radioactive material and sources of radiation should be handled in the Atomic Energy Establishment in a manner, which not only ensures that no harm can come to workers in the Establishment or anyone else, but also in an exemplary manner so as to set a standard which other organisations in the country may be asked to emulate.[45]

Nuclear Safety During the Early Years

During the early years, there was no formal regulatory body to oversee the safety aspects of India's nuclear facilities—it was mainly ensured through *self-regulation*. When DAE started the design and construction of its first research reactor Apsara in 1955, there was no formal safety analysis report. The designers of the reactor, on their own, ensured the safety of the system. Bhabha personally reviewed and directed the design. When the second research reactor CIRUS came up, a design and safety report was prepared at the insistence of the Canadian authorities. With the expansion of nuclear activities in India, the necessity of stringent nuclear safety oversight was felt, thus, the

45. Quoted in "Message from M.S.R. Sarma", http://www.aerb.gov.in/T/sj/book/appendix.pdf, p. 229.

Now when independence of the AERB is mooted, it must be kept in mind that the cohesion with which different divisions of the Indian atomic establishment have so far functioned should not be disturbed.

health physicists were assigned nuclear facilities to provide safety surveillance. In 1962, Bhabha set up a formal reactor safety committee with A.S. Rao as the Chairman, and V. Surya Rao, V.N. Meckoni and A.K. Ganguly as members. This committee devised a scheme of multi-level safety review of reactors. In 1963, the Health Physics Division brought out a Manual for Radiation Protection in the Atomic Energy Establishment (AEET, which became BARC in 1966). Bhabha made it mandatory for all the nuclear facilities to follow this manual.

In the same year, the Directorate of Radiation Protection (DRP) was constituted for monitoring the non-DAE radiation facilities, with P.N. Krishnamoorthy as the Deputy Director. In 1969, when the Tarapur reactors were ready for commissioning, there was no such regulatory system in place. Sarabhai set up an independent committee to review the commissioning activities. In 1972, when Unit 1 of the Rajasthan Atomic Power Station (RAPS-1) was about to be commissioned, the committee for Tarapur was renamed as the DAE Safety Review Committee (DAE-SRC) and safety review of RAPS-1 was accorded to it.[46] In 1973, both the Health Physics Division (HPD) and the DRP were brought under the Chemical Group of BARC headed by A.K. Ganguly who played a pioneering role in solving safety-related issues and formulating and setting up a culture of nuclear safety consciousness. The DRP, renamed as Division of Radiological Protection (DRP) in 1972, was responsible for radiation protection surveillance of hospitals, industries and research institutes, authorising users to procure radioactive sources. The HPD of BARC provides safety surveillance of DAE facilities and the Directorate of Radiation Protection is the competent authority to oversee the regulation of radiological safety in non-DAE facilities. The HPD controls the personnel radiation exposures, effluent discharges and radiological conditions within the NPP through Health Physics Units (HPU) established

46. Sundararajan, n. 26, p. 13.

at each nuclear plant.[47] It also carries out environmental surveillance around the NPPs through Environmental Survey Labs.

One finds sufficient interdependence and interconnectedness among the various organs of the nuclear establishment in an evolutionary manner during the early years. However, all these safety departments, irrespective of their name labels, have always functioned as independent units.[48] Now when independence of the AERB is mooted, it must be kept in mind that the cohesion with which different divisions of the Indian atomic establishment have so far functioned should not be disturbed for the sake of making one wing more autonomous than, and from, the other.

Nuclear Safety Framework in Vogue

The current nuclear safety culture of India, described as based on the principles of 'zero tolerance', 'defence in-depth', 'redundancy' and 'diversity', has its roots in the sustained and coordinated efforts by different organs of the nuclear establishment during the past decades. The responsibility to ensure the safety of nuclear facilities, especially nuclear power plants, today rests with the AERB, created on November 15, 1983.

In coordination with its eight technical divisions, Safety Review Committees – the Safety Review Committee for Operating Plants (SARCOP) and Safety Review Committee for Applications of Radiation (SARCAR) – and advisory committees, the AERB has set a tradition of maintaining safety in nuclear facilities as an overriding priority. The codes, guides and standards issued by the AERB are the mandatory basis for the NPCIL's operation of NPPs. Firstly, systematic approaches using well-defined principles are practised in the design of the NPPs. Secondly, during normal plant operation, the ALARA (As Low As Reasonably Achievable) principle is followed to limit the radiation exposure. The operational and maintenance strategies of Indian NPPs are based broadly on two aspects: design basis safety and operational nuclear safety.

To ensure **design basis safety** of the NPPs, the following *design safety principles and procedures* are practised during the process of design,

47. *Annual Report 2009-2010*, AERB, Government of India, p. 25.
48. Sundararajan, n. 26, pp. 10-11.

manufacturing, construction and commissioning of different components.

Defence-in-Depth: The defence-in-depth principle consists of several successive levels like surveillance, protection and safeguards regarding three fundamental safety functions of safe shut-down, heat removal from core and confinement of radioactivity.[49] This is ensured through high-quality design and construction of equipment, comprehensive monitoring and regular testing to detect equipment or operator failures, redundant and diverse systems to control damage to the fuel and prevent significant radioactive releases, and provisions to confine the effects of severe fuel damage to the plant itself. These can be summed up as: prevention, monitoring, and action to mitigate the consequences of failures.[50]

In pursuit of this, both national and international codes and guides are referred to during the design of the plants, with emphasis throughout to produce robust safety designs with sufficient safety margins to ensure safety under all normal operating conditions. To ensure this, strict control on manufacturing and commissioning procedures is maintained to ensure the intended design. To detect abnormal conditions and to control them, the system of 'control-set back-step back' is in place.[51] To mitigate the consequences of accidents, many design basis safety systems and engineered safety features like self-shutdown systems, emergency core cooling systems, and containments are provided. Also, to mitigate probable off-site release of radioactivity, radiation safety measures are in place.

Redundancy and Diversity

All safety systems installed are ensured with adequate redundancy and diversity to achieve specified reliability. Redundant provisions allow a safety function to be satisfied when one or more items (but not all) are unavailable, due to a variety of unspecified potential failure mechanisms. On the other hand, diversity requires having more than one way of doing the same thing so that if there is a generic failure that applies to all of the same type of equipment, then

49. n. 3, p. 159.
50. "Safety of Nuclear Power Reactors", http://www.world-nuclear.org/info/inf06.html
51. n. 3, p. 159.

there is also back-up for it.[52] Diversity particularly provides protection against inherent dependencies and human error related dependencies.[53]

Passive Safety

Traditional reactor safety systems are 'active' in the sense that they involve electrical or mechanical operation on command. Some engineered systems operate passively, e.g. pressure relief valves. "Passive" safety design depends only on physical phenomena such as convection, gravity or resistance to high temperatures, not on functioning of engineered components. In the new designs of Pressurised Water Reactors (PWRs) there is a series of valves and pipes designed to supply an "emergency core cooling system". They rely upon natural means, including gravity fed water from tanks, to transfer heat from the fuel. Passive systems avoid reliance on nuclear operators to deal with emergency situations, and, thereby, try to remove human and emergency power supply errors.[54]

System of Segregation

Despite redundant systems and diverse provisions, the threat of 'common cause failures' particularly from hazards like fire may take place because of complex interaction among varied components and system. This is reduced by system segregation and isolation – physical separation of components by distance or barriers. This principle includes: separation by geometry (distance, orientation, etc.); separation by barriers; or separation by a combination thereof. Also, the functional isolation principle is used to reduce the likelihood of adverse interaction among equipment, components and systems of redundant or connected trains to achieve system independence, particularly in relation to certain common origin events which are not immediately apparent.

Fail-to-Safe Design: In the event of a plant failure, the principle

52. "Nuclear Reactor Safety", *Briefing*, January 2007, http://www.no2nuclearpower.org.uk/reports/Nuclear_Safety.pdf
53. "Diversity, Redundancy, Segregation and Layout of Mechanical Plant", T/AST/036 - Issue 02, http://www.hse.gov.uk/foi/internalops/nsd/tech_asst_guides/tast036.htm
54. "Safety of Nuclear Power Reactors", http://www.world-nuclear.org/info/inf06.html

The degree of safety depends on the quality of design, procurement, manufacture, construction, commissioning and operation of the NPPs.

incorporated into the design of Systems, Structures and Components (SSCs) of the plant is the *fail-to-safe*. This ensures that the plant which fails to operate goes into the safe mode, thus, not hindering the performance of a safety function. In the case of failure of the system or the component, the plant would pass into a safe state without a requirement to initiate any action.

Probabilistic Safety Assessment (PSA): Comprehensive safety analysis by a rigorous deterministic and complementary probabilistic method is followed for building scenarios for hypothetical accidents that might result in severe core damage, and to estimate the frequency of such accidents. This method assesses potential hazards that might be encountered in the absence of any protective measures, and the residual risks that will remain despite the measures taken.[55] India has learnt lessons by analysing incidents like the Three Mile Island and Chernobyl and closely monitoring the Fukushima event.

Quality Assurance: The degree of safety depends on the quality of design, procurement, manufacture, construction, commissioning and operation of the NPPs. The AERB Code of Practice on "Quality Assurance for Safety in Nuclear Power Plants" establishes the requirements for the management principles and objectives to be met in all activities in NPPs. In 2006, the NPCIL, in consultation with the AERB, revised the Topical Quality Assurance document in line with the IAEA Safety Standard GS-G-3.1 on "Application of Management System for Facilities and Activities". The revised document on "Corporate Management System – Quality Management System Requirements" lays emphasis on an integrated approach for the management system for safety, health, environment, security, quality and economic requirements.[56]

Comprehensive Review and Assessment: This principle rests on the objective of emphasis on *prevention of an accident rather than its mitigation*. Prior to the issuance of authorisation for construction, the AERB completes

55. "Probabilistic Safety Assessment", http://nuce.boun.edu.tr/psaover.html. p.3.
56. *National Report*, n. 3, p. 104.

the review of the Preliminary Safety Analysis Report (PSAR). At this stage, the effort is directed at the safety analysis of Design Basis Events (DBEs). The regulatory authority then considers the acceptability of the Postulated Initiating Events (PIEs).

The **operational nuclear safety** practice of Indian NPPs rests on internationally recognised principles and practices. First, the dose limits on radiation exposure for normal plant operation are specified and observed in line with the International Commission on Radiological Protection (ICRP) recommendations. For occupational workers, the AERB has prescribed 20 mSv averaged over five consecutive years and a maximum of 30 mSv in any year. For the public at the exclusion zone distance, the AERB has prescribed an effective dose of 1 mSv per year.[57] The AERB approves the annual collective dose budget for each NNP. Normal natural background radiation in different parts of the country varies from 2.7 mSv/year at Tarapur (Maharastra) to 3.1 mSv/yr at Narora (Uttar Pradesh). But according to the detailed survey, the annual average maximum individual exposure at a plant boundary is less than 0.1 mSv/yr.[58]

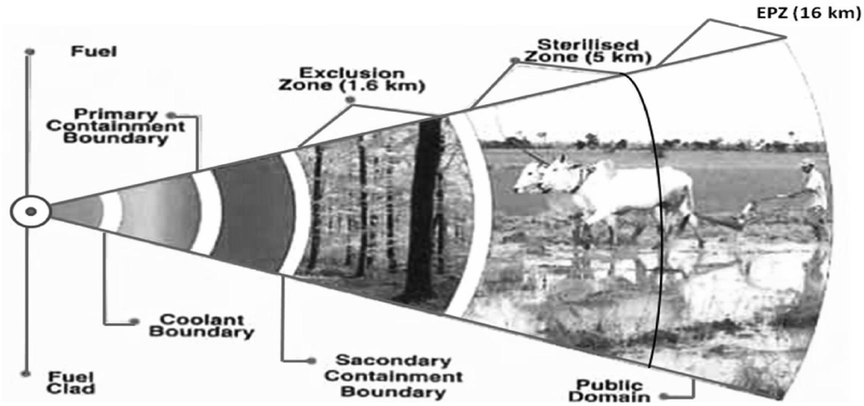
Second, only qualified and licensed staff operate the plants and all activities in the NPPs are carried out as per the operating procedures (AERB/SC/O) laid down by the AERB. Workers are allowed to function with the use of proper protective equipment and radiation work permits.

Third, all equipment and instruments are subject to periodic surveillance and in-service inspections. NPPs are also subject to corporate safety audit, regulatory inspections and peer reviews. Each station is subject to a peer review conducted by a group drawn from other stations owned by NPCIL. In the years 2007, 2008 and 2009, the World Association of Nuclear Operators (WANO) conducted 1 (Rajasthan 5), 2 (Kaiga 4 and Kakrapar) and 3 (Narora, Rajasthan 2, 3 &4, Tarapur 3&4) peer reviews of the Indian nuclear facilities respectively.[59]

57. Ibid., pp. 130, 133.
58. "Profile", Nuclear Power Corporation of India Limited, http://www.npcil.nic.in/pdf/NPCIL%20Profile%20English.pdf, p. 1.
59. "WANTO Review 09", http://www.wano.info/wp-content/uploads/2010/07/Review_2009.pdf, p. 8.

Fourth, all the plants are designed with multiple safety barriers and control zones to manage incidental release of radioactivity. Indian nuclear facilities are designed with a minimum of five successive barriers.

Fig 2: Multiple Safety Barriers



Source: National Report to the Convention on Nuclear Safety, November 2007, Government of India, p. 172.

In case of a radiological emergency, the confinement of radioactivity can be achieved by these independent barriers. They include the ceramic fuel pellet of UO2, fuel cladding of Zircalloy-2, primary system pressure boundary, primary containment and secondary containment. The Exclusion Zone of 1.5 km range radius is fully acquired and cordoned off from the public. The Sterilised Zone ranges 5 km radius from the plant where no new organised habitation is permitted. Beyond this, the Emergency Planning Zone (EPZ) ranges up to 16 km radius where constant monitoring of habitation and traffic is conducted. This zone is meant for the basic geographic framework for decision-making on implementing measures as part of a graded response in the event of an off-site emergency. It is divided into 16 equal sectors to optimise the emergency response mechanism and relief operations.

Fifth, for all significant events, Root Cause Analysis is carried out. The Station Operation Safety Committees (SORC) at each of the NPP review the safety issues. The Quality Assurance group stationed at the facility and the Audit Engineer are the channels of feedback on maintenance and operation of the plants.

Sixth, emergency preparedness plans for both on-site and off-site emergencies have been drawn up at all NPPs and are subject to periodic drills.

Seventh, to enhance the safety tradition, the Assessment of Safety Culture Organisation Team (ASCOT) conducts seminars, team building workshops, leadership development and sessions to improve inter-personnel relationships.

Lastly, as an attribute of robust nuclear safety culture, a Safety Conscious Work Environment (SCWE) is developed where every employee has the freedom to raise safety concerns without fear of retaliation.

India has "not lost even one life that is unambiguously attributable to an accidental *nuclear-emission* from a power plant. In India, more radiation-induced injury/deaths, and even a few genetic mutations, have been caused by malfunctioning/ poorly-handled medical imaging equipment.

"ANOMALIES" AND "INCIDENTS": LESSONS LEARNT

Though India's nuclear safety framework is sound and robust, instances of "anomalies" and "incidents" related to nuclear activities in the country have occurred, resulting in public scepticism about the technical and regulatory systems in place. However, no horrendous radiation hazard has taken place yet, nor is anyone known to have been affected by accidental radiation exposure in the Indian nuclear facilities. According to Dr. V. Siddhartha, the UNSC 1540 Committee Expert, and currently a Distinguished Fellow at the Centre for Air Power Studies (New Delhi), India has "not lost even one life that is unambiguously attributable to an accidental *nuclear-emission* from a power plant. In India, more radiation-induced injury/deaths, and even a few genetic mutations, have been caused by malfunctioning/poorly-handled medical imaging equipment and even perhaps from the low-level natural radiation from the sands of Kerala."[60]

60. E-mail interaction with Dr V. Siddhartha on March 25, 2011. Dr Siddhartha was the Scientific Adviser to the Defence Minister, Government of India.

The AERB maintains a yearly record of events on the basis of the Significant Event Reports (SER) from the operating NPPs. The events are divided into two categories: (1) Events; and (2) Significant Events, considering the gravity of the situation. They are also rated on the INES.[61] So far, the Indian nuclear facilities have faced one 'Level-3' event in 1993 (Narora fire incident) and three 'Level-2' events during 1998-2004. Out of the total reported events, a majority is in the 'Level-0' event category. On average, around 25-45 percent of the total events take place in the 'reactor primary', around 20-35 percent of the total events relate to 'electrical' problems and around 15-30 percent events take place in the 'instrumentation control'.[62] A majority of these are Level-0 events with "no safety significance." And, as Table 1 below shows, these events show a declining trend during the last one decade. This could be owing to the nuclear safety culture that India's nuclear establishment is evolving on the basis of the lessons learnt from past events and consequent corrective measures undertaken.

Table 1: "Events" Recorded by the AERB During 1998-2009

INES level	1993	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
0	--	22	16	42	43	26	21	39	26	34	38	28	23
1	--	5	2	10	2	5	10	4	2	5	8	4	0
2	--	**1**	0	0	0	**1**	0	**1**	0	0	0	0	0
3	**1**	0	0	0	0	0	0	0	0	0	0	0	0
>3	--	0	0	0	0	0	0	0	0	0	0	0	0
Total	--	**31**	21	54	45	32	31	44	28	39	36	24	23

Source: Compiled from AERB Annual Reports.

61. The INES system of the IAEA rates events at seven levels (1-7) depending on their safety significance. Events rated at Level-1 (anomaly), -2 (incident) and -3 (serious incident) are called 'Incidents'. Events rated at Level-4 (accident with local consequence), Level-5 (accident with wider consequence), Level-6 (serious accident) and Level-7 (major accident) are termed as 'accidents'. Events with no significance are rated at Level-0 or below scale. Security related events or malicious acts are not in the scope of the scale. http://www-ns.iaea.org/tech-areas/emergency/ines.asp
62. Compiled from *Annual Reports* during 20012002 to 2009-2010 of AERB.

While judging the frequency of incidents in the nuclear power plants, one needs to keep in mind their average occurrences per megawatt nuclear energy produced. Over the years India's nuclear energy production has increased, though slowly, while occurrences of anomalies in the plants have declined. Nuclear power supplied 15.8 billion kWh (2.5 percent) of India's electricity in 2007. After a dip in 2008-09, production is increasing as imported uranium becomes available and new plants come on line. For the year 2010-11, around 24 billion kWh is expected. For 2011-12, 32 billion kWh is now forecast.[63] However, no complacency is warranted even on a minor irregularity and the Indian scientific establishment is fully aware of, and learns from, these anomalies. From all these incidents, the Indian nuclear establishment has learnt lessons and drastic measures have been undertaken in strengthening safety practices.

Narora Fire Incident

Contrary to the critics' assertion, the Narora turbine fire incident in March 1993[64] has neither been "played down as a minor incident" nor "allowed to be forgotten."[65] There was no radiological impact of the incident but it was an eye-opener that brought a paradigm shift in India's nuclear safety considerations and review procedure. Prior to the NAPS-1 fire incident, there was no systematic programme for carrying out regulatory inspection of facilities by the AERB. The Civil Engineering Safety Committee for Operating Plants (CESCOP) was constituted to look after the civil and structural engineering issues of operating plants. The event was rated in the INES scale at Level-3 on account of the degradation of defence-in-depth of engineered safety features.

On the basis of the recommendations of the investigation committee under S.K. Mehta, modification of the LP turbine blade root design and a spate of

63. "Nuclear Power in India", http://www.world-nuclear.org/info/inf53.html
64. The cause of the fire was failure of two turbine blades in the last stage of the low pressure turbine which resulted in severe imbalance in the turbo-generator, leading to rupturing of hydrogen seals and lube oil lines.
65. Buddhi Kota Subbarao, a former Captain of the Indian Navy and a nuclear scientist, viewed that the Narora incident, "as usual, played down as a minor incident and within weeks of its occurrence, it was allowed to be forgotten". *Manushi*, no. 109, p. 24.

follow-up actions across the NPPs were undertaken. For the first time, the Safety Assessment Report for Renewal of Authorisation (SARRA) reviews for operating NPPs was introduced. This heralded the process of the multi-tier review mechanism. Some other innovative safety improvements made were:[66]

- Installation of a wall on the mezzanine floor of the turbine building.
- Incorporation of the Gravity Addition of Boron System (GRAB) for meeting the requirement of sub-criticality margin during station black-out condition.
- Provisions for reactor trip on "low coolant flow in adjuster rods."
- Incorporation of seismic monitors and seismic trip.
- A thermo-siphon test was conducted on the reactor.
- A sequential loading scheme for emergency power supply was evolved.
- Neutron shielding for the fuelling machine maintenance area was augmented.
- Design provision formulated for purification of the moderator under reactor shutdown, using boron saturated ion exchange columns.

Collapse of Containment Dome in Kaiga

In 1994, a large portion of the concrete from the under surface of the inner containment dome in Kaiga Atomic Power Project Unit-1 fell down. Both the AERB and NPCIL investigated the incident and found that nearly 40 percent of the surface area, that amounted to 130 tons, fell down due to excessive loading and tensioning during pre-stressing operations.[67] A number of tests were carried out on samples collected. The test results indicated that the materials were of acceptable quality and the indentations were not due to the weakness of the concrete in bond strength but due to the effect of split tension.[68] "The induced radial tension, coupled with the effect of membrane compression, was higher than the tensile load carrying

66. Ibid, pp. 36-37.
67. Ibid, pp. 40-41.
68. Prabir C. Basu, Vijay N. Gupchup, L.R. Bishnoi, "Containment Dome Delamination", http://www.iasmirt.org/SMiRT16/H1557.PDF, p. 4.

capability of the Kaiga-1IC dome in a radial direction".[69] Therefore, the V.N. Gupchup Committee recommended a modified dome with the following design improvements:

- Normal dome thickness to increase gradually to the higher value to minimise the induced radial tension in the transition zones.
- To introduce radial reinforcement.
- To avoid congestion.
- All design work should be carried out by independent peer consultants or by in-house experts and implementation of quality assurance programmes.

Flooding of Kakrapar Site

In June 1994, owing to heavy rain for 15 hours, flooding occurred in the Kakrapar site.[70] Water entered the turbine building basement, pump house and cable tunnels from the turbine building and the switchyard which jeopardised several safety systems. After investigation by NPCIL under the review of the AERB, the cause of the flooding was found to be clogging of the discharge sluice gates of the nearby Moticher lake into the Tapi river. Procedures were drawn up for adequate drainage and in RAPP-1&2 a 'flood' DG was installed at a higher elevation. Administrative measures were evolved for adequate draining of Moticher lake by the local authorities. A standard procedure has been evolved since then to assess the flooding potential at all operating plants, and embankments were mandated around all structures. Also, the system of continuous recirculation flow was specified instead of periodic purge flow of the Annulus Gas Monitoring System.[71]

Radiation Exposure Issue

Outcries over radiation leaks in Indian power plants are often reported in the media and seem to be without any basis of reasoning. In 1977-79, TAPS was in the news for exceeding the annual collective radiation dose. At RAPS, a large number of persons received exposure in excess of the prescribed

69. Ibid., p. 6.
70. "Country Report: INDIA", http://members.tripod.com/~no_nukes_sa/overview.html
71. Sundararajan, n. 26, p. 38.

level, which was investigated and it was found that it was due to non-use of protective equipment. A committee chaired by T. Subbaratnam prescribed the limit of collective dose in the new 220 MWe stations to be below 600 man-rem.[72] By implementation of the ALARA programmes, drastic reduction of internal exposure and implementation of chemical decontamination of systems to bring down radiation fields is going on. Due to automation and remotisation of maintenance activities, the current collective dose in TAPS and NAPS is below 500 man-rem, and for all other twin unit stations, it is below 300 man-rem a year.[73] The incident of overexposure of a person at the RAPP Cobalt Facility (RAPPCOF) on October 15, 1999, led to intense scrutiny and safety upgrades of the facility.

Lessons from Other Events

The failure of the zircaloy-2 pressure tube in Canada's reactor cautioned India to phase out all the zircaloy-2 pressure tubes, particularly from the PWHRs for Zirc-Niobium (Zr-Nb) pressure tubes. Seismic reevaluation of existing power plants was carried out in 2003 alongwith extensive modification in the emergency power supply system for the station, including three new diesel generators of higher capacity and unit-wise segregation of power supplies to obviate common cause failures. The tsunami in December 2004 that affected MAPS units located at Kalpakkam caused the water level in the seawater pump house of the plant to rise, and tripping of the condenser cooling water pumps.[74] In the light of this experience, NPCIL augmented the communication facilities of the sites and tsunami warning systems were installed. Relocation of equipment above the maximum flood levels was carried out.

Issue of Ageing NPPs

It is often said that many Indian NPPs are now aged and are still continuing operation, ignoring the safety issues involved. The Tarapur plant has been operating since 1969 whereas its contemporary plants like Dresden-1 in the USA

72. Ibid.
73. Ibid, p. 88.
74. "Nuclear Reactor Hazards", April 2005, http://www.greenpeace.org/seasia/th/PageFiles/106897/nuclearreactorhazards.pdf, p. 119.

have been phased out. It is also alleged that TAPS has now been downgraded to 320 MW due to ageing and excessive radiation level. Downgrading may be true but the real problem is public misperception and opposition for siting new plants that compels continued use of the old facilities. However, the PSR has identified various systems, structure and components requiring ageing management. Detailed review of the ageing management programme is in progress at the AERB. For some non-replaceable components such as Calandra and End Shields, adequate safety margins and operational parameters have been designed.[75] It is also ensured that the number of operational cycles do not exceed the number of permitted stress cycles. The AERB review process confirms that there is no concern in the short-term with respect to ageing.[76]

540 MWe PHWR Reactors

The safe operation and maintenance of large size reactors are extremely important. According to the National Report to the Convention on Nuclear Safety (2007), India has incorporated many advanced design provisions for 540 MWe PHWRs. Firstly, to enable the engineers safety and efficiency, operation of the plant is controlled from a centralised control room and a supplementary control room located away from the main control room to ensure safe shutdown in case of inaccessibility. Secondly, capability for zone control has been provided to take care of xenon-induced flux tilts. Thirdly, a new liquid zone control system has been designed and engineered for this function. Fourthly, a double containment structure is built with pre-stressed concrete designed to withstand internal pressure of 1.44 kg/cm2g.

Safety Features in Fast Breeder Reactors

With the successful operation of the Fast Breeder Test Reactor (FBTR) for 25 years, a 500 MWe Prototype Fast Breeder Reactor (PFBR) was designed and developed with the objective of techno-economic demonstration. This will follow a series of commercial reactors. The DAE is also planning to construct six more FBRs of 500 MWe. However, many scholars and the

75. Ibid.
76. Ibid., p. 47.

media have expressed concerns over the safety of Indian FBRs. According to M.V. Ramanna, Indian FBRs are dangerous for many reasons. First, the containment dome is not as strong as in other reactors. Second, they have a positive 'coolant void coefficient'. And if the coolant heats up and becomes less dense, forms bubbles, or is expelled from the core, reactivity increases.[77] In the same vein of argument, Swaminathan S. Anklesaria Aiyar refuses to "trust safety assurances from the nuclear establishment because it cannot be expected to reveal the skeletons in its cupboard."[78]

In response to these allegations, Baldev Raj, Director, Indira Gandhi Centre for Atomic Research (IGCAR), and Prabhat Kumar, Project Director, Bharatiya Nabhikiya Vidyut Nigam Limited (BNVNL), came out with an explanation on the safety adequacy of Indian FBRs, saying that "safety has been given highest attention in the design of the Prototype Fast Breeder Reactor (PFBR)" and the first reactors have rather "demonstrated robust safety characteristics, inherent safety features and possibility of introduction of passive safety function with less uncertainty and with high confidence."[79] Regarding containment of the PFBR, Raj and Kumar explain that it is designed to withstand "pressure generated due to sodium fire as a consequence of sodium expulsion under a postulated core disruptive accident." The containment function for the PFBR is needed only in the case of a beyond design basis core disruptive accident, and the containment pressure of PFBRs is not similar to that of the PHWRs. Rather, they have been designed with enhanced safety features compared to the early versions. Independent fast acting shut down systems, dedicated decay heat removal systems, and provision of in-service inspection of the main vessel have been introduced. In case of extreme condition of off-site power failure, the decay heat generated in the core will be removed comfortably by a set of dedicated 'safety grade decay heat exchangers' immersed in the sodium pool. Once the temperature is raised in the core, the sodium in the

77. M.V. Ramanna, "Indian Nuclear Industry: Status and Prospects", Nuclear Energy Futures Papers, Centre for International Governance Innovation, Waterloo, Canada, December 2009, p. 15.
78. Swaminathan S. Anklesaria Aiyar, "Fast Breeder Reactors are the Least Safe", *The Economic Times*, March 27, 2011.
79. Baldev Raj and Prabhat Kumar, "Safety Adequacy of Indian Fast Breeder Reactor", http://www.npcil.nic.in/pdf/Article_15april2011_01.pdf, p. 2, 6.

hot pool would be heated up, thereby developing adequate natural circulation without external power supply.

The possibility of coolant leak is a challenging issue. However, in Indian reactors, large leaks are prevented by appropriate actions following the sodium leaks, detected promptly by diversifying "leak detection systems".[80] The Indian nuclear scientists advance that "India's experience with sodium both in the Fast Breeder Test Reactor (FBTR) and various sodium loops over 40 years is benign." The incident of primary sodium leak in the FBTR in 2002 from a valve body in the primary purification circuit into the inerted cabin housing the circuit was "due to a generic manufacturing deficiency."[81] The valves of this genre used in the plant were inspected and rectified wherever found necessary. However, the sodium leak in the FBTR did not result in any fire or safety concern and the reactor was brought back to operation within two months.

No complacency is warranted on nuclear safety matters. Many anomalies relating to nuclear safety have occurred owing to organisational and technical deficiencies. These have been effectively addressed.

Many others believe that while the world has abandoned FBR technology, India has based its nuclear energy programme on this technology. However, the truth rather is that the world has not abandoned FBR technology; countries like China, France, Japan, Russia and South Korea are, in fact, expanding their programmes.

SAFETY CULTURE AND THE 'NUCLEAR VICIOUS CIRCLE'

Undoubtedly, no complacency is warranted on nuclear safety matters and the Indian nuclear establishment is not known to have entertained

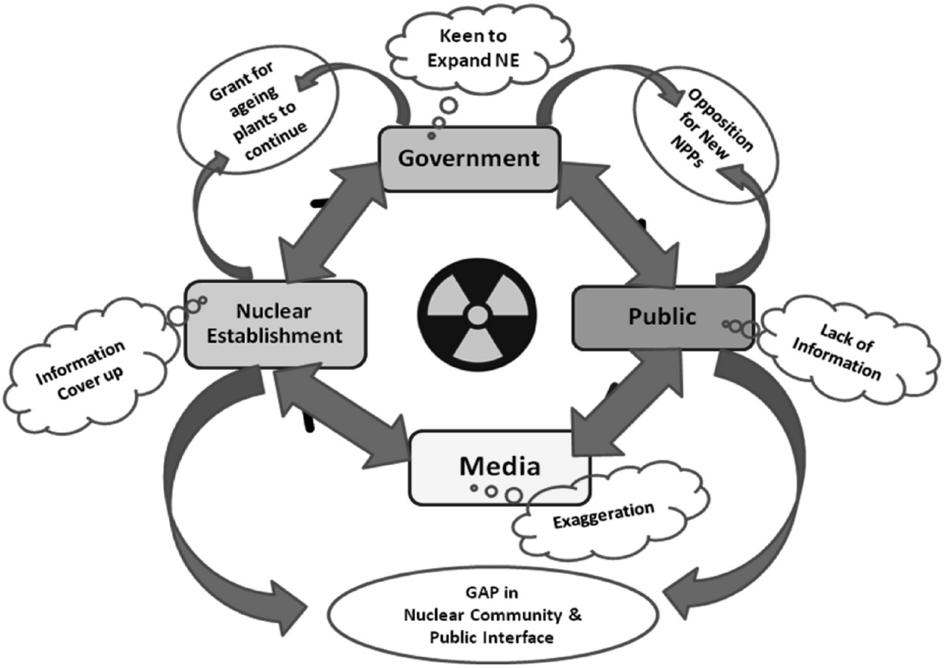
80. By providing the inert gas environment for primary sodium piping or guards pipes filled with nitrogen in the inter-pipes and incorporating the safety vessel surrounding the main vessel with nitrogen in the inter-vessel space, direct contact of radioactive sodium with air is prevented.
81. "Primary Sodium Leak Event in FBTR", http://www.igcar.ernet.in/lis/nl55/igc55.pdf, p. 5; B. Anandapadmanaba, A. Babu and G. Srinivasan, "Experience in the Maintenance of Sodium Systems of Fast Breeder Test Reactor", http://icapp.ans.org/icapp11/program/abstracts/11069.html.

any such complacency. Many anomalies relating to nuclear safety have occurred owing to organisational and technical deficiencies. These have been effectively addressed and, at the same time, have strengthened India's resolve to ensure judicious utilisation of nuclear resources. However, there may occur many unexpected and unavoidable events, inevitable in any complex industrial undertaking in general and the nuclear industry in particular. In all industries, accidents happen, people die, and pollution spreads but the world has not abandoned all industrial efforts. Rather, everyone studies what went wrong, tries to fix it, and moves on. Of course, a nuclear hazard is unique and its effects far-reaching but the benefits of nuclear energy are equally enormous. The question is how to maximise the benefits while minimising the hazards.

The way out is maintaining a strong *nuclear safety culture* – certain "principles and attributes, when embraced, will influence values, assumptions, experiences, behaviours, beliefs, and norms that describe what it is like to work at a specific facility and how things are done there."[82] It is shared by people and relates primarily not to an individual but to a group, community or organisation.[83] Thus, it denotes three general components: first, the necessary safety framework within an organisation which is the responsibility of the management hierarchy; second, the attitude of staff at all levels in responding to, and benefiting from, the framework; and third, a widely shared awareness of nuclear hazards and consequent patterns of norms and values adhered to. India seems to be evolving the first two components steadily whereas the third component appears blurred as the issue seems to be languishing in a vicious circle characterised by an intricate interplay of complex technology, populism politics and misinformed psychology.

82. "Principles for a Strong Nuclear Safety Culture", http://www.efcog.org/wg/ism_pmi/docs/Safety_Culture/Dec07/INPO%20PrinciplesForStrongNuclearSafetyCulture.pdf, p. i.
83. Giovanni Verlini, "The Mindset of Nuclear Safety", http://www.iaea.org/Publications/Magazines/Bulletin/Bull501/NS_Mindset.html.

Fig 3: Nuclear Power Problematic: A Vicious Circle



While the government and scientific community are keen to expand the nuclear industry, a pocket of the public is sceptical about anything nuclear. While the media exaggerate events and cause panic among the public, the gap between the scientific community and the public is wide. The resulting popular opposition for new nuclear plant sites compels the government to add more plants to existing sites and allow ageing facilities to continue, though with the necessary safety upgradation. This lopsided 'nuclear information management' is the crux of the nuclear vicious circle that India needs to crack while nourishing a holistic nuclear safety culture. A deep-rooted, stable and effective nuclear safety culture involves the entire society where everyone is personally responsible for nuclear safety, not just the placing of the safety apparatus and assigning of responsibilities on a few, and then blaming them for any anomaly.

To conclude, there are three straightforward approaches to a better nuclear future. First, the problem can be managed by adopting policies and by reforming organisations, as suggested by the high reliability theorists;

second, by abandoning nuclear technology altogether; and third, by changing the structure of organisations that control nuclear technology. While the first and third approaches may be explored further, a sensible understanding would discard the second approach as an unrealistic proposition. The bottom line, therefore, is to try eliminate probable risks by implementing the safety — and security — heightened approaches. India, while balancing the domestic public perception by keeping its nuclear safety record high, must avail of the window that the nuclear opportunity has opened.