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Fissile Materials in South Asia and the Implications of the U.S.-India Nuclear Deal

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The July 2005 U.S.–India joint statement represents a fundamental transformation of U.S.–India relations and at the same time a challenge to the disarmament and nonproliferation regimes. There is concern that the March 2006 separation plan proposed by India for demarcating its military and civilian nuclear facilities may allow a potentially rapid expansion of its capacity for fissile material production for weapons. In this analysis, we have assessed fissile material production capabilities in India and how they might change as a result of the U.S.–India deal. We look at current stockpiles of fissile materials in India and Pakistan and estimate the changing capacity for future fissile material production as India progressively places some of its heavy water reactors under safeguards. We assess India's uranium resource constraints and the additional weapons grade plutonium production in its unsafeguarded heavy water power reactors that would be made possible by imports of uranium allowed by the deal. We also estimate the weapons plutonium production from India's fast breeder reactor that is under construction and is to be unsafeguarded.

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INTRODUCTION

On July 18, 2005, U.S. President George Bush and Indian Prime Minister Manmohan Singh issued a joint statement in Washington, D.C. laying the grounds for the resumption of U.S. and international nuclear trade with India.[1] This trade has been restricted for about three decades because India is neither a signatory to the Nuclear Non-Proliferation Treaty (NPT) nor allows International Atomic Energy Agency (IAEA) safeguards on all its nuclear facilities. The July agreement has generated political debate in the United States and India, and concern on the part of a number of other countries.[2] Among the issues is the fear that the agreement serves to normalize India's status as a nuclear weapons state and so weakens the NPT and the larger nonproliferation regime. An important concern is that it may serve to expand India's potential nuclear weapons production capabilities and thus hinder international efforts to end the production of fissile materials for nuclear weapons.

As part of the July 2005 deal, the United States offered both to amend its own laws and policies on nuclear technology transfer and to seek the necessary changes in the international controls on the supply of nuclear fuel and technology managed by the Nuclear Suppliers Group (NSG) of states so as to allow nuclear trade with India. In exchange for the lifting of these restrictions, India's government offered to identify and separate civilian nuclear facilities and programs from its nuclear weapons complex, and volunteer these civilian facilities for IAEA safeguarding and abide by the IAEA Additional Protocol with respect to these facilities. However, the final shape and status of the deal is still unclear because it will require the United States Congress to amend existing laws and a consensus among the NSG countries, both of which may attach conditions that India may not accept.[3]

At the March 2006 summit in New Delhi between President Bush and Prime Minister Singh, it was announced that the U.S. government was satisfied with the proposed Indian plan to separate its program into a civilian and a military component.[4] The separation plan offers to subject to IAEA safeguards eight Indian power reactors that are either operating or under construction in addition to the six reactors that are already subject to safeguards because they were purchased from abroad (see Appendix 1 for a list of India's operating and under construction reactors). These "civilian" facilities will be put under safeguards in a phased manner by 2014 and remain open to inspections in perpetuity. India's remaining eight power reactors, all its research reactors, and the plutonium-fueled fast breeder reactor program are to be part of the military program. India also offered to shut down by 2010 a reactor supplied by Canada for peaceful purposes but whose plutonium was used in the 1974 nuclear weapon test. India also claimed the right to classify as either civilian or military any future reactors it might build.

The nuclear agreement has elicited great concern from Pakistan, which has demanded from the United States (and been refused) the same deal as is being offered to India.[5] China has called for any exemptions for international nuclear cooperation and trade agreed to by the NSG to be open to Pakistan as well.[6] The United States and some other NSG members are opposed to this.[7]

Pakistan's Prime Minister, Shaukat Aziz, observed that "nuclear nonproliferation and strategic stability in South Asia will be possible when the US fulfills the needs of both Pakistan and India for civil nuclear technology on an equal basis," and warned that "a selective and discriminatory approach will have serious implications for the security environment in South Asia."[8] Pakistan's National Command Authority (NCA), which is chaired by President Pervez Musharraf and has responsibility for its nuclear weapons policy and production, declared that "In view of the fact [that] the [U.S.–India] agreement would enable India to produce a significant quantity of fissile material and nuclear weapons from unsafeguarded nuclear reactors, the NCA expressed firm resolve that our credible minimum deterrence requirements will be met."[9] However, at the same time, Pakistan's ambassador to the United States, and former Army chief, General Jahangir Karamat has offered that "if bilaterally, the U.S. can facilitate a moratorium on fissile material production or on testing: we are very happy to be part of that."[10]

We discuss here the technical issues related to fissile materials that are involved in these concerns about the agreement.[11] First we review the estimated fissile material production and stockpiles in South Asia. We then assess the significance for India's future weapons-useable fissile material production capabilities of the line India has drawn between its civilian and military facilities.

SOUTH ASIAN NUCLEAR PROGRAMS

India and Pakistan have long-standing nuclear weapons programs that are linked to their civilian nuclear infrastructure. International support was crucial in the development of these complexes in both states. Most of this support followed the 1953 launch of the U.S. Atoms for Peace program, which sought to encourage third world countries to become U.S. allies by offering nuclear technology, and had unfortunate consequences for proliferation in South Asia and elsewhere.[12]

India

Established in 1948, India's Atomic Energy Commission turned to the United Kingdom for the design and enriched uranium fuel for its first nuclear reactor, Apsara. Similarly, the CIRUS reactor was supplied by Canada whereas the heavy water used in it came from the United States. India's first power reactors at Tarapur and Rawatbhata were supplied by the U.S. and Canada, respectively. A U.S. design was used for its first reprocessing plant in Trombay. Some of these technologies and materials contributed to the production and separation of the plutonium used in India's 1974 nuclear weapons test. Due to this test and its subsequent refusal to give up its nuclear weapons and sign the NPT, India has been kept largely outside the system of trade of nuclear technology that has developed over the past three decades.

India has over the years built a nuclear power program, with 15 reactors (Appendix 1) providing an installed capacity of 3310 megawatts electric (MWe), which accounts for about 3 percent of India's installed electricity generation capacity. Thirteen of the reactors are Pressurized Heavy Water Reactors (PHWRs), the first two of which were supplied by Canada. The other PHWR reactors are largely based on the Canadian design. The latest evolution of the design has increased the capacity from 220 to 540 MWe. The other two power reactors are Boiling Water Reactors supplied by the United States.

Only the four foreign supplied reactors are currently under IAEA safeguards. Two 1000 MWe reactors being built by Russia, under a 1988 deal, will also be safeguarded. These two large reactors will increase India's nuclear capacity by over 50 percent in the next few years.

For decades, India's Department of Atomic Energy (DAE) has pursued an ambitious fast-breeder reactor development program. This involves separating plutonium from the spent fuel produced in natural uranium reactors and using it to fuel fast-neutron breeder reactors, which in turn could be used to produce U-233 that would eventually serve to fuel breeder reactors operating on a Th-U-233 closed fuel cycle.[13] These efforts have made halting progress: the first breeder reactor to be built, the Fast Breeder Test Reactor, was due to become operational in 1976 but started only in 1985 and has been plagued with problems.[14] The 500-MWe Prototype Fast Breeder Reactor is not expected to be completed until 2010, if all goes according to plan. India has also begun work on a prototype plutonium-thorium-uranium-233 fueled Advanced Heavy Water Reactor (AHWR) to gain experience with the thorium and uranium-233 fuel cycle.[15]

India conducted its first nuclear weapon test in May 1974. There were another five tests in 1998, involving fission weapons and a thermonuclear weapon. There are reports that at least one test used plutonium that was less than weapons grade.[16] India is believed to have a stockpile of perhaps 40–50 nuclear weapons, and one report cites plans for 300–400 weapons within a decade.[17]

Pakistan

Pakistan obtained its first research reactor from the United States as part of the Atoms for Peace Program. The first power reactor, a 137 MWe PHWR built by Canada, began operating in 1972. Since 2001, a 325 MWe Pressurized

(Light) Water Reactor (PWR), designed and built by China, has been operating at Chashma. A second reactor of the same type is under construction at the same site. All of these reactors are under IAEA safeguards (Appendix 1).

After India's 1974 nuclear test, Pakistan sought technology both to separate plutonium and to enrich uranium for its nuclear weapons program. A 1974 deal with France for a reprocessing plant was canceled in 1978 amid growing concerns about a possible Pakistani nuclear weapons program.[18] But A.Q. Khan, a Pakistani metallurgist working for a subsidiary of the European enrichment company, URENCO, was able to acquire centrifuge technology and Pakistan succeeded in enriching uranium at its Kahuta centrifuge uranium enrichment facility in 1982.[19] In 1998, Pakistan also began operating a plutonium-production reactor at Khushab.[20]

In 1998, Pakistan followed India in testing nuclear weapons. A 2001 estimate suggested Pakistan may then have had an arsenal of 24–48 nuclear weapons.[21]

CURRENT STOCKS OF FISSILE MATERIALS IN INDIA AND PAKISTAN

India and Pakistan are producing fissile materials for their nuclear-weapon programs. Along with Israel and perhaps North Korea, they may the only states currently doing so. The five NPT nuclear weapons states, U.S., Russia, U.K., France, and (informally) China, have all announced an end to fissile material production for weapons.

Weapons Grade Plutonium

India's weapons grade plutonium comes from the 40 megawatt thermal (MWt) CIRUS and 100 MWt Dhruva reactors. CIRUS became critical in 1960 and fully operational in 1963. An extended refurbishment of CIRUS started in October 1997, and it resumed operation in October 2003.[22] Dhruva was commissioned in 1985 but began normal operation in 1988.[23]

Public details of the operating histories for CIRUS and Dhruva are sparse. One figure that has been published is the availability factor, which is the fraction of time that the reactor is operable. CIRUS is reported to have an "availability factor of over 70%."[24] In 2000, Dhruva was claimed to have "achieved an availability factor of over 68% during the year which is the highest so far."[25] Assuming that the reactors operate at full power when they are available allows an upperbound estimate of plutonium production. At full power and an availability factor of 70 percent, each year CIRUS would produce about 10.2 tons of spent fuel, containing about 9.2 kg of weapons grade plutonium, and Dhruva would produce about 25.6 tons of spent fuel containing 23 kg of weapons grade plutonium.[26]

Pakistan has a smaller plutonium production potential from its 50 MWt Khushab reactor.[27] It is a natural uranium fueled, heavy water reactor and

Table 1: Estimated cumulative weapons grade plutonium production (kg) up to 2006.

	India		Pakistan
Reactor	CIRUS	Dhruva	Khushab
Cumulative Plutonium production (kg)	234	414	92

appears to be similar to India's CIRUS reactor. There is little information available about the history and operating experience of Khushab, other than that construction started in 1985 and the reactor started operating in early 1998.[28] Assuming that the Khushab reactor has been operated in a fashion similar to India's CIRUS reactor, it could produce almost 12 kg of plutonium per year.[29]

The estimated cumulative weapons-grade plutonium production for India and Pakistan is given in Table 1.[30] It does not include the possibility of a few tens of kilograms of plutonium from the lower burn-up initial discharges of India's unsafeguarded PHWRs having been added to this stockpile.[31] For both India and Pakistan, it is hard to know how much of the plutonium that has been recovered from spent fuel has been incorporated into weapons.

Spent fuel from CIRUS and Dhruva is reprocessed at the Trombay reprocessing plant. It started functioning in 1964 with a capacity of 30 tons/year, but was shut down after the first Indian nuclear test in 1974 for renovation and a capacity increase. When it restarted operation in 1985, its capacity had increased to 50 tons/year.[32] India also has two much larger reprocessing plants at Tarapur and Kalpakkam to recover plutonium from spent power reactor fuel (Table 2).[33] India plans to increase its annual reprocessing capacity to 550 tons by 2010 and to 850 tons by 2014 to meet the needs of its fast breeder reactor program and AHWR.[34]

The spent fuel from Pakistan's Khushab reactor is believed to be reprocessed at the New Labs facility near Islamabad, which has a capacity of 10–20 tons/year of heavy metal.[35] In March 2000, it was reported that "recent air samples," which had been "taken secretly" showed that "Pakistanis have begun reprocessing."[36] This report seems to be consistent with estimates of the detectability of krypton-85 released by reprocessing at the New Labs facility.[37]

Table 2: Reprocessing plant capacities in India and Pakistan (tons of heavy metal in spent fuel per year).

	India	Pakistan
Trombay	50	
PREFRE (Tarapur)	100	
KARP (Kalpakkam)	100	
New Labs (Rawalpindi)		10–20

Some of India's weapons-grade plutonium has been consumed over the years in nuclear weapons tests, as reactor fuel and in processing losses. We estimate about 6 kg for India's 1974 nuclear weapons test.[38] We assume that another 25 kg may have been used in the five presumably more advanced weapons tests in 1998. As for reactor fuel, we assume India used 20 kg for the core of the Purnima I research reactor, and 60 kg for the first (Mark I) core of the Fast Breeder Test Reactor.[39] We estimate about 20 kg to have been lost in processing. Taken together, this suggests a total of 131 kg of weapons grade plutonium was consumed. This would leave India with a current stockpile of about 500 kg of weapons grade plutonium, sufficient for about 100 nuclear weapons.[40]

Civil Plutonium

Power reactors produce plutonium in their fuel as a normal byproduct of energy generation. In India, the chosen way of dealing with the spent fuel is through reprocessing, the result is a large additional stockpile of separated plutonium. This plutonium could be used to make nuclear weapons.[41]

As of May 2006, India's unsafeguarded reactors had produced about 149 terrawatt hours (TWh) of electricity. Their spent fuel would contain about 11.5 tons of plutonium.[42] They are producing about 1.45 tons of plutonium per year. This spent fuel has to be cooled for some years before reprocessing, but this does not greatly change the total plutonium content.[43] Assuming fuel is cooled on average for 3 years, only spent fuel generated before 2003 would have been reprocessed by 2006, in which case, no more than about 9 tons of plutonium could have been separated (Table 3). It is not clear how much has actually been extracted.[44] PREFRE, the only reprocessing plant dedicated to dealing with power reactor spent fuel before 1998, has apparently operated at very low capacity factors.[45]

India's safeguarded power reactors have produced 108 TWh of electricity, and 1,266 tons of spent fuel, containing about 6.8 tons of plutonium.[46] Little of this spent fuel has been reprocessed; it is stored in spent fuel pools and then moved to dry cask storage.[47]

Pakistan has no unsafeguarded civil plutonium stocks. Both its power reactors, Kanupp (137 MWe PHWR) and Chashma (325 MWe PWR), are under safeguards. As of May 2006, they had generated cumulatively about 22 TWh of

Table 3: Estimated cumulative civilian reactor grade plutonium production (May 2006).

	Plutonium content in spent fuel (kg)	
	Unsafeguarded	**Safeguarded**
India	11,500	6,800
Pakistan	—	1,200

electricity and discharged spent fuel containing roughly 1.2 tons of unseparated plutonium.[48]

Enriched Uranium

India has two gas-centrifuge uranium enrichment facilities. The Bhabha Atomic Research Center complex has had a pilot scale plant operating since 1985 and there is a larger production scale plant at Rattehalli, near Mysore, Karnataka that has been working since 1990.

Rattehalli is believed to enrich uranium to fuel the land-prototype reactor for India's nuclear-powered submarine project, the Advanced Technology Vessel (ATV). Assuming that the ATV prototype core contains 90 kg U-235, and was available when the core was tested in 2000–2001, a 2004 estimate suggested the enrichment capacity of the Rattehalli plant was about 4,000 SWU/y.[49] This corresponds to the facility producing about 40–70 kg/year of 45 percent to 30 percent enriched uranium respectively. This enrichment capacity could yield 20 kg/year of weapons grade uranium (93 percent U-235).

For Pakistan, it has been suggested that the enrichment capacity at Kahuta may have increased over the past two decades.[50] In this case, it could have produced a stockpile of 1,100 kg of highly enriched uranium by the end of 2003.[51] If production continued at 100 kg/year, Kahuta would have produced about 1,400 kg of weapons grade uranium by the end of 2006 (Table 4).[52]

These estimates do not take into account the possibility that Pakistan may have other enrichment facilities. In 1999, the U.S. Department of Commerce listed centrifuge facilities at Golra, Sihala, and Gadwal as subject to export restrictions.[53] There is no public indication of their capacity.

Pakistan claims to have tested six nuclear weapons in 1998. Assuming that each weapon used 20 kg in its core, the tests would have consumed 120 kg of HEU. This would give Pakistan a weapons HEU stockpile now of about 1,300 kg, sufficient for about 65 weapons.[54] It is not known how much of this fissile material is actually in the form of weapon cores.

DRAWING THE LINE

A central feature of the U.S.–India agreement is the separation of India's nuclear facilities into civilian and military, with the former category being made

Table 4: Estimated cumulative enriched uranium production (kg) in South Asia.

	Assumed SWU Capacity (2005)	Highly Enriched Uranium (kg)
India	4,100	460–700 (45–30% enrichment)
Pakistan	20,000	1400 (90% enrichment)

available for IAEA monitoring. At the time of writing, the U.S. administration had accepted a separation plan presented by Prime Minister Manmohan Singh to the Indian Parliament on March 7, 2006.[55]

According to this proposal, civilian facilities "after separation, will no longer be engaged in activities of strategic significance" and "a facility will be excluded from the civilian list if it is located in a larger hub of strategic significance, notwithstanding the fact that it may not be normally engaged in activities of strategic significance." Further, the separation would be conditioned "on the basis of reciprocal actions by the U.S."

From the 22 power reactors in operation or currently under construction, India has offered to place 8 additional reactors under safeguards between 2006 and 2014, each with a capacity of 220 MWe. These are:

- Two Rajasthan reactors still under construction, RAPS 5 and 6, which would be made available for IAEA monitoring when they commence operation in 2007 and 2008, respectively;
- RAPS 3 and 4, which are already operating but would only be available for safeguards in 2010;
- The two Kakrapar reactors, which would be made available for safeguards in 2012; and
- The two reactors at Narora which would become available for safeguards in 2014.[56]

Currently, India has four reactors under IAEA safeguards, the U.S.-built Tarapur 1 and 2, and the Canadian-built Rajasthan 1 and 2. The two Koodankulam reactors that are under construction by Russia also will be subject to safeguards under the associated India–Russian contract.

Some of the facilities at the Nuclear Fuel Complex, Hyderabad, have been identified as civilian and are to be offered for safeguards by 2008.[57] Other facilities to be declared civilian include three heavy water plants (leaving at least two out of safeguards), and the two Away-from-Reactor spent fuel storage facilities that contain spent fuel from the safeguarded Tarapur and Rajasthan reactors.

India would permanently shut down the Canadian-built CIRUS reactor in 2010 that has been used to make weapons grade plutonium. It would also shift the spent fuel from the APSARA reactor to a site outside the Bhabha Atomic Research Centre and make it available for safeguarding in 2010.

A significant proportion of India's nuclear complex would remain outside IAEA safeguards and continue to have a "strategic" function. This military nuclear complex would include the Tarapur 3 & 4 reactors, each of 540 MWe capacity, the Madras 1 & 2 reactors, and the 4 power reactors at Kaiga.[58] Together, these unsafeguarded reactors have 2350 MWe of electricity generation capacity. India also will not accept safeguards on the Prototype Fast Breeder Reactor

(PFBR) and the Fast Breeder Test Reactor (FBTR), both located at Kalpakkam. Facilities associated with the nuclear submarine propulsion program would not be offered for safeguards. Reprocessing and enrichment facilities also are to remain outside safeguards.[59]

Finally, under the deal, India retains the right to determine which future nuclear facilities it builds would be civilian and open to safeguards and which would not.

The Uranium Constraint

One important reason for the DAE's willingness to agree to have more of its nuclear facilities placed under safeguards is India's severe and growing shortage of domestic uranium. Nuclear Power Corporation of India data shows that most of its reactors have had lower capacity factors in the last few years.[60] The Indian Planning Commission noted that these reduced load factors were "primarily due to non-availability of nuclear fuel because the development of domestic mines has not kept pace with addition of generating capacity."[61] An Indian official told the BBC soon after the U.S.–India deal was announced, "The truth is we were desperate. We have nuclear fuel to last only till the end of 2006. If this agreement had not come through we might have as well closed down our nuclear reactors and by extension our nuclear program."[62] The former head of the Atomic Energy Regulatory Board has reported that "uranium shortage" has been "a major problem . . . for some time."[63]

We analyze here the extent to which this uranium constraint will be eased if the nuclear deal goes through and the ways in which the uranium supply so liberated could be used to increase India's rate of production of plutonium for weapons.

As background, recall that apart from imported low-enriched uranium for two very old imported U.S. reactors, India relies on its domestic uranium reserves to fuel its nuclear reactors. As of May 2006, the total electric capacity of India's power reactors that were domestically fueled was 2990 MWe—this includes the Rajasthan 1 and 2 reactors, which are under safeguards but have to be fueled by domestic uranium. At 80 percent capacity, all these reactors would require about 430 tons of natural uranium fuel per year. The weapons grade plutonium production reactors, CIRUS and Dhruva, consume about another 35 tons of uranium annually. The uranium enrichment facility would require about 10 tons of natural uranium feed a year. Thus, the total current requirements are about 475 tons of domestic natural uranium per year.[64]

In comparison, we estimate that current uranium production within India is less than 300 tons of uranium a year, well short of these requirements, but is being expanded rapidly.[65] DAE has been able to continue to operate its reactors by using uranium stockpiled when India's nuclear generating capacity was much smaller. Our estimates are that, in the absence of cut backs in India's nuclear power generation or uranium imports, this stockpile will be exhausted by 2007.

India is estimated to have total conventional uranium resources of about 95,500 tons of uranium, sufficient to supply about 10 GWe installed capacity of PHWRs for forty years or so.[66] However, the Department of Atomic Energy's efforts to open new uranium mines in the country have met with stiff resistance, primarily because of concerns in the communities around existing mines about the health impacts of uranium mining and milling.[67] State governments in Andhra Pradesh and Meghalaya, where DAE has found significant uranium deposits, have yet to approve new licenses for uranium mining and milling activities.[68] It is possible, however, that DAE may be able to overcome this resistance. The most likely new sites are in the district of Nalgonda, in Andhra Pradesh, with a potential capacity of about 150–200 tons of uranium a year.[69] If these mines are developed, then India could meet its current domestic uranium needs for both its nuclear power reactors and weapons program. In the meantime, old mines are being re-opened and existing mines expanded, including at Jaduguda.[70]

In the next few years, the domestic uranium demand for India's unsafeguarded reactors will increase further by about 140 tons/year, to 575 tons per year, as the 540 MWe Tarapur-3 and the 220 MWe Kaiga-3 & Kaiga-4 reactors are completed and begin operation in 2007. However, the total domestic uranium requirement will begin to decrease as some of the currently unsafeguarded reactors are opened for inspection in 2010, 2012, and 2014 as well as the Rajasthan-1 and 2 reactors can be fueled with imported uranium (Figure 1). Consequently, if India is able to meet the additional demand for domestic uranium until 2010, the availability of uranium imports allowed by the U.S.–India deal thereafter will give it a growing excess uranium production capacity that could be used for weapons purpose.

India has offered to put 1760 MWe of PHWRs under safeguards (including two reactors under construction) in addition to the two Rajasthan PHWRs with a combined capacity of 300 MWe that are already under safeguards. Without access to international uranium, all these reactors would have to be fueled using domestic uranium. At an 80 percent capacity factor, they would require about 300 tons of uranium annually. If the deal goes through, the DAE will be able to purchase these 300 tons of uranium from the international market, in effect freeing up the equivalent of India's entire current uranium production for possible use in military facilities. With Nalgonda on line, the uranium available for the unsafeguarded power and weapons grade plutonium production reactors and the enrichment program increases to 450–500 tons/year. This would yield a uranium surplus of 75–125 tons a year after 2014.

There are several ways in which India could use its freed-up domestic uranium. In particular, concern has been raised about the possibility that it might be diverted to use in the weapons program. This option has been suggested

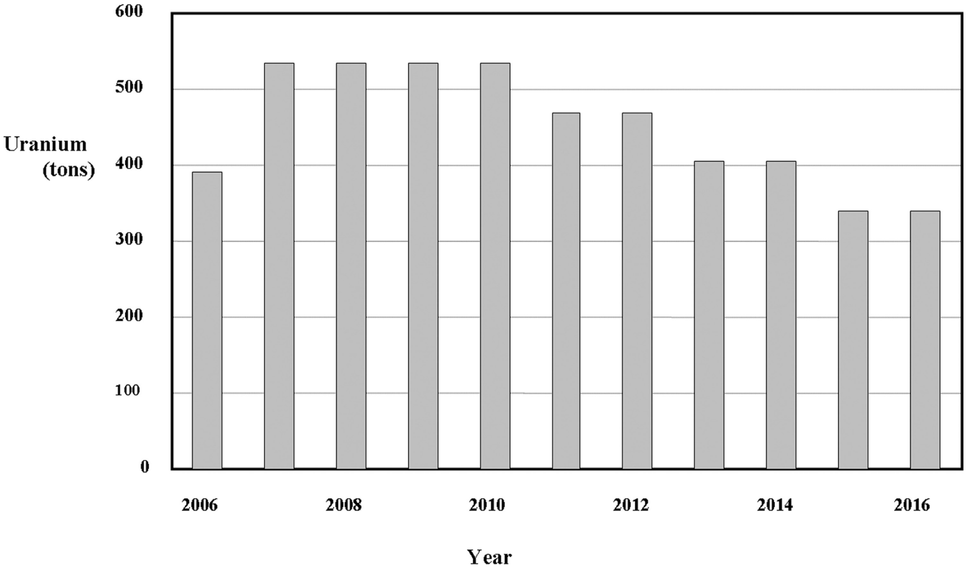

Figure 1: Estimated annual domestic uranium requirements for unsafeguarded heavy water power reactors. (This includes under construction HWRs as they come into operation and excludes HWRs once they come under safeguards and can be fueled by imported uranium. It also excludes CIRUS and Dhruva and uranium demand from the enrichment program, which add up to about 45 tons per year.)

by, among others, K. Subrahmanyam, former head of the National Security Advisory Board, who has argued that "Given India's uranium ore crunch and the need to build up our minimum credible nuclear deterrent arsenal as fast as possible, it is to India's advantage to categorize as many power reactors as possible as civilian ones to be refueled by imported uranium and conserve our native uranium fuel for weapons grade plutonium production."[71]

There are different ways in which this could be accomplished. One is that India could choose to build a third reactor dedicated to making plutonium for its nuclear weapons. There have been proposals for many years to build another large plutonium production reactor at the Bhabha Atomic Research Centre in Bombay.[72] The proposed reactor would be similar to the 100 MWt Dhruva that has been operating at BARC since 1985. A decision on whether to go ahead is expected early in 2007.[73] If a reactor of the same power rating as Dhruva is built, it could yield an additional 20–30 kg of plutonium, that is several bombs worth, each year.

India also could choose to use some of its domestic uranium to make weapons grade plutonium in one of its unsafeguarded PHWRs. This can be done by running the reactor in a "production" mode, that is, by limiting the time the fuel is irradiated, through faster refueling.[74] This is beyond the normal design requirement of PHWR refueling machines but might be possible. Assuming such high refueling rates are sustainable, then a typical 220 MWe pressurized heavy water reactor could produce between 150–200 kg/year of weapons grade

Table 5: Uranium requirements for India's unsafeguarded reactors in various operating modes.

	Burn up (MWd/tHM)	Uranium demand (tons/year)	Reactor grade plutonium (kg/y)	Weapons grade plutonium (kg/y)
Dhruva	1000	29		26
One 220 MWe reactor run for weapons grade plutonium	1000	222		200
Seven reactors in power mode and one 220 MWe reactor in production mode		528	1147	200
Seven reactors in power mode with partial depleted uranium cores and one 220 MWe reactor in production mode		467		200
All eight reactors in power mode	7000	338	1265	—
All eight reactors in power mode with partial depleted uranium cores		270		—

Notes: All reactors are assumed to run at 80% capacity factor. If the 170 MWe Madras 1 reactor were used to produce weapons plutonium, its annual uranium requirement would be the 170 tons, and consequently the total uranium requirement for that and the other 7 unsafeguarded HWRs would be reduced to 485 tons, instead of 528.

plutonium when operated at 60–80 percent capacity.[75] Even one such reactor, if run on a production mode, could increase the existing rate of plutonium production by a factor of six to eight.[76] The net penalty for running one 220 MWe reactor in production mode is 190 tons of natural uranium.[77]

To see if this option can be sustained given India's supply of domestic uranium, we summarize in Table 5 various possibilities. The table shows estimates for the uranium requirements for Dhruva, and of running an unsafeguarded 220 MWe power reactor at very low burn-up to optimize weapons grade plutonium production. The table also gives the aggregate uranium demand of the eight unsafeguarded power reactors if they operate normally.

Rows 1 and 3 of Table 5 show that if one power reactor were to be run to produce weapons grade plutonium, and with normal operation of the other unsafeguarded power reactors, plus Dhruva, India would require almost 560 tons of uranium per year, for which additional domestic sources would have to be found.

To offset the additional 190 tons/year of uranium required if India were to operate a single 220 MWe PHWR in weapons grade plutonium production mode, it could recycle some of the depleted uranium recovered from the spent fuel from this reactor into the other seven unsafeguarded power reactors. This scheme involves fuelling 25 percent of the core with depleted uranium (containing 0.61 percent U-235) and ends up saving 20 percent of the normal natural uranium requirement, with the average burn up reduced to 5,400 MWd/tHM.[78]

The resulting 20 percent saving on the roughly 306 tons/year of natural uranium the 7 power reactors require is equivalent to 61 tons/year of natural uranium. The net penalty of running one reactor in production mode is reduced from 190 tons/year to about 130/tons per year.[79] This implies that India could operate an unsafeguarded 220 MWe heavy water reactor in production mode, provided the Nalgonda and other mines can yield an additional 200 tons/year of uranium, and that India has sufficient reprocessing capacity to maintain the necessary flow of depleted uranium.

India has already fueled some PHWRs using natural uranium and depleted uranium recovered as a byproduct of weapons grade plutonium production—including the Rajasthan-3 & 4, Kaiga-2, and Madras-2 reactors.[80] It has used depleted uranium recovered from low burn-up fuel from CIRUS and Dhruva.[81] These reactors generate only about 30 tons/year of spent fuel. However, there is a stock of about 750 tons of such spent fuel.[82] This would suffice for roughly four to five years if all the power reactors ran on a mixed natural and depleted uranium core.

Power Reactor Spent Fuel

The nuclear deal does not constrain India's use of the plutonium from the spent fuel discharged by any of its currently unsafeguarded reactors. The 6 currently operating reactors to be placed under safeguards will add to the current stock of 11.5 tons of reactor grade plutonium before they are opened to inspection. Operating at 80 percent capacity, each reactor will add about 120 kg/year of plutonium during its remaining unsafeguarded operation. The total contribution from these 6 reactors will be about 4,300 kg before they are all finally under safeguards (Table 6).

The total annual unsafeguarded plutonium production will increase from the current 1,450 kg/year as reactors under construction come into operation next year and then decline in coming years as reactors are opened for

Table 6: Projected plutonium production from 2007 until reactors are safeguarded.

Reactor	Proposed date of safeguarding	Plutonium production (kg) before reactor is safeguarded
Rajasthan-3	2010	475
Rajasthan-4	2010	475
Kakrapar-1	2012	712
Kakrapar-2	2012	712
Narora-1	2014	950
Narora-2	2014	950
Total		4274

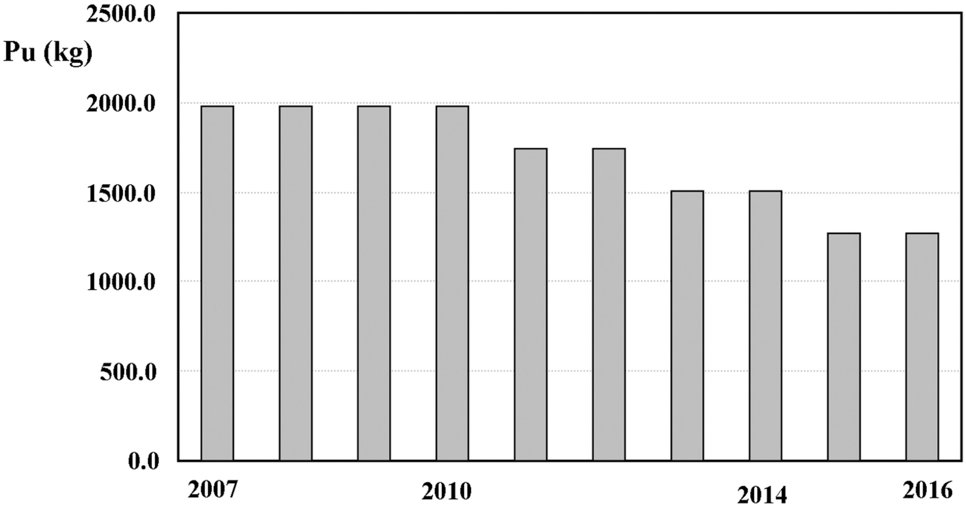

Figure 2: Annual production of unsafeguarded plutonium from all Indian power reactors from 2007 until 2016, as reactors are progressively placed under safeguards.

inspection. Plutonium production will be reduced from about 2,000 kg/year in 2007 to about 1,250kg/year after 2014, when it will stabilize (Figure 2) unless additional unsafeguarded reactors are built. Thus, the separation plan will serve to reduce India's annual production of unsafeguarded plutonium by about one-third.

The "reactor-grade" plutonium in the high burn-up spent fuel being discharged by these reactors has a different mix of isotopes from weapons grade plutonium. However, reactor grade plutonium can be used to make a nuclear explosive and, as mentioned earlier, one of India's May 1998 nuclear tests is reported to have involved such material.[83]

An estimated 8 kg of reactor grade plutonium would be required to make a simple nuclear weapon.[84] If this plutonium is not put under safeguards, it could provide an arsenal of over 1,300 weapons.

A commonly cited problem with the use of reactor grade plutonium is the increased risk of a "fizzle yield," where a premature initiation of the fission chain reaction by neutrons emitted by fissioning of plutonium-240 leads to predetonation of the weapon and an explosive yield only a few percent of the design value. In Indian PHWR spent fuel, plutonium-240 is over 22 percent of the total plutonium (compared to about 5 percent in weapons grade plutonium).[85] The greater abundance of plutonium isotopes other than Pu-239 in reactor grade plutonium also leads to increased heat generation and radiation from a mass of this material. However, these are not insuperable engineering difficulties.

The U.S. Department of Energy has noted that "At the lowest level of sophistication, a potential proliferating state or sub-national group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a nuclear weapon from reactor grade plutonium that would have an assured, reliable yield of one or a few kilotons (and a probable yield significantly higher than that). At the other end of the spectrum, advanced nuclear weapon states such as the United States and Russia, using modern designs, could produce weapons from reactor grade plutonium having reliable explosive yields, weight, and other characteristics generally comparable to those of weapons made from weapons grade plutonium."[86] India presumably falls somewhere in this spectrum.

One "modern design" feature that allows reactor grade plutonium to be used for weapons is "boosting," in which a gas mixture of deuterium and tritium is introduced into the hollow core of an implosion weapon as it begins to detonate.[87] The fusion reaction that is triggered releases a large quantity of neutrons, which are able in turn to initiate fission more quickly in a larger mass of the fissile material than the normal chain reaction. This serves to reduce both the mass of fissile material required for the weapon and greatly increase a fizzle yield. Indian weapon designers claim to have tested a thermonuclear weapon with a boosted fission primary in 1998.[88] One history of India's nuclear weapons program notes explicitly the use of boosting in a reactor grade plutonium device test in 1998 and observes that "if validated it would increase India's stock of fissile material dramatically."[89]

The Fast Breeder Reactor Program

India's Department of Atomic Energy has consistently offered the potential shortage of domestic uranium and India's abundant thorium reserves as the justification for its plutonium fueled fast breeder reactor program. India would gain access to the international uranium market as part of the agreement with the United States and so end the prospect of future uranium shortages.

An important concern is that the DAE has chosen to keep the breeder program out of IAEA safeguards as part of the nuclear deal. In support of this, DAE has raised concerns that safeguards would unduly constrain reactor research and development programs.[90] But IAEA safeguards do not seem to have compromised or limited the development of commercial breeder programs in Germany and Japan, or that of new generations of PHWRs in Canada. The many technical and safety problems that breeder programs in various countries have experienced have been for other reasons.

DAE chairman Anil Kakodkar has also declared that, "Both from the point of view of maintaining long term energy security and for maintaining the minimum credible deterrent the Fast Breeder Programme just cannot be put on the civilian list."[91] This suggests that the breeder may be used to produce weapons-grade plutonium.

India's first large breeder reactor, the 500 MWe, Prototype Fast Breeder Reactor (PFBR) is located at Kalpakkam, near Madras. It is part of a larger complex that includes the Madras PHWR reactors and a reprocessing plant.

This entire complex is being kept outside safeguards.[92] The PFBR is expected to be completed in 2010.

Fueled initially by reactor grade plutonium separated from PHWR spent fuel, the PFBR would produce weapons grade plutonium in both its radial and axial blankets of depleted uranium while the plutonium recovered from the core could be recycled for use again as fuel. To recover the weapons grade plutonium, the core and blanket fuel assemblies would have to be reprocessed separately. This will include separating the axial blanket from the part of the fuel assembly that lies within core, which can done by shearing machines that are used to cut the fuel assemblies prior to reprocessing.[93] Plans for a dedicated reprocessing plant for the FBR have been developed.[94]

The PFBR is designed to have a thermal power of 1250 MW and an initial inventory of 1910 kg of plutonium in its core.[95] The current design is reported to have an overall, equilibrium cycle breeding ratio of almost 1.05.[96] Applying the neutron balance in a generic breeder reactor with a homogeneous core permits a first order estimate of plutonium production in the PFBR core and its radial and axial blankets.[97] With these uncertainties in mind, we find that at 80 percent capacity the PFBR could produce on the order of 135 kg of weapons-grade plutonium every year in its blanket (about 1/3 in the axial blanket and 2/3 in the radial blanket).[98] This would amount to about 25–30 weapons worth of plutonium a year, a four- to fivefold increase over India's current weapons plutonium production capacity.

India plans to build four additional breeder reactors by 2020, and then move to larger 1000 MWe breeders and eventually install 500 GWe of breeder capacity.[99] Each of the 4 planned 500 MWe breeder reactors would need two initial cores before they would be able to begin recycling their own plutonium, a total of about 16 tons.[100] India would appear to have more than sufficient unsafeguarded plutonium for placing all four of the planned breeders in the military sector. If these 5 breeders are built and all are kept military, then in about 15 years, India would be able to produce about 500–800 kg per year of weapons grade plutonium from them.

CONCLUSIONS

The July 2005 U.S.–India joint statement poses a challenge to the disarmament and nonproliferation regime. In particular, the March 2006 separation plan proposed by India as the basis for demarcating its military and civilian nuclear facilities lays the basis for a potentially rapid expansion of its capacity for fissile material production for weapons.

In this article, we have assessed the fissile material production capabilities in India and how they might change as a result of the U.S.–India deal.

We have estimated India's current stockpile of weapons grade plutonium from its CIRUS and Dhruva reactors and found it to be about 500 kg. Assuming a typical figure of 5 kg of plutonium for each nuclear warhead, this stockpile would be sufficient for roughly a hundred weapons.

Under the deal, India will be able to produce another 45 kg of weapons-grade plutonium from its CIRUS reactor before it is shut down in 2010. The Dhruva reactor will continue to operate and add about 20–25 kg/year. A second Dhruva sized reactor that is being considered would add a similar amount each year.

The most important potential increase in India's weapons grade plutonium production will come from its unsafeguarded fast breeder reactor, the PFBR, to be completed in 2010. We have estimated that it could produce about 130 kg of weapons grade plutonium each year, a fourfold increase in India's current production capability. Note that even in the absence of the U.S.–India deal, the breeder would have remained unsafeguarded and produced the same amount of plutonium.

India has plans for four more breeder reactors by 2020, which would produce over 500 kg a year of weapons grade plutonium. The safeguards status of these reactors has not yet been announced.

These breeders would be fueled by India's stockpile of about 11 tons of unsafeguarded reactor grade plutonium. This stockpile is currently increasing at about two tons/year. As part of the U.S.–India deal, India will place six of its reactors under safeguards between now and 2014—these will be in addition to the six imported reactors that are required to be under safeguards. We have estimated that the reactors newly assigned to be safeguarded will contribute in total another four tons of unsafeguarded plutonium before they are opened for inspection. Meanwhile, the eight reactors that are designated as military and will remain unsafeguarded will contribute 1,250 kg of reactor grade plutonium per year.

Without the deal, India would have 16 unsafeguarded nuclear reactors (including 5 under construction and expected to begin operating in 2007–2008). They would have produced altogether 2,200 kg/year of reactor grade plutonium. India's proposed nuclear facilities separation plan will serve to reduce its annual unsafeguarded plutonium production by about 40 percent, to roughly 1,250 kg/year. All this reactor grade plutonium is also potentially weapons-useable.

India currently fuels 13 heavy water reactors with a total capacity of 2,990 MWe from domestic uranium. Under the deal, it will be able to fuel the eight of them that are to be safeguarded using imported uranium. Of the five heavy water reactors under construction, two are to be safeguarded, whereas three will be military and not open to inspection. This will give India 2,350 MWe of unsafeguarded heavy water reactor capacity that it will have to fuel using domestic uranium.

We find that India's current domestic production of natural uranium of about 300 tons/year is insufficient to fuel its unsafeguarded reactors and sustain its current weapons grade plutonium and enriched uranium production, which altogether require about 475 tons a year. India has been able to escape this constraint so far by using stocks of previously mined and processed uranium. As new unsafeguarded reactors come on-line in 2007–2008, India would need altogether about 615 tons of domestic uranium per year. However, this requirement will decline from 615 tons/year to about 380 tons because India will be able to import uranium for reactors when they come under safeguards in 2010, 2012, and 2014.

To meet the increased demand, India expects to expand uranium mining. The proposed Nalgonda mines are hoped to produce about 150–200 tons per year, increasing the total availability to about 450–500 tons a year. Assuming this happens, and as the requirement falls to 380 tons of uranium per year, India may be able to divert the additional 70–120 tons/year toward producing 60–100 kg/year of weapons grade plutonium by partially running one of its unsafeguarded power reactors at low burn-up. This will require operating the reactor refueling machines at much higher rates than normal and may limit the extent to which this is possible.

We found that it would require an extra 190 tons of natural uranium a year if an entire 200 MWe heavy water reactor were to be shifted from power production to weapons grade plutonium production. We considered the possibility of India offsetting some of this natural uranium demand by using recycled depleted uranium (containing 0.61 percent uranium-235) as part of the fuel for its other unsafeguarded power reactors. We found that this reduces the natural uranium requirement to 130 tons per year, not very far from the additional 70–120 tons that may be available. A key constraint on the recycling of depleted uranium on this scale may be the operational capacity of India's reprocessing plants.

It should be noted that only the weapons grade plutonium that could be produced by the unsafeguarded power reactors (because of the availability of imported uranium) is a direct consequence of the U.S.–India deal that has been negotiated. The breeder and production reactors would have remained unsafeguarded even if there had been no deal. Only a deal that would have brought the PFBR and all the power reactors under safeguards would have ensured that Indian fissile material production for weapons remained at about the current levels.

An expansion of fissile material stockpiles in South Asia would be at odds with the stated doctrine of both India and Pakistan of pursuing a "minimum deterrence." It has been shown that half a dozen modest Hiroshima-yield weapons if dropped on major cities in South Asia could kill over a million people.[101] This suggests that several dozen weapons would more than suffice to meet any reasonable criteria for "minimum deterrence."[102] This number would permit a nuclear attack with a dozen warheads and provide for sufficient redundancy to deal with any concerns about survivability, reliability, and interception.[103]

Both India and Pakistan have already achieved the fissile material requirements for a "minimal" arsenal and it has been argued for some time that they should end production of fissile material for weapons.[104] Rather than pursue the option of a large expansion of their nuclear arsenals, they should choose to suspend all further production of fissile materials for weapons purposes pending the negotiation and entry into force of a Fissile Material Cutoff Treaty. This is also a necessary step in progress toward nuclear disarmament.

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requires 2–3 hours to change 4–8 fuel bundles, see, e.g., *CANDU Fundamentals*, http://canteach.candu.org/library/20040700.pdf, p. 179. For 1000 MWd/tHM burn up such refueling would have to be repeated seven times a day.

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77. Uranium consumption is about 222 tons/year in production mode versus 32 tons in power mode.

78. Baltej Singh, P. D. Krishnani, and R. Srivenkatesan, "Use of Depleted Uranium in Equilibrium Core of Standard PHWRs: A Complete Study" (Paper presented at the 16th Annual Conference of the Indian Nuclear Society, 2005), http://www.indian-nuclear-society.org.in/conf/2005/pdf_3/topic_1/T1_CP5_Baltej_Singh.pdf. The depleted uranium requirement is twice that of the natural uranium it replaces, in order to maintain reactor performance.

79. These 130 tons are the difference between the 467 tons in Row 4 and the 338 tons in Row 5 of Table 5.

80. Baltej Singh, P. D. Krishnani, and R. Srivenkatesan, "Use of Depleted Uranium in Equilibrium Core of Standard PHWRs: A Complete Study" (Paper presented at the 16th Annual Conference of the Indian Nuclear Society, 2005), http://www.indian-nuclear-society.org.in/conf/2005/pdf_3/topic_1/T1_CP5_Baltej_Singh.pdf. It has been studied for Tarapur 3&4; V. K. Chaturvedi, "Economics of fuel cycles of PHWRs, VVERS and TAPS BWR." (Paper presented at the 14th Indian Nuclear Society Annual Conference, Kalpakkam, December 17–19, 2003), http://www.indian-nuclear-society.org.in/conf/2003/2.pdf.

81. Depleted uranium fuel is manufactured at the Nuclear Fuel Complex using uranium recovered by the reprocessing plant, which handles spent fuel from CIRUS and Dhruva; C. Ganguly, "Manufacturing Experience Of PHWR and LWR Fuels." (Paper presented at the 14th Indian Nuclear Society Conference, Kalpakkam, December 17–19, 2003), http://www.indian-nuclear-society.org.in/conf/2003/8.pdf. In a PHWR at a burn-up of 1000 MWd/tHM, the 0.7% U-235 in natural uranium fuel is reduced to 0.6% U-235, whereas fuel with a burn-up of 7000 MWd/tHM contains 0.2% uranium-235.

82. As of 2003, the Nuclear Fuel Complex at Hyderabad had produced about 76 tons of depleted uranium fuel, *ibid*.

83. George Perkovich, *op. cit.*, 428–430, claims "knowledgeable Indian sources confirmed" use of non-weapons grade plutonium in one of the 1998 tests; Raj Chengappa, *op. cit.*, 417–418 claims "one of the devices . . . used reactor grade or dirty plutonium."

84. J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium." *Science and Global Security*, 4 (1) (1993): 111–124.

85. The plutonium produced by an Indian PHWR at a burn-up of 7000 MWd/tHM, typical of power generation, is about 72% Pu-239 and over 22% Pu-240, whereas at a burn-up used for weapons plutonium production of 1000 MWd/tHM, the plutonium produced is almost 95% Pu-239 and about 5% Pu-240.

86. U.S. Department of Energy, Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives, DOE/NN-0007, Washington, D.C., Jan. 1997, pp. 37–39, http://www.ccnr.org/plute.html.

87. India's CIRUS and Dhruva and its heavy water power reactors produce tritium as a normal byproduct of their operation.

88. George Perkovich, *op. cit.*, 427.

89. Raj Chengappa, *op. cit.*, 416–418.

90. Pallava Bagla, "On the Record: Anil Kakodkar." *Indian Express*, February 8, 2006.

91. *Ibid.*

92. The four reactors at Kaiga have also all been designated as military and may imply this site is to host another reprocessing plant and unsafeguarded breeder reactor, similar to the arrangement at Madras.

93. India already cuts fuel assemblies into large sections prior to the chopping into small pieces that accompanies reprocessing. This is done for instance with spent fuel assemblies from Dhruva; M. S. Rajkumar, "Remote Technologies for Handling Spent Fuel." in *Remote Technology in Spent Fuel Management (*Proceedings of an Advisory Group meeting, Vienna, September 22–25, 1997), IAEA TECDOC-1061, 1999, 35–48.

94. India plans a series of "FBR parks." each of which will have two to four FBRs, a dedicated reprocessing plant and a fuel fabrication plant, including at Kalpakkam; T. S. Subramanian, "A Milestone at Kalpakkam." *Frontline*, Nov. 6, 2004.

95. *Design of Prototype Fast Breeder Reactor*, Indira Gandhi Centre for Atomic Research, Dec. 2003, http://www.igcar.ernet.in/broucher/design.pdf. The plutonium content of the fuel is reported to be 20.7% in the inner core and 27.7% in the outer core, with approximately 91% of the total power generated in the core; D. G. Roychowdhury, P. P. Vinayagam, S. C. Ravichandar, and M. V. Sridhar Rao, "Thermal Hydraulic Design of PFBR Core." *LMFR Core Thermohydraulics: Status and Prospects,* IAEA-TECDOC-1157, June 2000, http://www.iaea.org/inis/aws/fnss/fulltext/1157_3.pdf.

96. "National Presentations: India." in *Primary Coolant Pipe Rupture Event in Liquid Metal Cooled Reactors*, IEA TECDOC-1406, August 2004, http://www.iaea.org/inis/aws/fnss/fulltext/te_1406_web.pdf. The breeding ratio is the mass of fissile isotopes produced by the reactor divided by the amount of fissile material consumed. It appears the PFBR breeding ratio was reduced to 1.049 after a redesign of the radial blanket. It had previously been given as 1.07; S. M. Lee, S. Govindarajan, R. Indira, T. M. John, P. Mohanakrishnan, R. Shankar Singh, S. B. Bhoje, "Conceptual Design of PFBR Core." *Conceptual Designs of Advanced Fast Reactors,* IAEA-TECDOC-907, 1996, http://www.iaea.org/inis/aws/fnss/fulltext/28014311.pdf.

97. We assume roughly two-thirds of all fissions in the inner and outer cores are from Pu-239 nuclei, 13.5% are of Pu241, and 1.5% are of U-235. For the inner and outer cores, we assume generic capture to fission ratios for Pu-239, Pu-241, and U-235 of 0.25, 0.1, and 0.25, respectively; see Alan E. Waltar and Albert B. Reynolds, *Fast Breeder Reactors*, (New York: Pergamon Press, 1981), 123–134. The actual values for the PFBR may be somewhat different.

98. We assume a core breeding ratio of 0.68 and an overall breeding ratio of 1.05. Note that Japan's Monju and the cancelled US Clinch River fast breeder reactors had core breeding ratios of 0.6–0.75; S. Usami, et al., *Reaction Rate Distribution Measurement and the Core Performance Evaluation in the Prototype FBR Monju* (last updated July 5, 2005),http://aec.jst.go.jp/jicst/NC/tyoki/sakutei2004/sakutei17/siryo41.pdf. For this range of core breeding ratios, the PFBR would produce about 164–109 kg of weapons grade plutonium. Preliminary results from MCNP calculations on PFBR plutonium production support this range of plutonium production (Alexander Glaser, private communication).

99. T. S. Subramanian, "A Milestone at Kalpakkam." *Frontline*, November 6–19, 2004, http://www.hinduonnet.com/fline/fl2123/stories/20041119003210200.htm.

100. The spent fuel from the breeder would need to cool before it could be reprocessed and the plutonium recycled, and so an initial plutonium stock for two cores, about four tons in total, is required for each breeder.

101. M. McKinzie, Z. Mian, A. H. Nayyar, and M. V. Ramana, "The Risks and Consequences of Nuclear War in South Asia." in *Out of the Nuclear Shadow*, Smitu Kothari and Zia Mian, (eds.) (Delhi: Lokayan and Rainbow Publishers and London: Zed Books, 2001).

102. R. Rajaraman, "Save the Indo-US Agreement." *Hindustan Times*, November 5, 2005.

103. R. Rajaraman, "Cap the Nuclear Arsenal Now." *The Hindu*, January 25, 2005, R. Rajaraman, "Towards DeNuclearisation of South Asia" (paper presented at the 2nd Pugwash Workshop on South Asian Security, Geneva, Switzerland, May 16–18, 2003).

104. Zia Mian, M. V. Ramana, "Beyond Lahore: From Transparency to Arms Control." *Economic and Political Weekly* April 17–24, 1999; Zia Mian, A. H. Nayyar, and M. V. Ramana, "Making Weapons, Talking Peace: Resolving The Dilemma of Nuclear Negotiations." *Economic and Political Weekly*, July 17, 2004; R. Rajaraman, "India-U.S. Deal and the Nuclear Ceiling." *The Hindu* (Sept. 10, 2005); R. Rajaraman, "Nurturing the Indo-US Agreement." in *The Debate on the Indo–US Nuclear Cooperation*, Delhi Policy Group and Bibliophile South Asia, 2006.

Appendix 1: Power reactors in India and Pakistan.

Power reactor	Type	Gross Power (MWe)	Start-up date	Safeguards (June 2006)	Open for safeguards
India					
In operation					
Kaiga-1	PHWR	220	16-Nov-00	Unsafeguarded	Military
Kaiga-2	PHWR	220	16-Mar-00	Unsafeguarded	Military
Kakrapar-1	PHWR	220	6-May-93	Unsafeguarded	2012
Kakrapar-2	PHWR	220	1-Sep-95	Unsafeguarded	2012
Madras-1	PHWR	170	27-Jan-84	Unsafeguarded	Military
Madras-2	PHWR	220	21-Mar-86	Unsafeguarded	Military
Narora-1	PHWR	220	1-Jan-91	Unsafeguarded	2014
Narora-2	PHWR	220	1-Jul-92	Unsafeguarded	2014
Rajasthan-1	PHWR	100	16-Dec-73	Safeguarded	Safeguarded
Rajasthan-2	PHWR	200	1-Apr-81	Safeguarded	Safeguarded
Rajasthan-3	PHWR	220	1-Jun-00	Unsafeguarded	2010
Rajasthan-4	PHWR	220	23-Dec-00	Unsafeguarded	2010
Tarapur-1	BWR	160	28-Oct-69	Safeguarded	Safeguarded
Tarapur-2	BWR	160	28-Oct-69	Safeguarded	Safeguarded
Tarapur-4	PHWR	540	12-Sep-05	Unsafeguarded	Military
Under construction					
Kaiga-3	PHWR	220	2007 (planned)	Unsafeguarded	Military
Kaiga-4	PHWR	220	2007 (planned)	Unsafeguarded	Military
Kudankulam-1	VVER	1000	2007 (planned)	Safeguarded	Safeguarded
Kudankulam-2	VVER	1000	2008 (planned)	Safeguarded	Safeguarded
Rajasthan-5	PHWR	220	2007 (planned)	Unsafeguarded	2007
Rajasthan-6	PHWR	220	2008 (planned)	Unsafeguarded	2008
Tarapur-3	PHWR	540	2007 (planned)	Unsafeguarded	Military
PFBR	Fast Breeder	500	2010	unsafeguarded	military
Pakistan					
In operation					
Chashma-1	PWR	325	13-Jun-00	Safeguarded	
Karachi	PHWR	137	28-Nov-72	Safeguarded	
Under construction					
Chashma-2	PWR	325	2011 (planned)	Safeguarded	

Note: Military reactors will not be open for IAEA safeguards.