India's Nuclear Power Program: A study of India's unique approach to nuclear energy

by

Caitlin Lenore Murray

Submitted to the Department of Nuclear Science and Engineering in partial fulfillment of the requirements for the degree of

Bachelor of Science in Nuclear Science and Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 2006

[June 2006]

Author ....
Department of Nuclear Science and Engineering
May 12, 2006

Certified by ....
Richard K. Lester
Professor of Nuclear Science and Engineering
Thesis Supervisor

Accepted by ....
David G. Cory
Chairman, NSE Undergraduate Committee

India's Nuclear Power Program: A study of India's unique approach to nuclear energy

by

Caitlin Lenore Murray

Submitted to the Department of Nuclear Science and Engineering
on May 12, 2006, in partial fulfillment of the
requirements for the degree of
Bachelor of Science in Nuclear Science and Engineering

Abstract

India is in the middle of the biggest expansion of nuclear power in its history, adding 20 GWe in the next 14 years in the form of pressure water reactors and fast breeder reactors. At the same time, the United States is overturning decades of policy in order to resume the export of nuclear materials to India, opening up the possibility of private investors in the Indian nuclear industry for the first time. This is a period of progress and turmoil in India's nuclear power program. This thesis seeks to describe and analyze India's nuclear prospects and to qualitatively assess the system's strengths and weaknesses. Using the inception of the country's nuclear power program as a starting point, this thesis will trace India's nuclear lineage to the present. In the process, it will evaluate what makes the Indian program unique, and why it may not be ideal for India that the United States is finally renewing its offers of a cooperative nuclear alliance.

Thesis Supervisor: Richard K. Lester
Title: Professor of Nuclear Science and Engineering

Contents

Chapter 1

Introduction

India's nuclear power program significantly outperformed the United States nuclear industry over the last decade and a half. In addition to putting ten new commercial reactors into service since 1990, with just one minor accident, nearly every one of these nuclear projects was completed ahead of schedule.

In many ways India has the perfect regulatory structure for such an enterprise. A vertical industry, the nuclear power program is entirely controlled by the Government of India. Although there are decided disadvantages to a command economy, it seems to have been ideal for nuclear power in India. It has allowed the administration to disregard the competitive concerns, to determine what was best for the country, and to dictate the course of the program.

It is easy to imagine a culture in which this system would fail utterly — the Soviet Union is an obvious example. But in the technocratic meritocracy of India's nuclear community, where the regulatory agencies are administered by scientists and engineers, this system has fostered and encouraged a healthy, strong nuclear industry.

This makes the United States's recent alliance with India slightly troubling; with the new influx of private investment and competition, the technology focus of the administration may wane. Although it is certainly in India's advantage to be receiving exports from the United States once again, after a 26 year moratorium, it does pose a danger to India's nuclear program. Nuclear energy has yet to become truly competitive, and turning nuclear power into a commercialized, competitive industry will eliminate the one advantage India has.

On the other hand, it is possible that India has been sacrificing safety to progress and efficiency. Although the details are difficult to verify, because of the tight-lipped nature of the nuclear power community, there have been reports that the centralized nature of the Indian nuclear power program have resulted in errors, because of pressure to approve the project. Although the vertical, centralized structure is ideal for rapid growth, it is dangerous in terms of safety.

This is another reason to follow the progress of India's nuclear industry. As the world gets smaller, what happens on the other side of the world can directly affect public policy in the United States. Modern reactors in operation today are estimated to have a core-damage event probability of 1 in 10,000 reactor-years. With a projected capacity of 1000 GWe for 2050, this is predicted to result in four core accidents globally.[1] Yet just one accident may be too many. The Chernobyl disaster nearly put an end to American nuclear power production, despite its location on another continent. A similar accident in India could continue the US nuclear industry's stagnation for another few decades.

Additionally, with the advent of international terrorism, what occurs in India can have a direct impact on the security of the United States. Problems in the regulatory structure, weaknesses in the non-proliferation defenses, or corruption in the system could all lead to domestic crises. Although it seems unlikely that India would be the source of such a problem, not being especially prone to corruption or incompetence, it is important for the United States to be vigilant with respect to all nuclear countries.

Whether it be as a model of success or a weak link, India will serve as an essential case study in the growth of a nuclear industry. This thesis will provide a detailed description of the Indian nuclear power program, its strengths and its weaknesses, and will provide evidence for the conclusions articulated in this chapter.

Chapter 2

India's Need for Nuclear Energy

In July 2005, before a joint session of the US Congress, Indian Prime Minister Dr. Manmohan Singh articulated his desire to eliminate poverty and foster democracy through economic success. He stated that his country would continue to encourage enterprise and trade "so that Indian talent and enterprise can realize its full potential, enabling India to participate in the global economy as an equal partner." [2] India is looking to raise itself by its bootstraps, to the status of a developed nation.

In order to achieve this goal, India needs to continue its economic growth and ratchet up its electricity production. Although India has established itself as an undeniable presence in the global community, its per capita GDP remains low, ranking 136th worldwide. It has one of the world's top technological communities, yet nearly half of its population still lives without electricity, a demographic larger than the entire population of the United States.

2.1 Electricity Demands

Electricity has proven to be the deciding factor in economic progress for more than 100 years. The industrial revolution guaranteed that a plentiful, reliable source of electricity is a prerequisite to competing in the international market.

With 1.1 billion people, India is the world's second largest country by population, grow by roughly 1.4% per year, and is expected to surpass China in population by the year 2025. Despite its size (16% of the global population), India produces just 2% of the world's electricity.[3] While ranking ninth internationally in gross production, with an output of over 600 billion kWh, India is far behind every European and North American country, not to mention nations like Fiji, Zimbabwe, Mongolia, and Azerbaijan, in per capita electricity production. In 2002, India ranked 137th, producing a little over 500 kWh per person, far below the United States's approximately 13,000 kWh and Kyrgyzstan's 2,600 kWh per capita. [1]

There is an undeniable relationship between per capita GDP and per capita energy production. Figure 2-1 illustrates this trend, comparing kilowatt hours to the per capita GDP. Although the data are noisy, with a number of outliers, and causality is indeterminate, the presence of a correlation is clear. It is relatively unambiguous that the per capita GDP is proportional to the per capita electricity production.

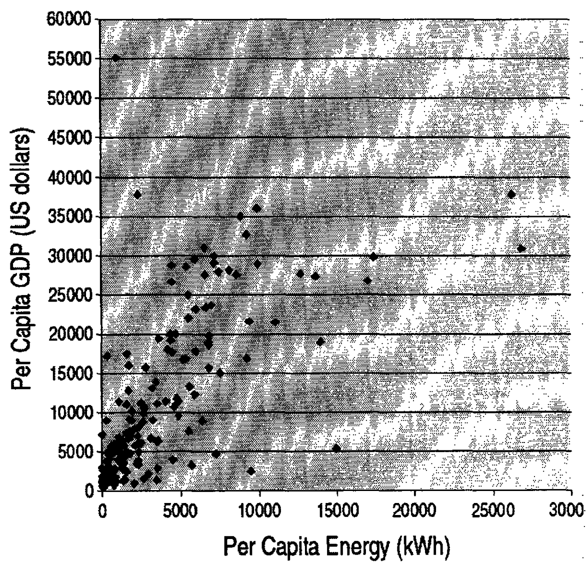

Figure 2-1: Per capita GDP estimates plotted against per capita energy production production estimates from 2002

India is aware of this demand. With a growth rate of 6%, India's GDP is growing rapidly, but to sustain this improvement, India's electricity industry will have to grow with it. The Nuclear Power Corporation of India, Limited, and the Government of India have estimated that to achieve "moderate levels of economic growth" India

[1]Per capita values and rankings were calculated using the CIA Factbook 2002 estimates.

needs a production capacity of at least 900 GWe, an order of magnitude increase from current output levels.[3] In their "Strategy for Growth of Electrical Energy in India" the Government of India set as its ultimate goal an electricity capacity of 8 trillion kWh by 2050.[4]

2.2 Limited Traditional Fuels

Approximately 70% of India's energy output is generated through the burning of coal, and 70% of the coal recovered in India is used for electricity production.[5] However, in addition to dealing with an urgent need for increased energy production, India is, for the first time in recent history, encountering widespread coal shortages. Although these shortages are the result of myriad problems, and appear to be temporary, they are indicative of a larger problem India will face within the next few decades.[6]

India's Ministry of Coal recently reported that with an estimated growth rate of 5% per year in coal production, as would be necessary to sustain the growth in electricity proposed by the Government of India, the country's extractable coal reserves would be exhausted within 40 years.[7]

Aware that the country will be unable to meet those demands solely through the use of traditional fuels, the government has turned to alternative sources of energy. In addition to investing in renewable sources of electricity, including hydro power, wind power, solar energy, biofuels, geothermal energy, and ocean energy, India has made nuclear power a top priority since winning its independence in 1947.

2.3 Environmental Concerns

2.3.1 Carbon Emissions

As the number of people concerned about global climate change increases, the focus turns more and more to carbon-less sources of energy. The 2003 MIT study, "The Future of Nuclear Power," analyzes the role nuclear power will play in this century in lowering carbon emissions. For the purposes of the study, a goal of no more than twice the pre-industrial CO_2 concentration is assumed. This value comes from a scientific consensus that anything greater would cause serious climate alterations. [8]

Given this assumption, the study imagined a global growth scenario in which the world's nuclear capacity grew to 1000 GWe by 2050. A global deployment scenario necessary to achieve this threefold increase in nuclear energy was projected in the study. Figure 2-2, taken from the study, shows the projected development between 2002, when the data were gathered, and 2050. Although the exact kilowatt values have large associated uncertainties, the regional projections between 2000 and 2050 are striking.

In order for the global capacity to increase to 1000 GWe, which would only increase nuclear's share of the electricity market from 17% to 19% and would eliminate only a quarter of the carbon-emission increase between now and 2050, the market share of nuclear power in the developing world would have to increase from 2% to 11%.[1] In particular, China, India, and Pakistan would need to increase to on the order of 200 GWe. This study provides evidence to support the assertion that although the United States will have to lead the way, key to nuclear power's role in reducing carbon emissions is the wholehearted participation of developing countries like India.[1]

REGION	PROJECTED 2050 GWe CAPACITY	NUCLEAR ELECTRICITY MARKET SHARE 2000	NUCLEAR ELECTRICITY MARKET SHARE 2050
Total World	1,000	17%	19%
Developed world	625	23%	29%
U.S.	300		
Europe and Canada	210		
Developed East Asia	115		
FSU	50	16%	23%
Developing world	325	2%	11%
China, India, Pakistan	200		
Indonesia, Brazil, Mexico	75		
Other developing countries	50		

Projected capacity comes from the global electricity demand scenario in Appendix 2 which entails growth in global electricity consumption from 13.6 to 38.7 trillion kWe-hrs from 2000 to 2050 (2.1% annual growth). The market share in 2050 is predicated on 85% capacity factor for nuclear power reactors. Note that China, India, and Pakistan are nuclear weapons capable states. Other developing countries includes as leading contributors Iran, South Africa, Egypt, Thailand, Philippines, and Vietnam.

Figure 2-2: "The Future of Nuclear Power" Global Projection Scenario[1]

2.3.2 Pollution Control

Although it may seem as though India is more likely to focus on the immediate economic concerns, instead of comparatively intangible concerns or greenhouse gasses and climate change, there are elements to the environmental concerns that are urgent for India.

The rapid urbanization of India over the past few years has led to a dramatic increase in pollution levels. Airborne particulate matter, the primary measure of the success of pollution controls, has been measured in New Delhi at ten times the legal limit.[9] Of the global 3 million deaths that are credited to air pollution, the highest percentage is attributed to India.[9] Although some of the pollution can be ascribed to urbanization, transportation, and industry, the high number of coal-fired plants play an undeniable role in the problem.

In addition to domestic pollution concerns, India has been under pressure from Europe and other developed countries to manage its emissions. Between 1990 and 2001, India's carbon emissions increased by more than 61%, second only to China.[9] Because of its status as a developing country, India was exempt from the requirements of the Kyoto Protocol. Nevertheless, the international community is looking to India to make some good faith effort to improve conditions.[10]

2.4 The Nuclear Option

In response to the problems outlined above, India has begun an extensive diversification process, promoting energy solutions as traditional as coal and as untried as ocean power. But India has come to the conclusion that nuclear is an essential component to its economic growth and have made the development of nuclear energy a priority.

Water, wind, and ocean power are certainly clean energy, but still, in the early stages of development, and prohibitively expensive, they are incapable of providing the massive scale-up India requires. India's focus on nuclear is in many ways a compromise: cleaner than coal and more powerful than wind. The rest of this thesis will address whether nuclear can satisfy India's demands.

Chapter 3

India's Nuclear Program

3.1 Nuclear History

In 1948, India launched its long-term program to develop nuclear power as an energy alternative by passing the Atomic Energy Act of 1948 and establishing the Atomic Energy Commission (AEC). Six years later, a presidential order created the Department of Atomic Energy (DAE), which reported directly to the Prime Minister, and the Atomic Energy Commission was then relocated to the DAE. This move coincided with the United States's "Atoms For Peace" initiative, which included a massive campaign to whet the appetites of developing nations for nuclear energy. The US's predisposition to favor nuclear power advancement in India, coupled with active lobbying by India's nuclear energy chief, allowed the US to sell India ten tons of heavy water for its first heavy-water research reactor, CIRUS (Canada-India Reactor US).[11] This was just the first exchange in nearly two decades of friendly relations between the US and India, over which time the US supplied India with nuclear technology, material, and expertise, as well as more than $93 million in grants and loans, easing India's path to nuclear development.[12]

Despite the substantial help of international allies, India's priority has always been self-sufficiency. With this in mind, the administration carefully laid the groundwork for a system capable of sustaining the nuclear program in the absence of outside intervention. In 1962, the legislature updated the Atomic Energy Act, transforming the Atomic Energy Commission from a small body with a primarily research focus to a powerful governmental unit responsible for all policy and regulatory decisions concerning nuclear power. The same act gave the DAE full and exclusive responsibility for the "the theory, design, construction and operation of nuclear reactors" and made the DAE the enforcer of the policy decisions made by the AEC.[13]

In addition, the Indian government founded a national research center in Trombay, called the Bhabha Atomic Research Centre (BARC). The facility includes a training center, which prepares scientists and engineers for careers in nuclear power, an array of research reactors, a thorium facility, and a number of other installations designed for the support and study of all stages of the fuel cycle. Aspara, the first research reactor, both in India and Asia, was installed in 1956, and was followed soon after by CIRUS and Zerlina in 1960 and 1961 respectively. As the AEC placed a heavy emphasis on the importance of human resources, the training center became the center of the nuclear community - all professional nuclear scientists and engineers cite their Batch number from BARC, indicating their nuclear training group. [1]

3.1.1 India's Three-Stage Plan

India has set three stages for the development of nuclear power, with energy autonomy as the ultimate goal. The first stage takes advantage of India's domestic supplies of natural uranium, employing pressurized hard-water reactors (PHWRs) to produce electricity, with the added bonus of a plutonium fission product. The second stage will use this plutonium in a number of fast breeder reactors (FBRs), which produce electricity, along with extra plutonium and U-233, through the development of thorium. The third and final stage of development will include a series of self-sustaining reactors which use thorium to produce U-233.[14]

In addition to having limited supplies of coal and natural gas, India has just 0.8% of the world's uranium resources. Although this uranium is sufficient for the first few rounds of development, relying ad infinitum on natural uranium would require India

[1]For instance, the AERB Vice-Chairman includes in his Internet bio that he graduated "from the 12th Batch of BARC Training School"

to depend on the unpredictable global community. In accordance with its focus on self-reliance, a significant part of India's nuclear progress has been the development of thorium, a natural resource India has in virtually unlimited supply. Thorium, though not itself fissile, becomes Th-233 upon absorbing a neutron. It then decays to the highly fissile U-233, which, with a forty times higher yield, can be used in place of U-235 to greater effect.

3.1.2 Plan Implementation

In 1965, construction on India's first nuclear power facility commenced. Comprising two boiling water reactors, Tarapur Atomic Power Station (TAPS) went in to operation in 1969. In addition to providing 320 MWe to the surrounding area, TAPS proved the viability of nuclear power in India and gave the administration some much needed experience, although it remains the country's only BWR facility and the reactor core was provided by the United States.[15] In the meantime, in a venture more relevant to the country's ultimate goal, construction began on a series of pressurized heavy water reactors, each with a capacity of 220 MWe. PHWR installations were constructed in Kaiga, Kakrapar, Kalpakkam, Narora, and Rawatbhata. Shortly after Tarapur achieved criticality, the nuclear plan's second stage commenced in earnest. In 1971, at the Indira Gandhi Center for Atomic Research (IGCAR), the fabrication of plutonium fuel rods marked the first step towards the completion of India's first fast breeder test reactor. This FBR, known as PURNIMA-I, achieved criticality a little more than a year later, in May of 1972.[16]

3.1.3 *Smiling Buddha*

As a result of constructive efforts on the part of the administration to steer the country towards energy autonomy, the nuclear industry was relatively prepared when the United States turned its back on India, cutting off nuclear exports. The impetus behind the US policy shift was India's 1974 detonation of the "Smiling Buddha," their first nuclear explosive device, in Pokhran. Manufactured using plutonium from the Canadian-Indian joint enterprise CIRUS, the test was a shock to the nation's North American allies.[17] The Indian government, noting that the test was on Indian soil and below ground, classified the event as a "Peaceful Nuclear Explosion," a designation employed on a number of occasions by the US and the USSR. But the international community viewed it as a weapons test, and Canada and the United States immediately reversed their policy of providing financial and technical assistance.[18] Despite claims by the Indian government at the time that the detonation was entirely peaceful, the project leader, Raja Ramanna, announced to the press in 1997 that "The Pokhran test was a bomb, I can tell you now." He then added, "An explosion is an explosion, a gun is a gun, whether you shoot at someone or shoot at the ground... I just want to make clear that the test was not all that peaceful."[19]

3.1.4 Public Enterprise

After the Pokhran test, India continued to move forward, albeit more slowly, in its development of both nuclear energy and nuclear weapons, this time in relative isolation. Research, construction, and production continued under the administration of the DAE. In addition to developing innovative technology, the nuclear community was looking for a more efficient administrative infrastructure. In 1987, motivated by the theory that a business could be run more effectively than a government department, the Government of India founded a public enterprise corporation to take over the job. The Nuclear Power Corporation of India, Limited (NPCIL), a company controlled by the DAE, took over the job of producing and distributing electricity through the generation of nuclear power. The DAE and AEC remained in place as a regulatory agency, making and enforcing all the relevant nuclear policies and regulations, but the NPCIL was introduced as a business, with the operational freedom and investment opportunities not available to government departments.[20]

As with any public sector enterprise, the question arises as to what extent it is in the control of the government. In the case of the NPCIL, it is clear that the interests of the administration are closely mirrored by the policies of the corporation. Although the NPCIL is independently audited and issues its own corporate bonds to the public, the Chairman and Managing Director, along with the Board of Directors, are appointed by the governing party.[21] Typically those appointed to the Board and chosen as managers have been prepared for their position by a career in the DAE. In fact, at present, no fewer than seven of the twelve men on the Board of Directors are simultaneously employed by the NPCIL and a regulatory body of the Government of India.

3.1.5 Nuclear Weapons Test

Ten years after the commissioning of the NPCIL, India was making great strides in nuclear technology and was well on its way towards the successful completion of the first of its three stages. But in 1998, two days after Pakistan performed a highly-publicized missile test, Prime Minster Vajpayee, who was elected on a platform of making India an openly declared nuclear weapons state, ordered the detonation of five nuclear weapons.[22] The development of the Shakti Test devices, as it was known, employed a team of researchers and engineers from BARC and the Defense Research and Development Organization. Three devices were detonated on May 11 and two more two days later: a thermonuclear device; a pure fission missile warhead; and three experimental fission devices. Each device contained fissile material from BARC's stage-two research reactors.[23]

Both before and after the detonations India claimed a no-first-use policy, despite vigorously asserting its right to have first strike capabilities while Pakistan controls its own nuclear arsenal and refuses to abide by a no-first-use policy.[24] Nevertheless, these tests reiterated India's status as somewhat of a pariah in the international nuclear community. Under the provisions of the 1968 Nuclear Non-Proliferation Treaty, no state without nuclear weapons at the time was permitted to develop them. India refused to sign the treaty on the grounds that it includes a baseless discrimination against those countries that had not developed nuclear weapons by the arbitrary date of 1968. The administration stated that if there were a provision for universal disarmament India would sign the treaty, but until that time, nuclear weapons were necessary to protect itself against an aggressive Pakistan.

The reaction to the tests served only to demonstrate India's continued isolation from the nuclear community. However, the scientists and engineers seemed undaunted. In the days after the weapons test, at a press conference, the scientists who worked on the devices were asked whether they were concerned about the export sanctions imposed upon them. Dr. A. P. J. Abdul Kalam, the Secretary of Department of Defense Research and Development, responded "Technologically, we have faced sanctions for a long time. When we were refused the supercomputer, we went ahead and made our own. In the space programme, when we were refused cryogenic engines, we have gone ahead and made our own which should be ready next year. No one can trouble us technologically. There is a challenge to be met and we rise to the occasion."[25]

3.2 Current Capacity

In spite of India's relatively limited access to civilian nuclear technology from other nations, it has been remarkably successful in the development of nuclear power. In stark contrast to United States nuclear programs, nearly every nuclear power facility has been constructed ahead of schedule.[26] Today the country has fifteen commercial power plants in operation, thirteen PHWRs and the two TAPS BWRs, for an operating capacity of 3260 MWe with an average capacity factor of 71% for the fiscal year 2005-2006.[27]

Until 2005, all the commercial plants were small reactors with an output of under 220 MWe, but in order to meet their electricity goal, India began to construct bigger plants. In September 2005, India's first mid-sized nuclear power plant went on-line in Tarapur, with an operating capacity of 540 MWe. Construction on an identical facility is near completion, and another 540 MWe are anticipated by January 2007.[28] Table 3.1 shows the capacity and each unit's average capacity factor for the current fiscal year, 2005-2006, of India's on-line commercial nuclear power plants. A full list of reactors, including research reactors and decommissioned reactors can be found in Appendix A.

Commercial Reactors	**Reactor Type**	**Capacity** (MWe)	**Capacity Factor** (2005-2006)
Tarapur Unit-1	BWR	160	94%
Tarapur Unit-2	BWR	160	96%
Tarapur Unit-4	PHWR	540	70%
Rajasthan Unit-1	PHWR	100	0%
Rajasthan Unit-2	PHWR	200	80%
Rajasthan Unit-3	PHWR	220	79%
Rajasthan Unit-4	PHWR	220	78%
Madras Unit-1	PHWR	170	84%
Madras Unit-2	PHWR	170	80%
Narora Unit-1	PHWR	220	71%
Narora Unit-2	PHWR	220	69%
Kakrapar Unit-1	PHWR	220	54%
Kakrapar Unit-2	PHWR	220	68%
Kaiga Unit-1	PHWR	220	66%
Kaiga Unit-2	PHWR	220	81%
Total		**3260**	**71%**

Table 3.1: India's Commercial Nuclear Power Capacity

3.3 Safety

There have been some concerns about compromising safety for efficiency. Since the inception of the nuclear program, possibly because rapid growth and short construction-times, there have been a number of accidents at nuclear power facilities. Narora Units 1 and 2 each suffered a fire that brought them down for more than a year, in 1993 and 1996 respectively. In 1994, the containment dome collapsed during the construction of Kaiga's first unit, delaying its deployment.[29]

In 1996, the IAEA placed all nine of India's operating nuclear power facilities on its list of the 50 least reliable of the 399 reactors it monitors.[29]

3.4 The Next Wave of Expansion

In 2003, recognizing that the growth of the electricity industry was being outstripped by the growth of the population, the Ministry of Power issued a brand new National Electricity Policy.[30] In it were the administration's energy goals:

- Access to Electricity - Available for all households in next five years
- Availability of Power - Demand to be fully met by 2012. Energy and peaking shortages to be overcome and adequate spinning reserve to be available.
- Supply of Reliable and Quality Power of specified standards in an efficient manner and at reasonable rates.
- Per capita availability of electricity to be increased to over 1000 units by 2012.
- Minimum lifeline consumption of 1 unit/household/day as a merit good by year 2012.
- Financial Turnaround and Commercial Viability of Electricity Sector.
- Protection of consumers' interests.

This optimism has permeated the whole administration. India's Tenth Five Year Plan was introduced by K.C. Pant, the Deputy Chairman of the Planning Commission, with stirring, encouraging rhetoric: "The Tenth Five Year Plan marks the return of visionary planning to India after a long interregnum of cautious optimism.... It calls for us to stretch beyond our immediate capabilities and set targets which are in consonance with our needs and the evident aspirations of our people."[31] With these goals in mind, India embarked on the biggest commercial nuclear expansion program in its history.

3.4.1 Stage One Construction

The Government of India, with the consensus of the DAE, AEC, and NPCIL, have set a target of 20,000 MWe of commercial nuclear capacity by the year 2020, and to produce 25% of their electricity from nuclear power by 2050. Taking steps towards that goal, the NPCIL currently has seven PWRs under construction, all scheduled for commercial operation by December 2008. In addition to four more small PHWRs at Kaiga and Rajasthan, and the one mid-sized reactor at Tarapur, the NPCIL will also connect two massive 1000 MWe reactors to the grid in Kudankulam in the next two years. Water-cooled water-moderated energy reactors (WWERs), first developed by the Soviet Union in their quest for an energy solution, are pressurized water reactors that use low enriched uranium dioxide pellets as fuel. The primary difference between this and the western PWRs are the horizontal steam generators used in the former.[32] Table 3.2 shows the capacity and expected completion date of the seven facilities under construction.

With a comprehensive knowledge of PHWRs, such that their construction has become routine, India has mastered stage one of its three-stage plan.

Under Construction	**Reactor Type**	**Capacity** (MWe)	**Expected Completion**
Kaiga Unit-3	PHWR	220	Mar 2007
Kaiga Unit-4	PHWR	220	Sep 2007
Rajasthan Unit-5	PHWR	220	Aug 2007
Rajasthan Unit-6	PHWR	220	Feb 2008
Tarapur Unit-3	PHWR	540	Jan 2007
Kudankulam Unit-1	WWER	1000	Dec 2007
Kudankulam Unit-2	WWER	1000	Dec 2008
Total		**3420**	

Table 3.2: India's Commercial Nuclear Power Capacity

3.4.2 Stage Two Construction

In 2003 India moved to the second stage in commercial nuclear power, with the formation of another public sector Government of India enterprise: Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI). BHAVINI, according to its Chairman and Managing Director, has been set up "with the specific mandate of implementing the Fast Breeder Reactor Programme in a commercially successful manner in our country."[33] With the prototype designed by researchers at IGCAR, and the management team staffed almost entirely from within the NPCIL, the new venture is inseparably linked to the old. In fact, the Chairman and Managing Director of the NPCIL, S.K. Jain, was appointed to fill the role simultaneously of BHAVINI's first Chairman and Managing Director, and the Board of Directors were appointed to their positions by the

President of India from within the NPCIL and IGCAR.[34]

In August 2003, BHAVINI began excavation in Kalpakkam for the construction of India's first indigenous fast breeder reactor.[34] With the ability to run on recycled plutonium and depleted uranium, the plant will demonstrate India's commitment to the three-stage plan and provide 500 MWe without requiring any natural uranium. It is expected to become operational in 2010.

3.5 Industry Structure

The relationship between the commercial industry and the research establishment is relatively streamlined in India, because of the government-owned nature of the nuclear enterprise. Everything from design to decommissioning, including construction, commissioning, and operation, is done by the NPCIL, and literally every aspect of the electrical output is controlled by some part of the government, including fuel fabrication, grid maintenance, and waste management.

The first stage is at the Government of India Central Electricity Authority, which assesses the country's growing electricity needs. A portion of these demands are meted out to the Department of Atomic Energy, which is responsible for meeting that demand. Within the DAE, the Atomic Energy Commission is responsible for directing the construction and operation of the nuclear power plants to meet these goals. The AEC then directs the NPCIL on where and when to build new commercial power plants.

3.5.1 Design

By the time a commercial power plant is commissioned, decades of research have been done on the subject within the DAE and a prototype has been created by IGCAR. The NPCIL has a design team which tailors the prototype to the geography of the construction site.

3.5.2 Manufacture and Construction

One direct result of India's insistence on self-reliance is that all the materials necessary for the construction are produced domestically. For the parts that are not nuclear-specific, generic manufacturers are commissioned to provide the materials. Although some of the producers of parts such as turbines, steam generators, and circuits are private companies, the NPCIL is empowered to make whatever alterations it deems necessary. In the early years of the program, the NPCIL made a number of such changes to the production facilities to take into account the foreseen demand, regardless of public or private status.[35] The NPCIL also installs its own quality control inspectors whenever parts for nuclear purposes are commissioned.[35]

For the nuclear specific materials, including heavy water, control rods, and fuel, the DAE has created divisions to manufacture the products and meet any and all needs of the NPCIL. Uranium and thorium analysis is done by the Atomic Minerals Directorate of Exploration and Research of the DAE and the mining and processing is then done by the Uranium Corporation of India, Ltd (a public sector company created along the same lines as the NPCIL). The fuel fabrication process is performed by the Nuclear Fuel Complex of the DAE, which also assembles the fuel matrices and manufactures the zirconium alloy sheaths. The heavy water is provided by the Heavy Water Board of the DAE.

Once the parts are manufactured, the NPCIL employs firms with experience with fossil fuel plants to construct the actual facility.[35]

3.5.3 Operation

Commercial nuclear power plant operation runs on a hierarchical system based almost entirely on educational qualifications. The "professionals," engineers who have studied at BARC and passed the NPCIL's training course, fill the managerial positions. In addition to the managerial staff, professionals are assigned the more technically demanding jobs, and fill the senior-engineer positions, similar to the US senior-engineer position. These people are almost exclusively graduates of India's elite institutions, such as the India Institute of Technology, and have engineering Masters degrees and PhDs in a variety of disciplines, including metallurgy, electrical engineering, bio-sciences, and mechanical engineering.[36]

In the middle are the "semi-professionals." Having earned degrees in engineering or advanced trade degrees, these men are employed as supervisors, directing the day-to-day activities in the different departments, acting, frequently, as the liaison between the managers and the technicians. The technicians, as their name implies deal with the daily manual labor. Generally technicians are those without advanced degrees, and have earned only their high school diploma or a trade certification.[20]

Within the power plant, the staff is divided further. In many ways similar to the American system, each nuclear power plant has several teams dealing with different aspects of the plant performance: Operation, Maintenance, Technical, and Training divisions. Within each group is a hierarchy of managers, engineers, supervisors, and technicians.

3.6 Regulatory Structure

In 1948, when the Atomic Energy Commission was created, research into the implementation of nuclear power protocols was in its infancy. Today, with the commercial success of stage one and the commencement of the commercial life of stage two, a much more complicated regulatory regime is necessary, particularly as the operational scope of India's nuclear program is under the control of the government.

Figure 3-1 provides an outline of the organizational structure of the Department of Atomic Energy. Although the AEC directs the activities of the DAE, it remains a part of the larger department. In addition to the public sector enterprises, such as the NPCIL and BHAVINI, and the research and development organizations, including BARC and IGCAR, the DAE is responsible for a number of industrial organizations, support organizations, and institutions for education.

The process for constructing a new nuclear power plant extends beyond the DAE. The first step is an analysis by the Central Electricity Authority on the specific

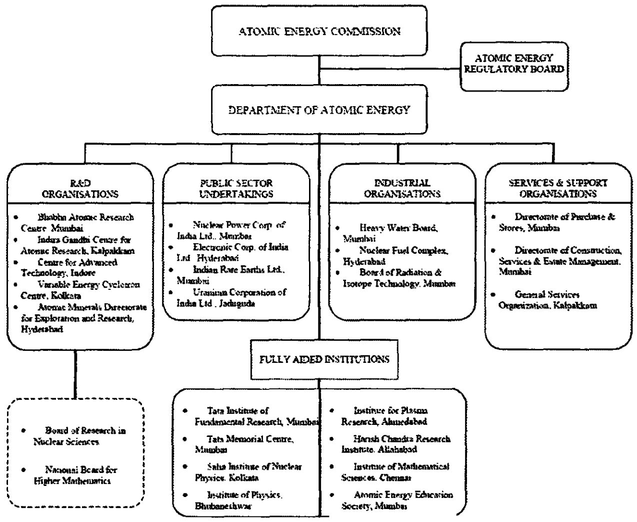

Figure 3-1: The organizational structure of India's Department of Atomic Energy [37]

geographic demands for electricity.[38] Then, taking the recommendations of the DAE and the CEA into account, the Government of India designs a capacity addition program, and then delegates the implementation to the DAE.[39] The NPCIL, in its capacity as a subsidiary of the DAE, commissions its design team to refine the IGCAR prototype to a site-specific model. They then write up an application and submit it for examination and approval to the Atomic Energy Regulatory Board (AERB), which is responsible for approving all the country's nuclear facilities.

3.6.1 The Atomic Energy Regulatory Board

When India's first commercial nuclear power plant was commissioned in 1965, the government of India recognized the need for an oversight committee, an independent department responsible for careful scrutiny of the nuclear industry. The Design and Operations Review Committee was created as a permanent safety body upon the commissioning of the Tarapur station. Three years later, when the Rajasthan Atomic Power Station was launched, a second body was created to authorize and monitor its safety status. Eventually the two committees were consolidated to form the DAE Safety Review Committee (SRC), which was responsible for the general safety oversight of all aspects of the DAE.[40]

In 1980, a committee assigned to make a recommendation on the advantages and disadvantages of the SRC issued a report called the "Reorganization of Regulatory and Safety Functions" which recommended the formation of the AERB with "powers to lay down safety standards and assist DAE in framing rules and regulations for enforcing regulatory and safety requirements envisaged under the Atomic Energy Act 1962."[40]

The Board was created within three years of the report and immediately took on the oversight of the DAE, including the authorization of new power plants proposed by the NPCIL as well as the enforcement of safety protocols on facilities outside the DAE.

Over time, the scope of the committee has grown dramatically. With the rise of the use of nuclear technology in the fields of medicine, agriculture, and transportation, the specialization of the AERB has increased in proportion. Figure 3-2 shows the organizational structure of the AERB, giving an idea of the size of the Board. However, their mission has never changed; it remains"To ensure that the presence of ionizing radiation and the use of nuclear energy in India do not cause unacceptable impact on the health of workers, members of the public, and the environment."[40]

3.7 The Licensing Process

Over the years, despite its expanding scope and objectives, the AERB's primary role has been as the licensor of commercial nuclear power plants. Each nuclear power plant must be approved by the AERB at every step in the process: site approval, construction, commissioning, operation, and decommissioning.

3.7.1 Process Overview

In the first step of the licensing process, the utility crafts a comprehensive application for the proposed facility. This requires a complete design and prototype, along with an assessment of every conceivable safety factor. Once each risk has been considered and quantified, the application is submitted to the AERB Secretariat.

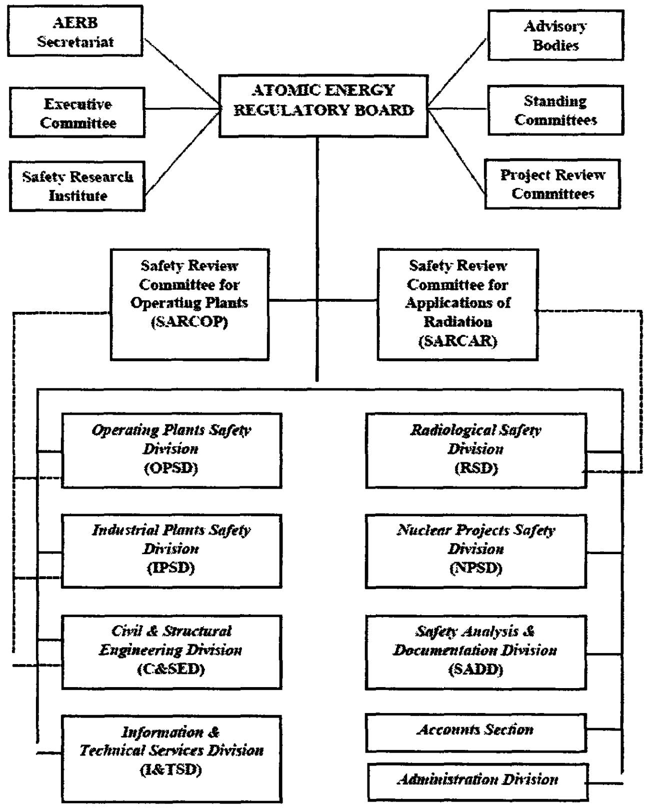

Figure 3-2: The organizational structure of India's Atomic Energy Regulatory Board [40]

The Secretariat then passes it on to the relevant Design Safety Committee, which works with the utility to evaluate the application. In addition to passing its recommendation along to the Secretariat and the advisory committees, the Design Safety Committees work alongside the utility to improve the application, telling them what information and supplemental material must be submitted along with the application. The application must include everything relevant to the extensive regulations enacted by the AEC and the AERB. With the Design Safety Committee as its first stop, no application makes its way to the advisory committee incomplete.[40]

Once the utility has provided enough information to satisfy the Design Safety Committee, they send it back to the Secretariat, who farms it out to the relevant advisory committee which reviews the application. The advisory committee, supported by smaller safety committees, gives a recommendation to the Board. The Board then reviews the application once more, and either rejects or denies the application, based primarily on the advice of the advisory committee.

3.7.2 The Committees, Divisions, and Task Forces

This blithe summation of the work flow drastically over-simplifies the process; there are more than 68 committees in the AERB taken from all across the country. The underlying philosophy is that more steps in the process correlates to a lower probability that mistakes make it all the way through. The committees range from overarchingly broad to intriguingly specific, including the Advisory Committee on Nuclear Safety alongside the Glossary Review Committee and the "Committee for selection of candidates for admission to M.Tech." A full list of AERB committees can be found in Appendix B.

Although the summary in Section 3.7.1 is accurate, it by no means gives an idea of the sheer number of people a given application is seen by. However, there is a method to the madness. When a nuclear power plant is commissioned, each step of the process and every detail of each step is examined minutely by the appropriate committee, which is composed of the foremost experts India has to offer on the subject.

Advisory Committees for Project Safety Review

The AERB is supported by three under-committees: the Safety Review Committee for Operating Plants (SARCOP), which carries out surveillance and periodic reviews of the nuclear power plants; Safety Review Committee for Applications of Radiation (SARCAR), which manages all applications of nuclear materials not related to nuclear power, such as radiation therapy and medical imaging; and, key to the licensing process, the Advisory Committees for Project Safety Review (ACPSRs).

There exists an ACPSR for every type of nuclear power project, including the Advisory Committee for Project Safety Review of Light Water Reactor Projects (ACPSR-LWR), the Advisory Committee for Project Safety Review of New Radioactive Waste Management Plants/Facilities, and the Advisory Committee for Project

Safety Review of PHWR-based NPPs and PFBRs (ACPSR-PHWR/PFBR). These advisory committees review the application with the support of the subsidiary committees devoted to the minutia.[41]

3.7.3 The Steps

Rather than issuing a single license for the design and construction of a nuclear power plant, the AERB separately authorizes each step in the process, including site approval, construction, commissioning, operation, and decommissioning.

Site Approval

When a site has been proposed by the NPCIL, it must be approved before the next step of the process can commence. The ACPSR-PHWR/PFBR collects reports from the Site Evaluation Committee and site evaluation documents from the NPCIL. It examines the reports and studies the appropriateness of the site for a nuclear power plant, with respect to the safety of the surrounding population as well as the plant itself. It also evaluates any site-specific requirements the plant administrators are likely to encounter in the construction and operation stages. [42]

The recommendations are then forwarded to the AERB along with suggestions and requirements. The AERB typically follows the recommendation of the ACPSR, and if they give the site a positive review, the AERB is likely to give the project site clearance.[40]

Commissioning and Construction

The ACPSR also handles the construction and commissioning authorization. Taking into account evaluations from the Project Design Safety Committee and the Civil Engineering Safety Committee, the ACPSR assembles a report for the AERB with a complete recommendation, including "observations/suggestions/stipulations."[41]

The ACPSR generally takes into account the management structure, the staff qualifications, the caliber of the subcontractors, the quality control program, and the emergency preparedness of the project. These factors are evaluated on the basis of recommendations and reports from an assortment of committees.[2]

The ACPSR then makes its recommendation to the AERB, which will give the NPCIL authorization for commissioning or construction.

Operation

When a plant is finally constructed, before it can go operational, there is a joint review by ACPSR and the Safety Review Committee for Operating Plants (SARCOP). For the ACPSR, the process is nearly identical to the process for commissioning and construction: sub-committees are assigned to evaluate the details and the ACPSR makes recommendations concerning the safety of the plant.

The joint review is used for the plant's first two milestones: the first approach to criticality and the first time the capacity factor reaches 100%. All following reviews are handled exclusively by SARCOP, so the joint review is essential in this transition period.[42]

Decommissioning

Decommissioning for the most part follows the same process as commissioning, with safety evaluations, sub-committees, and reports to the AERB. Authorization by the AERB is required before any power station can be decommissioned. However, because decommissioning frequently involves the transportation of radioactive material, the Safety Review Committee for Applications of Radiation (SARCAR) is involved.

Drawing on the advice of other more specialized committees, SARCAR is responsible for authorizing transportation methods for radioactive material as well as waste-management facilities. It makes a recommendation to the AERB, which grants or denies authorization on the basis of SARCAR's report.

[2]For example, an evaluation of the control room computers would be done by the Standing Committee for Control, Instrumentation and Computer Based Systems

3.8 Pros and Cons of the Licensing Process

3.8.1 Autonomy

The primary advantage of this system is the autonomy of the licensing board. Independence is essential for any regulatory body, as the regulators should have no personal stake in whatever they authorize.

In recognition of this principle, the AERB's first chairman was Professor A.K. De, the former director of the India Institute of Technology, a man previously unaffiliated with the DAE.[43] Today, the AERB protects that reputation careful. Except by virtue of having studied and worked extensively at BARC or IGCAR, not one of the division directors of the AERB worked for the DAE before coming to the AERB, a difficult assertion to make, since the DAE runs virtually the entire nuclear community.[43] That executive board and final decision-makers are independent arbiters makes them more attune to biases in the information.

On the other hand, the AERB does receive extensive advice from the Advisory Committee on Nuclear Safety, which is staffed by experts from the DAE, in addition to scientists and engineers from the AERB and other independent agencies. And, as Section 3.7.2 should have made clear, the sheer volume of material that is authorized by the AERB is staggering. The board-members may be chosen because of their status as independent arbiters, but most of the recommendations on which they base their decisions come from engineers in the thick of it.[40]

Upon his retirement in 1996, A. Gopalakrishnan, the outgoing chairman of the Atomic Energy Regulatory Board, stated that safety at the nuclear power plants had been compromised because of the AERB's subsidiary status to the department it is supposed to be regulating, the DAE. He revealed that more than 130 accidents had taken place at Indian nuclear facilities, placing it only above Pakistan and Brazil in terms of safety. However, the DAE responded that Gopalakrishnan was simply retaliating because his stint as chairman had not been renewed.[29] Not only that, but since 1996 India has not seen an accident at any of its facilities that resulted in an outage.

Additionally, the training structure of India's nuclear community is such that the Board can never be truly independent. With every professional engineer in India making its way through the BARC training facility, there is a distinctly parochial, insular feel to the industry, and there are few true outsiders.

3.8.2 Multi-Pronged Approach

A committee is less likely to overturn its own decision than an outside agency. Having both SARCOP and the ACPSR review every project before it achieves criticality is a sound administrative choice, involving a system of checks and balances, improving the chances of catching a mistake.

On the other hand, SARCOP works with the ACPSR, receiving copies of their recommendations and basing many of their conclusions on identical committee reports. A truly ideal system would have these two authorizations conducted in parallel rather than in concert, in order to achieve genuine system checks.

3.8.3 Experts and Redundancy

The AERB takes for granted the assumption that the more experts on staff, the better, and it always strives to get the foremost experts in every field to serve on the committee. There is no doubt that in some sense this is ideal: it seems trivial to assume that there is an advantage to always having the best.

However, there is an innate disadvantage therein. In a relatively small nuclear community, like India's, the subject expert is likely to have been the one to design the system in the first place. It seems like a good idea to have the man who worked on the FBR prototype at IGCAR on the FBR committee, but if there is a problem in the design, he is the least likely to catch it.

Yet the AERB seems to have effectively dealt with that problem. For example, the Standing Committee for Control, Instrumentation and Computer Based Systems, comprises ten members: two from BARC's electronics division; two from BARC's software section; two from IGCAR; two from the NPCIL; one from CIRUS; and one from the Operating Plant Safety Division of the AERB. On any given project evaluation, some form of expert bias might arise. However, because of the distribution of experts, it is unlikely that a majority of the committee would share the same biases. Again, the system has a buil-in system of checks.

The AERB works under the assumption that redundancy is something to strive for. Part of their stated philosophy is that the extra levels and seemingly infinite committees "provide the necessary Independence, Redundancy, and Defence in depth characteristics." [44]

Chapter 4

US-India Nuclear Policy

4.1 Cooperation

In the early days of atomic energy, the United States's primary strategy in controlling the flow of nuclear technology and the proliferation of nuclear weapons was secrecy. Unwilling to share technology or expertise with even its closest allies, the US maintained a policy of staunch nuclear isolationism for over a decade.[45]

In 1953 a new philosophy changed this policy permanently: the belief that nuclear energy and plentiful electricity were the key to a peaceful coexistence. The "Atoms for Peace" policy, discussed in Section 3.1, was proposed in December of 1953 by President Dwight D. Eisenhower before the General Assembly of the United Nations. In addition to proposing the formation of an International Atomic Energy Agency, he outlined a policy that included a voluntary decrease in global nuclear-weapon stockpiles, with the fissionable material being collected by the IAEA. The material would then be used to "provide abundant electrical energy in the power-starved areas of the world. Thus the contributing powers would be dedicating some of their strength to serve the needs rather than the fears of mankind."[46] The changing policy was reflected in the Atomic Energy Act of 1954, which governs US nuclear exports.

President Eisenhower also expressed a particular desire promote peaceful uses of atomic energy in East-Asia, "a major battleground in the Cold War."[47] In a period before "rogue states" and international terrorism, this optimistic view of nuclear energy and its potential seemed entirely reasonable; the only nuclear power of concern was the Soviet Union. To combat this perceived threat and to encourage economic co-operation, the United States began a period of close alliance with India that continued for nearly twenty years.

The US went much farther than simply selling materials to India. It was actually responsible for the construction of the Tarapur boiling water reactors in 1963. Additionally, Indian engineers were sent to the United States for training at US nuclear laboratories.[45]

4.2 The Nuclear Non-Proliferation Treaty

In January 1968, after three years of wrangling over the language and debating the necessary terms, the United States and the Soviet Union released a joint draft of the Nuclear Non-proliferation Treaty (NPT) and submitted it to the Eighteen-Nation Conference on Disarmament (ENCD). Three months later, after further revisions, another draft was submitted to the 22 Session of the United Nations General Assembly.[48] On July 1, 1968, the NPT was signed by 62 countries. In addition to three acknowledged nuclear-weapon states, the USSR, the US, and the UK, 59 other countries without nuclear weapons signed the treaty, in the hope that acquiescence would assure their protection under the nuclear umbrella of the nuclear-weapon states.

4.2.1 Provisions of the Treaty

The NPT allowed the five states that were already in possession of nuclear weapons (the USSR, the US, the UK, France, and China – dubbed "nuclear-weapon states" (NWS)) to maintain their nuclear arsenal. The conditions on maintenance were that these five states would refrain from disseminating "nuclear weapons or other nuclear explosive devices." They also were banned from using nuclear weapons on a non-NWS, unless the non-NWS attacked using a nuclear weapon, or the non-NWS had launched a conventional attack and was allied with an NWS.[49]

The treaty included no provisions for disarmament, although it encouraged the nuclear-weapon states to make an effort towards disarmament.

For non-nuclear-weapon states, the treaty was more onerous. In addition to agreeing not to develop nuclear weapons, the non-NWS was required to allow IAEA safeguards on all civilian nuclear facilities. The safeguards, designed to detect the diversion of nuclear materials from energy facilities for military purposes, use surveillance and accounting methods to look for discrepancies.[49]

Despite the difficulties assumed in signing the treaty, there were a number of incentives for non-nuclear-weapon states to do so: they had a written guarantee that they would not be on the receiving end of a nuclear assault unless they were the aggressor state; they were supplied with plentiful fissile material for peaceful uses; and they were allying themselves with the world's most powerful nations. Most importantly, they risked a falling-out with their international allies if they refused to sign.

4.3 The Falling-Out

The NPT was the first crack in the previously-amicable US-India relationship. Over the course of the NPT negotiations, India had insisted that as written the NPT was discriminatory, imposing an undeserved double-standard. The nuclear-weapon states had no better qualifications for being entrusted with nuclear weapons aside from having made them first. India was also perturbed by the absence of enforceable demands for disarmament written into the treaty. India's third complaint was that the safeguards, which required allowing inspectors into its facilities with relative frequency, jeopardized their national sovereignty and put the country at the mercy of inspectors.[49]

India's refusal to sign the treaty put considerable strain on the US's cooperative alliance with India. But what really brought it to an end was India's 1974 detonation of the Pokhran test, described in Section 3.1.3. Despite the Indian government's claim that the test was entirely peaceful, the test illustrated the main problem with the Atoms for Peace program: that technology intended for peaceful purposes could ultimately be employed otherwise. The fissile material used in the device had been produced using American expertise and technology.[17]

The United States's reaction was dramatic. Although it took four years to turn sentiment in to law, the 1978 Nuclear Non-Proliferation Act was a direct response to the Pokhran test.

4.3.1 The Nuclear Non-Proliferation Act of 1978

The Nuclear Non-Proliferation Act (NNPA), which amended the Atomic Energy Act of 1954, includes a Statement of Policy asserting that "the proliferation of nuclear explosive devices or of the direct capability to manufacture or otherwise acquire such devices poses a grave threat to the security interests of the United States and to continue international progress toward world peace and development."[50]

It then adds, in a statement that might as well have had India's name on it, that "recent events emphasize the urgency of this threat and the imperative need to increase effectiveness of international safeguards and controls on peaceful nuclear activities to prevent proliferation."[50]

The Act, despite reaffirming the US commitment to provide an "adequate nuclear fuel supply" to countries that planned to use the fuel for peaceful purposes, effectively ended the United States's cooperative relationship with India. It required any country receiving the material to allow full-scope safeguards and denied nuclear exports to any country that attempted to build, acquire, or detonate a nuclear explosive device.[50]

Although the Act was signed in 1978, its full effect was not felt until 1980. President Jimmy Carter allowed two more shipments of nuclear fuel to be sent to India. Although the Nuclear Regulatory Commission would not authorize an export license, on the grounds that it violated the NPT and the NNPA, Carter circumvented the regulations by exporting them by executive order.[51]

However, by 1980, India felt the full consequences of its Pokhran test. The United States did not export any more nuclear material after 1980.

4.3.2 The Nuclear Suppliers Group

In addition to changing domestic policy to address its concerns with India's nuclear weapons program, the United States began to change international policy as well. In 1975, the year after the Pokhran test, the United States formed the Nuclear Suppliers Group (NSG), a coalition of nuclear exporters intent on slowing the proliferation of nuclear weapons, in direct response to India's test.

First meeting in 1975 in London (earning it the nickname "The London Club"), the NSG initially comprised the seven biggest suppliers of dual-use nuclear material: Canada, West Germany, France, Japan, the USSR, the UK, and the US. Their stated aim was to "ensure that nuclear trade for peaceful purposes does not contribute to the proliferation of nuclear weapons or other nuclear explosive devices which would not hinder international trade and cooperation in the nuclear field."[52]

The Pokhran test had demonstrated that there is a surfeit of nuclear materials that can seem benign when exported but can be diverted or transformed for military purposes. Additionally, there are materials that can aid in the construction of nuclear facilities, but have dual-uses, such as lasers, software, or "Zirconium with a hafnium content of less than 1 part hafnium to 500 parts zirconium by weight, as follows: metal, alloys containing more than 50% zirconium by weight, compounds, manufactures thereof, waste or scrap of any of the foregoing."[53]

The policies of the NSG are simple: the participating countries, along with the IAEA, compile a "trigger list" of parts and materials that can only be exported to a non-nuclear-weapon state if IAEA safeguards are implemented on the recipient facility.[52]

4.3.3 The International Reaction

By and large, the international community followed the US lead in their treatment of India. Although both France and Russia sold uranium to India in the days after the NNPA, neither has exported nuclear technology to India in the past decade. The two WWER under construction in India today were originally purchased from Russia, but since the weapons tests in 1998, India has had no success in acquiring more reactors from Russia.

4.4 Today

In February of 2006, President George W. Bush visited India and Prime Minister Dr. Manmohan Singh. While there, he was able to hammer out an agreement for a new cooperative nuclear relationship between the two countries. After 26 years of technological isolation, the United States and India reached a historic agreement that will re-open the avenues of trade and exchange of expertise.

In what is a major compromise on the part of the Government of India, the administration agreed to comply with NSG policies, and open its non-military facilities for IAEA inspections. It will also have to cease all nuclear weapons testing for the duration of the agreement, and must work towards negotiating a Fissile Material Cutoff Treaty.

In return, the United States will once again export nuclear materials to India. Although the remaining details of the plan have yet to be negotiated, private enterprises are already clamoring for the chance to invest in India's nuclear power program. However, the proposition has not yet passed the US Congress. In order for it to occur, Congress needs to amend the NNPA, which bans the sale of nuclear material to countries that have not signed the NPT.

Although this change will relieve India's recent nuclear fuel shortages, it will also undermine the energy autonomy that has been the single-minded focus of its nuclear program since its inception. Some Indian researchers have expressed distaste with the deal, saying that it undercuts India's third stage, by giving them access to centrifuge technology and natural uranium.

Another concern is the need to separate India's military and civilian nuclear facilities; because of the public nature of India's power production industry, the militiary facilities are virtually inseperable from the civilian research facilities.

Padmanabha Krishnagopala Iyengar, former chairman of the Atomic Energy Commission and one of India's top researchers, noted that "Nobody works full time in our weapons programme. The moment we compartmentalize, our research and development will be crippled and creativity will end."[54] However, many of the younger researchers see the isolation as something that was forced upon them, rather than an attribute to take pride in, and look forward to the end of export sanctions.

This deal recognizes India's excellent record of non-proliferation, despite its refusal to sign the NPT, and it could be an opportunity for unprecedented levels of cooperation between the United States and India. This agreement sends a message to the rest of the world that the US perceives India as a responsible partner in nuclear technology. Even if Congress does not amend the NNPA, India could see a lot of doors opening up in the near future.

Appendix A

India's Fleet of Nuclear Reactors

Station Name	Capacity	Type	Reactor Supplier	Percent Complete	Date of Operation
Apsara	1	PWR	UK	100	1956
Cirus	40	PHWR	Canada	100	1960
Dhruva	100	PHWR	BARC	100	1969
FBTR	100	FBR	DAE	100	1997
Kamini	100	FBR	DAE	100	1989

Table A.1: Research Reactors in Operation

Station Name	Capacity	Type	Reactor Supplier	Percent Complete	Date of Operation
Kaiga 1	220	PHWR	NPCIL	100	2000
Kaiga 2	220	PHWR	NPCIL	100	2000
Kakrapar 1	220	PHWR	NPCIL	100	1993
Kakrapar 2	220	PHWR	NPCIL	100	1995
Kalpakkam 1	170	PHWR	NPCIL	100	1984
Kalpakkam 2	220	PHWR	NPCIL	100	1986
Rajasthan 1	100	PHWR	AECL	100	1973
Rajasthan 2	200	PHWR	AECL	100	1981
Rajasthan 3	220	PHWR	NPCIL	100	2000
Rajasthan 4	220	PHWR	NPCIL	100	2000
Narora 1	220	PHWR	NPCIL	100	1991
Narora 2	220	PHWR	NPCIL	100	1992
Tarapur 1	160	BWR	GE	100	1969
Tarapur 2	160	BWR	GE	100	1969
Tarapur 4	540	PHWR	NPCIL	100	2005

Table A.2: Commercial Reactors in Operation

Station Name	Capacity	Type	Reactor Supplier	Percent Complete	Date of Operation
Kaiga 3	220	PHWR	NPCIL	84	2007
Kaiga 4	220	PHWR	NPCIL	66	2007
Rajasthan 5	220	PWHR	NPCIL	77	2007
Rajasthan 6	220	PWHR	NPCIL	58	2008
Kudankulam 1	1000	WWER	Russia	65	2007
Kadunkulam 2	1000	WWER	Russia	60	2008
Tarapur 3	540	PHWR	NPCIL	70	2007
Prototype FBR	500	FBR	BHAVINI	17	2010

Table A.3: Commercial Reactors under Construction

Appendix B

Advisory Committees of the Atomic Energy Regulatory Board

1. ACCGASSO Advisory Committee for Codes, Guides & Associated Manuals for Safety in Operation of NPPs
2. ACCGD Advisory Committee on Code, Guides & Associated Manuals for Safety in Design of NPPs
3. ACCGORN Advisory Committee for preparation of Code & Guides on Governmental Organization for the Regulation of Nuclear & Radiation facilities
4. ACCGQA Advisory Committee for Codes & Guides for Quality Assurance for Nuclear Power Plants Safety
5. ACIFS Advisory Committee on Industrail and Fire Safety
6. ACNS Advisory Committee on Nuclear Safety
7. ACOH Advisory Committee on Occupational Health
8. ACPSR-FCF Advisory Committee for Project Safety Review of Fuel Cycle Facilities
9. ACPSR-LWR Advisory Committee for Project Safety Review of Light Water Reactor Projects

10. ACPSR-PHWR/PFBR Advisory Committee for Project Safety Review of PHWRs/PFBR
11. ACRDCSE Advisory Committee for Regulatory Documents on Civil and Structural Engineering
12. ACRDS Advisory Committee for Regulatory Documents on Nuclear Power Plant Siting
13. ACRS Advisory Committee on Radiological Safety
14. AC-SD-FCF Advisory Committee on Safety Documents relating to Fuel Cycle Facilities other than Nuclear Reactors
15. AERB-Canteen AERB Canteen Committee
16. AERB-Infrastructure AERB Infrastructure Committee
17. AERB-Library AERB Library Committee
18. AERB-Space AERB Space Committee
19. CESC Civil Engineering Safety Committee (for nuclear power projects)
20. CESCOP Civil Engineering Safety Committee for Operating Plants
21. CESCOP-ITF Task Force to assist CESCOP in Inspection Activities
22. CPSA-Nuc Committee on Probabilistic Safety Assessment (PSA) for Nuclear Facilities
23. CRAASDRW Committee to Review Application for Authorisation of Safe Disposal of Radioactive Waste
24. CRMM-BSM Committee to Examine the Radiological Issues Involved in Mining and Milling of Beach Sands Minerals
25. CSECURITY Committee on Security

26. CSGA Committee to prepare a Safety Guide on Accelerators

27. CSRP Committee on Safety Research Programmes

28. ECSQ Expert Committee for Seismic Qualification of Existing DAE's Installations

29. EXECC AERB Executive Committee

30. FAAC Fatal Accident Assessment Committee

31. GRC Glossary Review Committee

32. LC-FBTR&Kamini Licensing Committee for FBTR and Kamini

33. LC-HWP Licensing Committee for HWPs

34. LC-NPS Licensing Committee for the Nuclear Power Stations

35. OIC-NONDAE Over Exposure Investigation Committee to Review Overexposure in Non-DAE Installation

36. PDSC-IFSB-PFBR New Project Design Safety Committee for Interim Fuel Storage Building for Prototype Fast Breeder Reactor

37. PDSC-KAIGA-3&4/RAPP-5&6 Project Design Safety Committee for Kaiga Atomic Power Project-3&4 and RAPP-5&6

38. PDSC-PFBR Project Design Safety Committee for Prototype Fast Breeder Reactor

39. PDSC-TAPP3&4 Project Design Safety Committee for TAPP-3&4

40. PPRC-SRI Project Progress Review Committee for Safety Research Institute

41. Purchase AERB Purchase Committee

42. QMP-NPPs Committee for Qualifying Management Personnel at NPPs

43. RDRC Radioactive Waste Disposal Review Committee

44. SACNUM Safety Committee for Nuclear Medicine Facilities

45. SARCAR Safety Review Committee for Applications of Radiation

46. SARCOP Safety Review Committee for Operating Plants

47. SC-C&I-CBS Standing Committee for Control & Instrumentation

48. SC-ECIL Safety Committee for ECIL

49. SC-HWP Heavy Water Plants - Safety Committee

50. SC-IGCAR Safety Committee for IGCAR

51. SC-IRE Safety Committee for Indian Rare Earths Ltd.

52. SC-KAIGA/RAPS3&4 Safety Committee for Kaiga - RAPS 3&4

53. SC-MIRA Safety Committee for Medical, Industrial and Research Accelerators

54. SC-NAPS/KAPS Safety Committee for Narora and Kakrapar Atomic Power Stations

55. SC-NFC Safety Committee for Nuclear Fuel Complex

56. SCOGRAPP Safety Committee on Gamma Irradiation Processing Plants

57. SC-RAPS/MAPS Safety Committee for Rajasthan and Madras Atomic Power Stations

58. SC-RPLLCL Safety Committee for Radiopharmaceutical Laboratory and Labelled Compound Facilities of BRIT

59. SC-RSD Standing Committee for Review and revision of AERB's Radiation Safety Documents

60. SC-TAPS Safety Committee for Tarapur Atomic Power Station

61. SC-UCIL Safety Committee for Uranium Corporation of India Ltd.

62. SCURF Standing Committee for Investigation of Unusual Occurrences in Radiation Facilities

63. SELECTIONC Committee for selection of candidates for admission to M.Tech.

64. SER-FRFCF Site Evaluation Committee for Fast Reactor Fuel Cycle Facility

65. SRI Council Safety Research Institute Council

66. SRI SC Safety Research Institute Scientific Committee

67. TGRDFI Task Group for Review of Dosimetry for Food Irradiation

68. VRSC VECC-RRCAT Unit Safety Committee

Bibliography

[1] The future of nuclear power. Technical report, MIT Interdisciplinary Study, 2003.

[2] Dr. Manmohan Singh. Prime Minister's address to the joint session of Congress. July 2005.

[3] Dr. R. Chidambaram. Towards an energy independent India. *NU Power: An International Journal of Nuclear Power*, 11(3), 1997.

[4] Strategy for growth of electrical energy in India. *Government of India, Department of Atomic Energy*, 2001.

[5] Key world energy statistics. *International Energy Agency*, 2003.

[6] Ananth Chikkatur. Making the best of India's coal resources. *Economic and Political Weekly*, December 2005.

[7] India energy outlook. Technical report, KPMG, 2005.

[8] John P. Holdren. Thoughts on science, technology, and human well-being in the next fifty years. Presented at the Plenary Session, American Association for the Advancement of Science, February 1998.

[9] India: Environmental issues. Technical report, Energy Information Administration, February 2004.

[10] India unlikely to agree to emission caps post-Kyoto. *Hindustan Times*, November 2005.

[11] Peter R. Lavoy. The enduring effects of Atoms for Peace. *Arms Control Today*, December 2003.

[12] Paul Olkhovsky. India and the U.S. *The Heritage Foundation*, July 1982.

[13] Atomic Energy Act of 1962, no 33. September 15, 1962.

[14] Nuclear Power Corporation of India Limited. What is India's 3 - stage nuclear power programme? 2004.

[15] Tarapur Atomic Power Station Units 1&2 re-connected to the grid. *NPCIL Press Release*, February 2006.

[16] David Albright and Susan Basu. Separating indian military and civilian nuclear facilities. *Institute for Science and International Security (ISIS)*, December 2005.

[17] Paul Leventhal. Cirus reactor's role in a US-India nuclear agreement. Nuclear Control Institute, Presentation to Center for Nonproliferation Studies, Washington, DC, December 2005.

[18] Treaty between the United States of America and the Union of Soviet Socialist Republics on Underground Nuclear Explosions for Peaceful Purposes, signed at Washington and Moscow May 28, 1976, entered into force december 11, 1990.

[19] Top Indian scientist rejects 'peaceful' nuclear test claim. *Agence France Presse*, October 1997.

[20] Atomic energy in India: A perspective. Technical report, Government of India, Department of Atomic Energy, September 2003.

[21] Aec chief tenure extended two years. *Business Line (The Hindu)*, November 1998.

[22] Amit Baruah. We will tread carefully: PM. *The Hindu*, May 2003.

[23] India special weapons facilities. Technical report, GlobalSecurity.org.

[24] No first strike, India assures Pakistan. *Indo-Asian News Service*, April 2006.

[25] Dr. A. P. J. Abdul Kalam and Dr. Anil Kakodkar. Press conference, Department of Atomic Energy. May 1998.

[26] S.K Jain. Annual report 2004-2005: CMD's statement. Technical report, Nuclear Power Corporation of India.

[27] Plants Under Operation, NPCIL, http://www.npcil.nic.in/plantsoperation.asp.

[28] Projects Under Construction, NPCIL, http://www.npcil.nic.in/projectsconstruction.asp.

[29] Eric Arnett. India's nuclear brownout. *Bulletin of the Atomic Scientists*, 52(6), November 1996.

[30] Minister of Power Mr. Sushil Kumar Shinde. Speech at luncheon meeting organised by US India Business Council (USIBC), Embassy of India press release. April 2006.

[31] India's economic roadmap: The next five years. Technical report, Planning Commission, Government of India, 2002.

[32] Dr. Scott Parrish. Russian reaction to the Indian nuclear tests. *Center for Nonproliferation Studies*, May 1998.

[33] SK Jain. Press release, BHAVINI: CMD's statement. 2003.

[34] Vinson Kurian. New co. to handle fast breeder reactor programme. *Asia Africa Intelligence Wire*, March 2004.

[35] Dr.Y.S.R. Prasad. Utility industry interaction in the Indian nuclear power programme. *Nu-Power*, 11(3), 1997.

[36] R K Bhatnagar. BARC training school: Where India's nuclear specialists are made. Technical report, Department of Atomic Energy, Government of India.

[37] Atomic energy in India: A perspective. Technical report, Government of India, Department of Atomic Energy, September 2003.

[38] Central Electricity Authority, http://cea.nic.in/.

[39] C.P. Jain. Chairman's statement. September 2005.

[40] Know About AERB, Atomic Energy Regulatory Board, http://www.aerb.gov.in/.

[41] Civil Engineering Safety Committee, Atomic Energy Regulatory Board, http://www.aerb.gov.in/.

[42] Advisory committee for project safety review of PHWR based NPPs and PFBR, Atomic Energy Regulatory Board, http://www.aerb.gov.in/.

[43] The Board, Atomic Energy Regulatory Board, http://www.aerb.gov.in/.

[44] Committees of the AERB, Atomic Energy Regulatory Board, http://www.aerb.gov.in/.

[45] Virginia I. Foran. Strategic non-proliferation: Balancing interests and ideals. *The National Security Archive*, January 1992.

[46] Dwight D. Eisenhower. Address to the 470th plenary meeting of the United Nations General Assembly. December 1953.

[47] U.S. policy toward South Asia. Technical report, National Security Council, February 1954.

[48] Jane A. Morse. The NPT: History's most successful non-proliferation treaty: Informative look at the success of the Nuclear Non-Proliferation treaty (NPT) and the accord's likely benefits in the future. *USIA*, November 1994.

[49] Treaty on the Non-Proliferation of Nuclear Weapons, entered into force march 5, 1970.

[50] Nuclear Non-Proliferation Act of 1978, Public Law 95-242, 92 stat. 120, March 1978.

[51] Executive Order 12055, President Jimmy Carter, Export of special nuclear material to India, April 27th, 1978.

[52] Nuclear Suppliers Group, http://www.nuclearsuppliersgroup.org.

[53] Communications received from certain member states regarding guidelines for the export of nuclear material, equipment, and technology, INFCIRC/254/rev.7/part1. Technical report, IAEA Information Circular, February 2005.

[54] Declan Butler and K. S. Jayaraman. Nuclear deal riles India's researchers. *Nature*, July 2005.