Safety First? Kaiga and Other Nuclear Stories

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The November 2009 exposure of employees at the Kaiga nuclear power plant to tritiated water is not the first instance of high radiation exposures to workers. Over the years, many nuclear reactors and other facilities associated with the nuclear fuel cycle operated by the Department of Atomic Energy have had accidents of varying severity. Many of these are a result of repeated inattention to good safety practices, often due to lapses by management. Therefore, the fact that catastrophic radioactive releases have not occurred is not by itself a source of comfort. To understand whether the DAE's facilities are safe, it is therefore necessary to take a closer look at their operations. The description and discussion in this paper of some accidents and organisational practices offer a glimpse of the lack of priority given to nuclear safety by the DAE. The evidence presented here suggests that the organisation does not yet have the capacity to safely manage India's nuclear facilities.

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1 Introduction

On 29 November 2009 the Atomic Energy Regulatory Board (AERB) put out a press release, which is available on its web site even as of January 2010. According to it,

> An incident of tritium uptake of some workers at the Kaiga Generating Station (KGS) occurred on 24 November 2009. This was noticed during the routine urine sample analysis of workers that is carried out regularly at all nuclear power plants that use heavy water... All persons working in the plant were checked and personnel found to have received any tritium uptake were referred to the hospital... With this, now only two persons are having tritium in their body that can cause their extrapolated annual radiation exposure to marginally exceed the AERB specified limit of 30 millisievert (mSv).

Little or no official news has come out about that event since then. The nuclear establishment has tried to downplay the import of this event. As might be expected of a regulator that is not independent, the AERB ended the press release by stating that it "would like to assure everyone that the incident is well under control and there is no cause whatsoever for any radiation safety concern". The chairman and managing director of the Nuclear Power Corporation of India Ltd (NPCIL), S K Jain, offered the assurance that "NPCIL has very high level of safety compliance and the limits of regulatory authorities are strictly complied with". Even Prime Minister Manmohan Singh has tried to mollify public apprehensions by describing it as a "small matter of contamination" and claiming that there was "nothing to worry".

But the history of poor operations, many involving lapses of safety at the many facilities run by the Department of Atomic Energy (DAE) and its sister organisations, indicates that the safety of the country's nuclear facilities is indeed a matter of concern. Many nuclear reactors and other facilities associated with the nuclear fuel cycle operated by the DAE have had accidents of varying severity.[1] That none of these led to catastrophic radioactive release to the environment is not by itself a source of comfort. Safety theorists have argued cogently that this absence of evidence of "accidents should never be taken as evidence of the absence of risk"...and "... just because an operation has not failed catastrophically in the past does not mean it is immune to such failure in the future" (Wolf 2001).[2]

To understand whether the DAE's facilities are safe, it is, therefore, necessary to take a closer look at their operations. The description of some accidents below offers a glimpse of the lack of priority given to nuclear safety by the DAE.[3] Moreover, the evidence that we present here suggests that the organisation has not developed the capability to reliably manage hazardous technologies (Kumar and Ramana in preparation).

2 Tritiated Heavy Water

Kaiga and most of the other atomic power stations in India have what are called pressurised heavy water reactors. As the name suggests, they require heavy water – water with the hydrogen replaced by deuterium, a heavier isotope of hydrogen. The heavy water is used both as moderator (to slow down neutrons emitted during fission so that they have a higher chance of being captured by other fissile nuclei) and as coolant (to carry away the heat produced).

Over a period of time, the heavy water loaded in a reactor becomes radioactive because some of the deuterium nuclei absorb a neutron to become tritium (an even heavier isotope of hydrogen with two neutrons). It is then called tritiated water. The radioactivity level of the tritiated water depends on the origin of the heavy water (i e, from the coolant or the moderator) and the length of the time it has been in the reactor. Typical values for coolant heavy water are in the range of 0.5-2 curies/kg. Heavy water from the moderator would have about 20-30 times more radioactivity.

Tritiated water is easily absorbed by the body as it is chemically identical to water. In the reactor environment, there could be a number of pathways for tritiated water to enter the body. It could be drunk, absorbed through the skin, or tritiated water vapour could be breathed in. In all these cases, the absorbed tritiated water is rapidly distributed throughout the body via the blood. This, in turn, mixes with extracellular fluid in about 12 minutes after ingestion. A special concern with tritiated water is that when ingested by pregnant women, it can pass through the placenta, and affect the foetus. During this stage, the developing organism (the embryo and fetus) is highly radiosensitive (ICRP 2003). In addition to forming tritiated water, tritium can also displace hydrogen in other types of chemicals, especially organic compounds where it gets bound to carbon. Such organically bound tritium (OBT) remains in the body for long periods of time and therefore contributes to a much greater radiation dose per unit of tritium absorbed (Harrison, Khursheed and Lambert 2002).[4]

Because of these biochemical properties of tritiated heavy water, the process of cleaning up the spills and recovering the heavy water or flushing it into the environment almost invariably leads to radiation doses to workers and, potentially, the general public.

3 A Partial History of Exposure

The Kaiga episode of this year is not the first time that workers at nuclear power plants have had high radiation doses due to exposure to tritiated water. There have been past cases of such exposures to tritiated water as well as other radionuclides, which demonstrate poor safety practice as well as organisational neglect of worker safety. What are described below are just a few of the many publicly known cases.[5] In addition, there could have been many more instances that have not been divulged to the public.

3.1 Kalpakkam 1999

In March 1999, some personnel at the second unit of the Madras Atomic Power Station (MAPS) were testing a device called BARCCIS (Bhabha Atomic Research Center Channel Inspection System) that was designed to inspect the reactor's coolant tubes, which had been routinely plagued by cracks and vibration problems (Rethinaraj 1999). Suddenly a plug that sealed one of the coolant channels, through which heavy water was to flow and remove the heat produced during reactor operations, slipped away and a large quantity of radioactive heavy water leaked out. Reportedly, 42 workers were involved in mopping up the leak and recovering the heavy water (Subramanian 1999). A previous leak of a much smaller quantity of heavy water at MAPS occurred on 5 March 1991, which took four days to clean up (BARC 1992).

For the leak in 1999, it can be shown using standard methods of dose calculation that the radioactive dose to individual workers was on average about 6-8 mSv for each hour of work (Ramana 1999). Even at the lower level, an employee working for over five hours would have received a dose in excess of the annual limit of 30 mSv.

Some weeks after the event, workers union representatives revealed to the press that seven of the workers who helped clean up were placed in the "removal category" and would not be allowed to work in any radioactive areas in the future (Radhakrishnan 1999). This suggests that they did indeed have radiation doses in excess of their annual quotas. Most of the remaining workers were placed in the "caution category", meaning that they could continue working but they were not allowed their usual radiation dose.

This was not the only such event. On 20 November 2001, there was a smaller leak involving 1.4 tonnes of heavy water at the Narora I reactor; one person involved in the mopping up operations received a radiation dose of around 18 mSv, as reported by the AERB (AERB 2002: 18). There have been numerous heavy water leaks in the DAE's reactors (Ghosh 1996; IAEA 1998: 301-20; AERB 2001: 13; 2004).

3.2 Kalpakkam 2003

On 21 January 2003, some employees at the Kalpakkam Atomic Reprocessing Plant (KARP) were tasked with collecting a sample of low-level waste from a part of the facility called the Waste Tank Farm (WTF). Unknown to them, a valve had failed, resulting in the release of high-level waste, with much higher levels of radioactivity, into the part of the WTF where they were working. Although the plant was five years old, no radiation monitors or mechanisms to detect valve failure had been installed in that area. The accident was recognised only after a sample was processed. In the meantime, six workers had been exposed to high doses of radiation (Anand 2003).

Apart from the lack of monitoring mechanisms, the greatest cause for concern was the response of management, in this case BARC. Despite a safety committee's recommendation that the plant be shut down, BARC's management decided to continue operating the plant. The BARC Facilities Employees Association (BFEA) wrote to the director setting forth 10 safety-related demands, including the appointment of a full-time safety officer. The letter also recounted two previous incidents where workers were exposed to high levels of radiation in the past two years, and how officials had always cited the existence of an "emergency situation" as a reason for the health physics department's failure to follow safety procedures. Once again there was no response from management. In desperation, some months later the union resorted to a strike. The management's response was to transfer some of the key workers involved in the agitation and threaten others with similar consequences; two days later, all striking workers returned to work. The BARC director's public interpretation was that if the place had not been safe, the workers would not have returned. Finally, the union leaked information about the radiation exposure to the press.

Once the news became public, management grudgingly admitted that this was the "worst accident in radiation exposure in the history of nuclear India" (Anand 2003). But it claimed the "incident" resulted from "over enthusiasm and error of judgment" on the part of the workers (Venkatesh 2003). Management also tried to blame the workers for not wearing their thermoluminescent dosimeter badges, but this has nothing to do with the accident; badges would not have warned the workers about radiation levels until well after they were exposed.[6]

For its part, the BFEA claimed the accident was only to be expected, and that because of the unrelenting pace of work at KARP and "unsafe practices being forced on the workers", accidents have become regular (Anonymous 2003). Thus, there was no consensus among management and workers on how to run the Kalpakkam plant safely.

This pattern of discontent on the part of workers seems to be commonplace. There is a history of poor relations between management and workers, from MAPS, KARP, and IGCAR. A long-standing problem seems to be one of control over safety at the workplace and outside. For example, in 1997, MAPS workers went on strike for 25 days after the management "suspended five radiation workers who refused to work in (areas with a) high radiation level" (*HT* 1997). In 2005, IGCAR employees had threatened to go on strike on account of a number of unmet demands. Among them was that the road from the plant to the housing area be broadened so that the workers would not get stuck in a traffic jam in the event of an emergency (Anonymous 2003). Organisation theorists who have examined high performing nuclear power plants around the world via in-depth field studies have found that they all share an atmosphere of openness and responsibility in which all employees feel free to point out their observations without fear. Unfortunately, DAE's facilities do not seem to share this feature.

3.3 Temporary Workers

The workers discussed above at least had recourse through their union to resort to strikes. The lot of the many temporary workers is worse. The employment of such workers, especially for cleaning tasks in a number of nuclear facilities, has been reported by many others. For example, in connection with the patterns of ill-health observed among villagers living near the Rawatbhata reactor (Gadekar and Gadekar 1996), former AERB chairman, A Gopalakrishnan pointed out that this may be because

> many villagers in the late 1970s and the late 1980s were used as temporary workers within the power station to clean up radioactive material. There is no database with RAPS about how many people entered the radioactive area or for how long each was exposed to it. As the chairman of the Atomic Energy Regulatory Board, I asked for such information. I never received any" (DTE 1999).

The DAE claims that temporary workers have an even lower dose limit (Mishra 2004), but such claims appear to be contradicted by many grass roots and independent accounts of poor working conditions at nuclear facilities.

For example, here is a newspaper report on what happened after a major radioactive leak "from ill-mantained pipelines in the vicinity of the CIRUS and Dhruva" reactors at the Bhabha Atomic Research Centre in 1991 (Chinai 1992). The management, reportedly,

> set six contract labourers on the task of digging a pit, to reach the burst pipeline, eight feet below the surface. These workers wore no protective gear or radiation monitoring badges... The contract labourers who had worked for almost eight hours inside the pit on 13 and 14 December 1991, were thereafter hastily pulled out, given a bath, new sets of clothing and packed off home. There is no evidence of the labourers having been subject to radiation monitoring tests (Chinai 1992).

Another example comes from the RAPS.

> On 27th of July (1991), there were barrels of heavy water which needed upgrading, standing in a corner of the upgrading plant building. The building was to be whitewashed and a contractor had been assigned the job. One of his labourers, Shri Madholal, who was to do the whitewashing found that there was no water in the taps. He made the wash in the barrel of heavy water and then proceeded to put a coat of whitewash on the walls of the room. After finishing his work, Shri Madholal washed his brush and then washed his hands and face with the same heavy water... As soon as information regarding this event reached the authorities, there was consternation and panic amongst them. The new coat of whitewash was scraped off the walls and sent to the laboratory for tritium analysis. Shri Madholal immediately disappeared from the scene and his whereabouts were unknown (*RP* 1991).

High radiation doses to temporary workers seem to have been especially common at the Tarapur reactors, which was reported in the late 1970s to have areas "so radioactive that it is impossible for maintenance jobs to be performed without the maintenance personnel exceeding the fortnightly dose...in a matter of minutes" (Bidwai 1978: 29). Because of the numerous high radiation areas which had to be serviced, TAPS personnel were "not capable of handling the larger-than-anticipated volume of maintenance jobs, especially in areas with a large number of hot spots" and so "outsiders...have to brought in so as not to overexpose the already highly exposed TAPS personnel to radiation" (ibid). Many of these "workers do not have adequate knowledge or understanding of radiation hazards" nor are they "entirely familiar either with the layout of TAPS or the precise nature of the job they are ordered to perform" (ibid).[7]

There is plentiful anecdotal evidence along these lines of poor safety practices that frequently cause ill-health to workers. The reason why these are mostly anecdotal is that outsiders do not have access to the health records of DAE workers.

Two lessons can be drawn from this brief and partial history of radiation doses to workers. One is that worker health has been compromised repeatedly. The second is that there has been a mple discord between management and workers at various facilities. Thus, it would seem that workers at DAE facilities do have reasons to be disaffected, and this should be borne in mind when thinking about the recent water cooler episode at Kaiga.

4 Poor Safety Management

One essential feature of safely run nuclear power plants around the world is reliable backups in technical operations and in management of personnel, which prevents failures from escalating. At the same time, there is always a belief that present levels of safety are not enough, so that the guard is never let down. This means that such organisations are always exploring what could go wrong, and learning not only from their mistakes but also from others'. In this section, we offer evidence of repeated failures at DAE facilities, which have sometimes led to accidents.

4.1 Kaiga 1994

Danger to the workers at Kaiga began even before the reactor was completed. On 13 May 1994, the inner containment dome – the structure that is supposed to prevent the escape of radioactivity into the environment should an accident occur – of one of the units of the Kaiga nuclear power plant collapsed during reactor construction. The dome itself had been completed but cabling and other tasks were being carried out (Havanur 1994). The official term for what occurred is delamination, but that does little justice to the approximately 130 tonnes of concrete that fell from the top of the containment (Subbarao 1998). The event happened during the day with workers on site but miraculously only 14 workers were said to have been hurt, that too with minor injuries. Analysts have offered several reasons that shed doubt on this claim that only 14 of the hundreds of workers employed at the site were hurt (Havanur 1994).

At least two underlying factors have been identified for the collapse. The first is faulty design (Pannerselvan 1999). Another is lack of adequate quality control: according to DAE officials, "while inputs such as cement and steel had been tested for quality, that was not the case with the concrete blocks as a whole" (Mohan 1994). This goes against a basic requirement of nuclear safety: "facilities (have to be) constructed to the highest standards" (NEA 1993: 51). Faulty work practices may also have played a role. Such practices led some years later to a fire involving many cans of paint on the same dome (*TOI* 1999). In addition, one local woman activist, Kusuma Soraba, met with some of the construction workers who accused the contractors of various malpractices in construction (Havanur 1994).

The former head of the AERB has stated:

> The delamination of the containment dome at Kaiga was an avoidable incident. Senior NPC civil engineers and the private firms which provide civil engineering designs and construction drawings to the DAE have had a close relationship. In this atmosphere of comradeship, the NPC engineers did not carry out the necessary quality checks on the designs they received before passing them on to the Kaiga project team. The AERB also did not check this, because it had almost no civil engineering staff with it. Serious design errors went undetected and these eventually led to the failure of the dome. It was negligence by the NPC civil engineering team that caused this. A distorted NPC report, which tried to cover up this reason, was rejected outright by the non-DAE members of the AEC, while the AERB report that spelt out in detail the actual reasons was approved (Gopalakrishnan 1999).

The Kaiga dome collapse is unprecedented in the annals of nuclear energy history. It also points to one of the dangers with relying on redundancy as a safety mechanism. The reason for constructing a containment dome is that even if all safety mechanisms within the reactor fail and a severe accident occurs, the strong containment building will be capable of withstanding the high pressures that would accompany the accident and hold ("contain") all radioactive substances released from the reactor core during the accident. So at face value this makes for greater safety. But as Subbarao argues,

> if such a collapse had taken place during operation of the nuclear plant, about 130 tonnes of concrete falling from a height of nearly 30 meters would have damaged the automatic control rod drives that lie below the crown of the dome, disabling them and making the safe shutdown of the reactor difficult. The massive weight of concrete might have led to damage to the nuclear coolant pumps and pipes, resulting in severe loss of coolant. This could have led to nuclear core meltdown and the escape of large amounts of radioactive substances to the environment (Subbarao 1998).

Fortunately, at the time of the accident, the reactor had not been fully constructed and the core had not been loaded.

4.2 Narora 1993

The most serious accident at an Indian nuclear reactor occurred on 31 March 1993. Early that morning, two blades of the turbine at the first unit of the Narora power station (two 220 MW PHWRs) broke off due to fatigue. These sliced through other blades, destabilising the turbine and making it vibrate excessively. The vibrations caused pipes carrying hydrogen gas that cooled the turbine to break, releasing the hydrogen which soon caught fire. Around the same time, lubricant oil had also leaked. The fire spread to the oil and through the entire turbine building. Among the systems affected by the fire were four sets of cables that carried electricity, which led to a general blackout in the plant. One set supplied power to the secondary cooling systems, which were consequently rendered inoperable. In addition, the control room became filled with smoke and the staff was forced to leave it about 10 minutes after the blade failure.

The operators responded by manually actuating the primary shutdown system of the reactor 39 seconds into the accident (Koley et al 2006). Although the reactor was shutdown, some operators, concerned about re-criticality, climbed onto the top of the building and, under battery-operated portable lighting, manually opened valves to release liquid boron into the core to slowdown the reaction. It was necessary to do so because even though the reactor was shutdown, it continued to generate heat; the fuel rods in a reactor accumulate fission products – the elements created when a uranium atom splits – and these continue to undergo radioactive decay and produce heat. While this so-called decay heat is produced at a much smaller rate than when the reactor is operating, it persists even with the reactor shutdown. If not removed promptly, decay heat can cause the fuel to reheat and meltdown. Thus, the reactor must continue to be cooled even after shutdown. To accomplish this task, operators had to start up diesel fire pumps to circulate water meant for fire control (NEI 1993).

It took 17 hours from the time the fire started for power to be restored to the reactor and its safety systems. Operators who were forced to leave the control room because of smoke could not re-enter for close to 13 hours. An attempt was made to take control of the plant from the emergency control room; but, since there was no power available, the Unit 1 control panel of the emergency control room was unusable. Thus, Narora was almost unique in that the operators had no indication of the condition of the reactor and were, in effect, "flying blind" (Nowlen, Kazarians and Wyant 2001).

The Narora accident has been the DAE's closest approach to a catastrophic accident. More worrisome is the evidence that the accident could have been foreseen and prevented.

First, the failure of the turbine blades was avoidable. In 1989, General Electric communicated information to the turbine manufacturer, Bharat Heavy Electricals Limited (BHEL), about a design flaw which led to cracks in similar turbines around the world. They recommended design modifications, and the manufacturer responded by preparing detailed drawings for NPC, which operated the Narora reactor. In addition to General Electric, the manufacturer of the turbine, BHEL, also recommended that NPC replace the blade design before an accident occurred. However, NPC did not take any action until months after the accident (Gopalakrishnan 1999).

Second, even if the turbine blade failed despite modification, the accident might have been averted if the safety systems had been operating, which they presumably would have if only their power supply had been encased in separate and fire resistant ducts. By the time the Narora reactor was commissioned, this was established wisdom in the nuclear design community and had been ever since the fire at Browns Ferry in the US in 1975. That accident resulted in a mandate to make significant changes at all US nuclear plants (Ramsey and Modarres 1998: 106). The physical and electrical systems were altered, with built-in redundancies, to prevent fires. Other countries adopted similar measures. All of this took place well before the Narora plant attained criticality in 1989. Nevertheless, the plant was constructed with the four backup power supply systems laid in the same duct, with no fire-resistant material enclosing or separating the cable systems.

Third, the DAE had not taken any serious steps towards fire mitigation despite earlier fire accidents at its own reactors. In 1985, an overheated cable joint at RAPS II caused a fire that spread through the cable trays and disabled four pumps (IAEA 1986: 244; Gopalakrishnan 1999). A few years later, in 1991, there were fires in the boiler room of the same unit and the turbo generator oil system of RAPS I (IAEA 1992: 394-96).

The factors that contributed to the Narora accident were repeatedly present prior to the accident. Excessive vibrations in the turbine bearings were common in Indian reactors. In 1981, RAPS II was shut down twice because oil leakage in the turbine building led to high levels of sparking in the generator exciter (IAEA 1982: 235). After it was restarted, it had to be shutdown yet again when it was found that large amounts of oil had leaked from the turbine governing system. Only when the reactor was restarted a third time, in early 1982, were the high vibrations of the turbine bearings noticed and the failure of turbine blades discovered (IAEA 1983: 250). This led to a prolonged shutdown of more than five months; even after this problem had apparently been fixed the reactor had to be shut down once again because of high turbine bearing temperatures (IAEA 1983: 230). Again in 1983, high vibrations were noticed in turbine generator bearings and it was revealed that two blades in the second stage of the high pressure rotor had sheared off at the root (IAEA 1984: 292). In 1985, the first unit of the Madras Atomic Power Station (MAPS I) was shutdown repeatedly because of high bearing vibrations in the turbine generator (IAEA 1986: 240). RAPS I had to be shutdown due to high bearing vibrations in 1985, 1989, and 1990 (IAEA 1986: 242; 1990: 302; 1991: 298).

Oil leaks have also been common in Indian reactors. In 1988, MAPS II was shutdown due to an oil leak from the generator transformer (IAEA 1990: 288). In 1989, a large spark was observed from slip rings on the exciter end of the turbine in MAPS I; there were also two other fires in the same reactor near the primary heat transport system (IAEA 1990: 298). Oil leaked from a turbine bearing in MAPS II in 1989 (IAEA 1990: 300). In 1992, there was an oil leak in the turbine stop valve in MAPS II (IAEA 1993: 288). In addition in 1992, there were two separate oil leak incidents in the Narora I turbine generator system (IAEA 1993: 289). There was at least one hydrogen gas leak prior to the Narora accident: this happened in 1991 in the generator stator water system of MAPS II (IAEA 1992: 390).

The DAE did not learn from these experiences, and this disregard was in part responsible for the Narora accident. When asked by an interviewer about the recurrence of turbine blade failures at nuclear reactors, AEC Chairman Chidambaram side stepped the issue by suggesting "this kind of failure at Narora has happened for the first time…two blades failing" and then offering the non sequitur, "You must remember that as far as nuclear reactor is concerned, there was no problem at Narora. The reactor worked perfectly according to design" (Chidambaram 1993). By ignoring these early warnings, the DAE set the stage for the Narora failure that led to "widespread damage to the (turbine generator) set, condenser and caused [a] fire which engulfed the cables, the turbine building and control equipment room" (Ghosh 1996: 30).

4.3 Recurring Patterns

Another indicator of poor safety practices is repeated occurrences of similar accidents. An important example is the set of failures that led to the Narora accident, which have persisted in many reactors.

In late 1993, high vibrations and temperature in both Narora-II and RAPS-1 turbine generator buildings led to their being shutdown (IAEA 1994: 333-36). The problems in these reactors persisted into 1994, with Narora-II being shutdown due to high bearing temperatures and RAPS-1 due to turbine bearing vibrations (IAEA 1995: 313-16). In 1995, even after repeated shutdowns supposedly meant to mitigate turbine problems, blades failed in the turbine of Narora-II (IAEA 1996: 314).

Even after being restarted following the accident in 1993, Narora-1 was shutdown repeatedly in 1995 because of high vibrations of the turbine generator bearing (IAEA 1996: 312). In 1997, RAPS-1 had to be repeatedly shutdown due to high turbine bearing vibrations (IAEA 1998: 314). In 2000, Kaiga-II suffered from repeated turbine vibration problems (IAEA 2001: 294).

Fires have also occurred repeatedly. In Narora-II in 1996, there was heavy oil smoke from the turbine building (IAEA 1997: 314). That same year, there was an oil fire in the turbine building of Kalpakkam-II (IAEA 1997: 310). The following year smoke was observed in Kalpakkam-II, there was a fire in the turbine generator of Kakrapar-I, and smoke was observed from the insulation of the main steam line of the turbine generator in Kakrapar-II (IAEA 1998: 302-08). There was a fire due to an oil leak in Kalpakkam-I in 2000 (IAEA 2001: 300). There have also been numerous oil and hydrogen leaks.[8]

Other examples are regular leaks and heavy water spills. While these leaks are not themselves serious safety hazards, they could be the precursors to more serious accidents, for example involving coolant failure. As mentioned earlier, the tritium in the water also poses a health risk to workers.

Such leaks started with RAPS, the first heavy water reactor constructed in India (Ghosh 1996). Despite much effort – understandable because heavy water is expensive and hard to produce – the DAE has not managed to contain the leaks. In 1997 alone, such leaks occurred at the Kakrapar I, MAPS II and Narora II reactors (IAEA 1998: 301-20). The leaks could involve significant amounts of water. For example, on 15 April 2000, there was a leak of seven tonnes of heavy water at the Narora II reactor (AERB 2001: 13). Three years later, on 25 April 2003, there was a six tonne leak at the same reactor (AERB 2004).

The 2003 leak occurred while a device called BARCCIS which is used to inspect coolant tubes in reactors, was in operation. After a similar leak in March 1999 at MAPS, the AERB reviewed the BARCCIS system and suggested design changes, operating procedures and training (AERB 2004: 18). But as mentioned earlier, there was a similar leak at the Narora I reactor in 2001 despite these changes. This indicates that there were weaknesses in the implementation of the AERB's suggestions, fundamental flaws in the technical system, or continued operator errors.

4.4 Inoperative Safety Systems

A second notable and disturbing trend is the frequent failure of safety devices. These are the mechanisms by which control of the reactor ought to be maintained under unanticipated circumstances. If they do not work as expected, it is more likely that a small event could cascade into a major accident. A related problem is of safety devices left in an inoperative state or neglect of periodic maintenance.

An example of how minor failures contributed to escalating an accident was during the 1993 Narora accident discussed earlier. The accident may have been prevented had the smoke sensors in the power control room at Narora detected the fire immediately. Since that did not happen, the fire was detected only when the flames were noticed by plant personnel (Srinivas 1993). A different complication arose three hours and fifty minutes into the accident when the two operating diesel-driven fire water pumps shutdown inexplicably (Nowlen, Kazarians and Wyant 2001). As yet, the cause for this failure has not been identified. A third pump was out of service for maintenance.

Many of these problems are recurring. In 2005, for example, the AERB found instances of failure in fire detectors at Kakrapar and in the power supply for emergency cooling at the MAPS (PTI 2005). Heat transport pumps are also frequently unavailable for many reasons, most commonly because of frequency fluctuations in the electricity grid. In 2004, MAPS-II was shutdown for eight days because the two main primary coolant pumps were unavailable. After it was restarted, the reactor had to be shutdown again because the motor bearings of one of the pumps had to be replaced.

5 Weakness of Safety Regulation

A separate reason to be concerned about the safety of the DAE's facilities is the regulatory structure that is involved in overseeing safety. The DAE established the AERB to oversee and enforce safety in all nuclear operations in 1983. This was modified in 2000 to exclude facilities involved, even peripherally, in the nuclear weapons programme. The AERB reports to the Atomic Energy Commission (AEC), whose chairman is always the head of the DAE. The chairman of NPC is also a member of the AEC. Thus, both the DAE and NPC exercise administrative powers over the AERB. The AERB is financed by the DAE. There are, therefore, institutional limits on the AERB's effectiveness.

This administrative control is compounded by the AERB's lack of technical staff and testing facilities. As A Gopalakrishnan, the former chairman of the AERB, has observed,

> 95% 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 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 (Gopalakrishnan 1999).

Elsewhere, Gopalakrishnan has pointed to an example of direct interference from the AEC, in the context of the collapse of the containment dome in 1994 of one of the reactors under construction at Kaiga, Karnataka. "When, as chairman, I appointed an independent expert committee to investigate the containment collapse at Kaiga, the AEC chairman wanted its withdrawal and matters left to the committee formed by the NPC (managing director). DAE also complained to (the prime minister) who tried to force me to back off" (Pannerselvan 1999).

Finally, the AERB's recommendations are often ignored. For example, according to Gopalakrishnan:

> [The] AERB had directed the DAE to carry out an integrated Emergency Core Cooling System (ECCS) testing in Kaiga I and II as well as RAPS III and IV before start up. It also wanted proof and leakage tests conducted on the reactor containment. And finally, a full-scope simulator was to be installed for operator training. None of these directives have been complied with so far (Pannerselvan 1999).

Conclusions

The AERB is fond of claiming that it has lived up to Homi Bhabha's injunction in February 1960, "Radioactive materials and sources of radiation should be handled in the Atomic Energy Establishment [the former name of the Bhabha Atomic Research Centre] in a manner which not only ensures that *no harm* (our emphasis) 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" (Mishra 2004: 98). Since Bhabha's time, it has been established that all radiation brings with an increased risk of cancer and other health damage. This risk is directly proportional to the radiation dose to the body and there is no threshold below which the increased probability of cancer from radiation exposure is zero. Regulatory limits are typically set at some level of cancer risk to workers that is considered acceptable, often by convention.

The largest study of nuclear workers, carried out by a large team of researchers and headed by a team from the International Agency for Research on Cancer (IARC), retrospectively examined the health records of over 4,00,000 workers in 15 different countries and demonstrated that a small excess risk of cancer exists, even at doses lower than typically mandated by radiation standards (Cardis et al 2005). At the typically mandated radiation standards, workers could receive up to 100 mSv over five years. This would, according to the IARC study, lead to a 9.7% increased mortality from all cancers excluding leukaemia and a 19% increased mortality from leukaemia (excluding chronic lymphocytic leukaemia). Radiation doses that exceed the annual regulatory limits lead to a correspondingly higher risk of cancer. Thus, numerous workers are likely to have been exposed to harm by the nuclear establishment.

At a more general level, while the DAE, like other organisations involved in nuclear activities, often verbalises safety goals, its performance and decision-making often depart from public pronouncements.[9] In its submission to the IAEA as part of its responsibilities under the 1994 Convention on Nuclear Safety, the DAE stated that:

> Safety is accorded overriding priority in all activities. All nuclear facilities are sited, designed, constructed, commissioned and operated in accordance with strict quality and safety standards… As a result, India's safety record has been excellent in over 260 reactor years of operation of power reactors and various other applications (GOI 2007).

Alas, the DAE's historical record is not even acceptable, let alone excellent, a fact that should be borne in mind when drawing lessons to be learned from what happened last year at Kaiga.

NOTES

1 We use DAE as an umbrella term for referring to both the DAE as well as its many allied organisations, including the Nuclear Power Corporation.

2 Or as James Reason argues, "even the most vulnerable systems can evade disaster, at least for a time. Chance does not take sides. It afflicts the deserving and preserves the unworthy" (Reason 2000).

3 To the extent possible, we derive these descriptions from documents put out by the DAE and its sister organisations. If these are not available, or as a supplement, we use news and media reports. We assume that these are being accurate unless there is some strong reason to not believe the fact. We try not to place too much stock on any one report.

4 Organically bound tritium also delivers energy more effectively than HTO and therefore imparts a higher radiation dose (Chen 2006).

5 Not included in these, for example, are uranium miners and millers who are exposed to both radon gas and relatively high levels of dust.

6 These badges measure cumulative exposure over

a period of time, and are meant to be submitted to the health physics department for assessment.

7 Herein lies one problem with the notion of risk as is commonly used – that the hazard possibility that underlies the risk calculation is not precisely determined, the way the association of probability figures would suggest. Rather, the risk involved in an activity depends on the control exercised by the worker in the workplace. British radiation safety professional Dave Rosenfeld offers this example: "ask a worker at the Windscale nuclear fuel reprocessing plant to repair pipework in a high-radiation area unfamiliar to him. Even if there are only a couple of lethal "hotspots" where doses are high, the whole area appears hazardous. To him (women are not employed in high-radiation zones) a walk in a straight line is like crossing the road blindfold. As the management gives him a chart of hotspots and a pocket alarm meter, he feels sure to avoid deadly spots, confidently and consistently – as long as experience tells him that the management or union safety committee have assured the chart and meter are reliable" (Rosenfeld 1984: 43).

8 Listed below are just those from the period between 1995 and 2000. Operating records reveal repeated oil leaks occurred in Kakrapar-II in 1995 (IAEA 1996: 306). In 1997, there were oil leaks in Kalpakkam-II and a hydrogen leak in Kakrapar-II (IAEA 1998: 304-08). In 1999, there was another hydrogen leak in Kakrapar-II, as well as one in Narora-II (IAEA 2000: 288-96). In 2000, there were hydrogen leaks in Narora-I, Narora-II and RAPS-III, and oil leaks in RAPS-III and Kaiga-II (IAEA 2001: 294-312).

9 The confidence that permeates within the nuclear establishment is also not conducive to safety. One of the many paradoxes about safety is that "if an organisation is convinced that it has achieved a safe culture, it almost certainly has not" (Reason 2000).

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