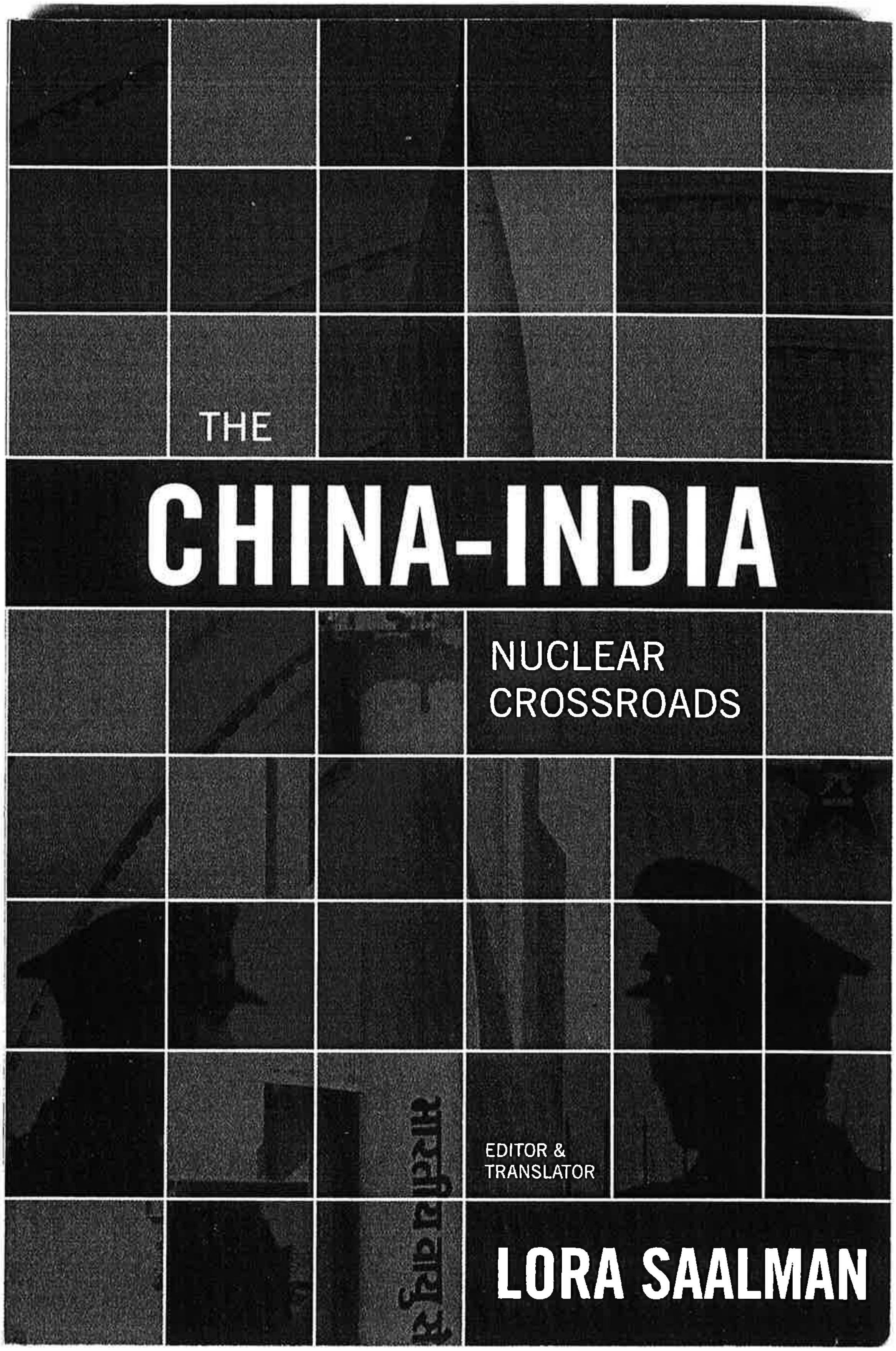

THE

CHINA-INDIA

NUCLEAR CROSSROADS

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CHAPTER 11

CONVERGING NUCLEAR ENERGY PROGRAMS

THE VIEW FROM INDIA

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India did not have access to nuclear technology, equipment, and fuel in the global market for several decades due to its refusal to accede to the Nuclear Non-Proliferation Treaty (NPT). The recent Indo-U.S. nuclear agreement has dramatically changed this embargoed status by opening up fuel, equipment, and technology access options for India.

The International Atomic Energy Agency (IAEA) has instituted a special safeguards agreement for India, and the Nuclear Suppliers Group (NSG) has given India a clean waiver for trade. These measures have been a major success, providing access to uranium and reflected in the high capacity of several Indian nuclear plants. However, there remains a case to pursue long-term self-reliance. A severance of fuel supply could have a potentially crippling impact on India. Thus, in moving toward the country's strategic goal of self-sufficiency, nuclear power has an important role to play.

The uranium-fueled pressurized heavy-water reactor (PHWR) has heretofore been the mainstay of the Indian nuclear program. But India's current uranium reserves of 61,000 metric tons provide an electricity potential of only 328 GW per year when used in a pressurized heavy-water reactor. Although a recent discovery of uranium stores in Andhra Pradesh may alter some of these supply predictions, plutonium derived by reprocessing the spent fuel of PHWR offers a massive potential of 42,231 GW per year, when used in a fast-breeder reactor (FBR).[1] Additionally, breeder reactors open up a path for exploiting India's extensive thorium reserves, which are capable of offering an electricity potential of 155,502 GW per year. This is why the success of India's breeder program is crucial to its energy security.

Fast-breeder reactors, which produce more fuel than they consume, were conceptualized as early as the 1950s to extend the world's uranium resources. By contrast, once-through reactors utilize less than one percent of the energy potential of uranium. However, FBRs are currently not popular in the global community for several reasons—threats of nuclear proliferation, concerns regarding operational safety, and high costs. Additionally, uranium has proved to be more abundant than original estimates suggested. Due to these various factors, the urgency of testing comparatively uneconomical breeder reactors has abated.

Although several countries have suspended their breeder programs, India, China, and Russia have continued with their active breeder programs. China was a late starter in this space and aims to have a commercial-scale breeder reactor by 2035, whereas India aims to have a 500 MW prototype FBR operational by 2012. The main concern regarding the safety of breeder reactors is due to sodium being a major fire hazard. However, Russia has successfully experimented with molten lead and lead-bismuth cooling in several designs.

India's justification for persisting with the FBR program has always been to exploit its huge thorium reserves and reduce dependence on its scarce uranium. As part of this, India has envisaged a three-phase strategy. In the first phase, PHWRs use uranium fuel and their spent fuel rods are reprocessed to extract plutonium. In the second phase, the FBR uses a plutonium core and depleted uranium blanket to breed more plutonium than the original output. In phase three, the plutonium core and thorium blanket yield U-233, and further uses the U-233 core and the thorium blanket.

On the basis of assumptions for the success of its FBR program, India's Planning Commission has targeted an installed nuclear capacity of at least 21,000 MW by 2020—almost five times the current operational nuclear capacity. The success of India's three-phase program, however, cannot be taken for granted. There are several challenges facing India—the most immediate one being the lack of adequate reprocessing capacity. Reprocessing spent fuel from uranium-fueled reactors is essential for the FBR fuel cycle.

The availability of adequate start-up plutonium for more breeder reactors, due to the limited throughput of the existing reprocessing plant, has been a mounting concern for India. Recent studies suggest that India needs to increase its reprocessing capacity by more than ten times the current capacity of 200 metric tons per year to achieve its capacity targets for 2020.[2] In addition, reprocessing plants have a short life span of fifteen years due to the highly corrosive chemicals used in them. Therefore, there is an urgent need for large investments.

Although India has successfully tested a small-capacity FBR, the prototype FBR of 500 MW, expected to be operational in 2012, will need to validate India's ability to operate a large-capacity fast-breeder reactor. There are also challenges further down the road in the nuclear program. Globally, there have been very few experiments using the thorium cycle. Irradiated thorium is known to be highly radioactive, and the know-how for handling these fuels can pose a big challenge for India. There are several such unknowns to be solved, while at the same time averting catastrophes using fundamental design and risk management principles.

From the outset, there was an awareness of the risks, and this has prompted several safety-in-design features like defense in depth to be made an integral part of FBR design. Nuclear reactors typically have several barriers, with each designed to withstand likely stresses and backup systems to ensure power. Lessons from accidents reveal that these barriers might still be broken due to several external factors. For example, an analysis of the recent Fukushima reactor accident suggests that both the intensity of the earthquake and tide levels went above its design basis, and backup systems thus proved inadequate.

Although there was no way to have predicted the occurrence of these failures, safety in nuclear reactors, in situations like these, can be ensured if the safety systems have sufficient redundancy to ensure the continuous control of both radioactivity and heat removal, at all times. A breakdown of one of these control systems has been the cause of all nuclear disasters. Designs that adopt passive control measures, eliminating the need for any active intervention, can preempt catastrophic accidents. These design measures are already being implemented in new-generation reactors.

Along with implementing traditional safety-in-design principles, there is also a need to anticipate unpredictable failures and plan for ways to minimize their impact. Analyses of several accidents like the Three Mile Island nuclear plant and the Challenger explosion have revealed that modern systems are extremely complex and that high-technology accidents often may not have a single clear cause. An unanticipated combination of seemingly trivial and discrete events can cause major accidents. Training stakeholders and personnel to follow set procedures in case of these unpredictable failures is a crucial element of disaster planning in the context of nuclear reactors.

Considering the large-capacity additions required over a short time frame, nuclear power is the only non-fossil, large-scale, and accelerated addition option available for India. Much depends on the successful operation of the prototype fast-breeder reactor. Further, a Massachusetts Institute of Technology study reveals that the costs of nuclear reactors doubled from $2,000 to $4,000 per kilowatt between 2003 and 2009. Developing countries like India that depend on imported reactors need to constantly monitor the cost of energy from these reactors.

Having invested in the development of competence in technology manufacture and construction in the nuclear domain, India will benefit by increasing the share of indigenous equipment used in these reactors, keeping in view safety requirements. Also, learning from past failures and moving toward passive control systems instead of active interventions in case of future challenges can significantly reduce the risks posed by nuclear reactors.

Still, the Fukushima disaster has not had a great impact on India's expansion plans. The current rectors in operation are newer by design, and India has already learned from its experiences with previous accidents. As many as six minor accidents have occurred in the past with respect to nuclear power plants in India—the most recent also being caused by the December 2004 tsunami, which hit the south of India, affecting the Kalpakkam power plant in the state of Tamil Nadu.[3]

Some concerns remain. Among these, India's plans for the Jaitapur nuclear power project will require the dedication of 931 hectares for new reactors. Such a project is estimated to affect the livelihood of approximately 10,000 people living in that area. The Fukushima accident further fueled anti-nuclear energy project protests. Residents who were opposing the Jaitapur project against displacement and inadequate compensation pointed to its vulnerability to seismic activity. Even in other parts of India, development projects have faced hurdles and state governments have also declined to host nuclear energy projects for fear of negative consequences in the regions.

Nonetheless, unlike countries such as Germany, which with its far smaller population and energy needs is planning to move away from nuclear reactors for safety reasons, countries as vast as India and China will continue to expand their number of nuclear power plants. Nations must invest in research and development and the further prospects for using alternative and sustainable energy sources and for the responsible disposal of nuclear waste. To this end, the further establishment and enhancement of international safety standards and international cooperation is essential.

THE VIEW FROM CHINA

GU ZHONGMAO AND ZHOU ZHIWEI

With the drastic increase in China's oil and gas consumption since the mid-1990s, the country is becoming increasingly dependent on imports of oil and gas, with the major source of oil imports being the Middle East, the most unstable region of the world. China's energy security is thus facing a major challenge and contradiction. The challenge remains the ever-increasing domestic demands and insufficient fossil fuel reserves. The contradiction is that despite this reliance on the rest of the world, the general principle of China's energy policy is to insist on self-reliance to ensure energy security.

Presently, China's per capita energy consumption is 84 percent of the world average. The country's energy supply must be significantly increased in the coming decades to support rapid development of its national economy. However, its per capita reserves of fossil fuels are much lower than the world average. The primary means of meeting its energy demands after 2020 will be to further increase the share of nuclear energy, so as to ensure both the country's energy security and environmental safety.

To achieve these goals, China has built three bases of nuclear power plants—Qingshan, Daya Bay, and Tianwan—with a total nuclear power capacity of 11 gigawatts electric (GWe) spread among 13 units. With the aim of nuclear capacity up to 70 GWe by 2020, in September 2010, 34 new units (36.9 GWe) were approved, and 25 units have been under construction. This accounts for approximately 30 percent of the nuclear power plant units under construction in the world.

For the large-scale development of nuclear power, China has selected pressurized water reactors (PWRs) as the main reactor types for the coming decades. Until now, China has established its ability to design and build 600 MWe nuclear power plants. It has the basic ability to design larger-scale plants with PWRs through cooperation with the industry's advanced foreign companies, while primarily relying on domestic efforts.

Considering China's pressing need to continue to construct nuclear power plants, there is a need to improve the existing second-generation (Gen-2) nuclear power plants with PWRs and to primarily deploy second-generation-plus (Gen-2+) plants with PWRs before 2020. After 2020, China should be capable of designing and constructing third-generation (Gen-3) plants with PWRs, which will become the leading units of nuclear power until the commercialization of the fast reactor system in China.

China's nuclear energy development will transition from PWRs to fast reactors gradually, with the total process requiring about fifty years. Considering that the economically exploitable uranium reserves in the Earth's crust are limited (4.7 metric tons for the cost of less than $130 per kilogram), the sustainable development of nuclear fission energy depends on the fast reactor energy system, which is based on the closed fuel cycle. By contrast, less than one percent of uranium resources are usable in the once-through fuel cycle.

If reprocessed plutonium (Pu) and uranium (U) are recycled in the present PWRs, the resource base can be extended by 20 to 30 percent (uranium utilization is still less than one percent). With the introduction of fast reactors and the closed fuel cycle, it is possible to multiply by 50 to 60 times the energy produced from a given amount of uranium. This would significantly reduce—by a factor of 10—the amount of highly radioactive waste for disposal.

China's experimental fast reactor (CEFR) reached criticality in July 2010. The near-term work will include the trial operation and power enhancement of the system. Experimental studies will be carried out to obtain data on basic processes, performance, and safety and to accumulate experience. With the aim of building a demonstration fast reactor (CFR 1000) by about 2020, a great deal of research and development must occur to gain the necessary design parameters based on the CEFR.

Considering the relatively limited reserves of the low-cost uranium resources in the Earth as well as in China, it is hoped that the fast reactor energy system will be commercialized by approximately 2035. To reach this goal, research and development work on a closed fuel cycle must be carried out simultaneously. The fast reactor fuel cycle includes PWR spent fuel reprocessing, fuel fabrication, spent fuel reprocessing, high-level waste treatment, and disposal.

China's PWR spent fuel reprocessing pilot plant was tasked with processing 50 metric tons of spent fuel and completed hot testing in December 2010. A commercial reprocessing plant is under consideration and is expected to be built by about 2020. This large reprocessing plant will be based on the experience of pilot plant operations and the experience gained in developed countries. As a result, international cooperation will be very important for designing and building China's commercial reprocessing plant.

The development of mixed oxide (MOX) fuel fabrication is now at its early stages in China. It is expected that MOX fuel pellets will be fabricated for irradiation tests by 2012 and the MOX fuel assembly will be fabricated for irradiation tests by 2015. MOX fuel will be first used in

CEFRs to gain experience and will eventually be replaced by U-Pu-Zr[4] metal alloy fuel so as to improve the breeding performance of the fuel in fast reactors. Therefore, the metal fuel should also be developed in the coming years.

To achieve this ambitious goal, the central government must pay special attention to the fast reactor program and organize it in a careful and unified manner. A development road map of China's fast reactor nuclear energy system, including the closed fuel cycle, needs to be worked out as soon as possible for the better implementation of the program.

So while Japan's disastrous earthquake-tsunami Fukushima nuclear accident on March 11, 2011, shocked the global nuclear energy industry, it will do little to alter the fundamentals of the world's nuclear power development, especially in Asian countries like India and China. In addition to learning from the Fukushima disaster, these two countries' nuclear industries will pay greater attention to further improvements in nuclear safety to ensure the reliability of nuclear energy. In this regard, the State Council of China made four important decisions on March 16:

1. Examine nuclear facility safety;
2. Strengthen safety management of all operational nuclear facilities;
3. Conduct comprehensive review of all nuclear facilities under construction;
4. Suspend review and approval of all new projects until new safety criteria and regulations are issued.

In the future, the siting, designing, and building of nuclear power plants within China will be stricter, but its nuclear energy program will be firmly pursued. We must learn from Fukushima and other such disasters, paying greater attention to nuclear safety, in order to guarantee China's path toward a safe and reliable supply of nuclear energy.

NOTES

1 "A Strategy for Growth of Electrical Energy in India," document 10, August 2004, Department of Atomic Energy, Government of India.

2 Anshu Bharadwaj, L. V. Krishnan, and S. Rajgopal, "Nuclear Power in India: The Road Ahead," Center for Study of Science, Technology, and Policy, 2008, www.cstep.in/docs/CSTEP percent20Nuclear percent20Report.pdf.

3 Almost 100 kilograms of radioactive sodium at a fast breeder reactor leaked into a purification cabin, ruining a number of valves and operating systems. Although no deaths have been reported in these cases, the personnel involved were in danger of exposure to hazardous radiation levels, and the cost of these accidents has amounted to approximately $910 million. To avoid recurrences of such issues, India takes into account siting issues and proximity to seismic zones.

4 U = uranium; Pu = plutonium; Zr = zirconium.