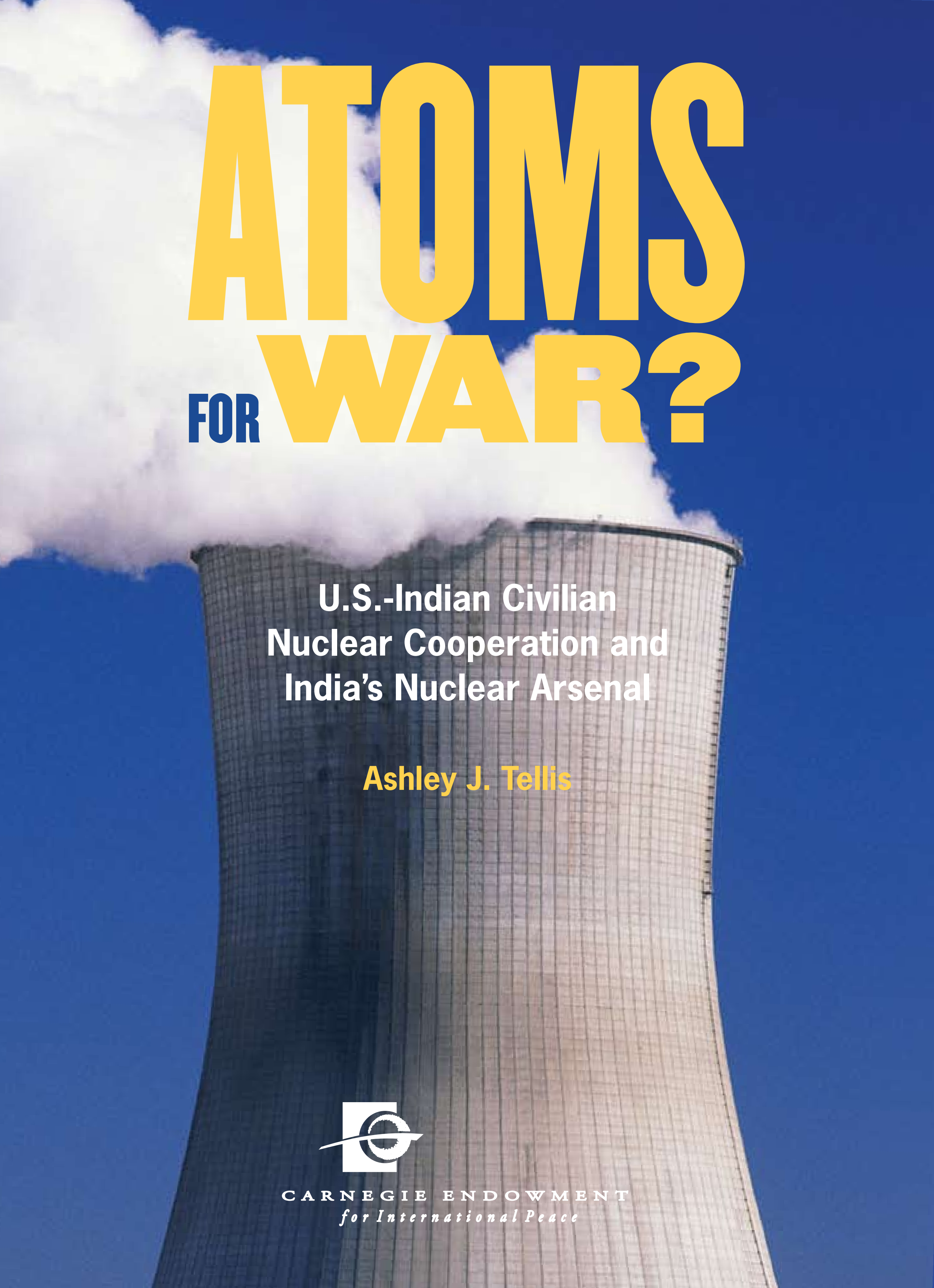

ATOMS FOR WAR?

U.S.-Indian Civilian Nuclear Cooperation and India's Nuclear Arsenal

Ashley J. Tellis

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for International Peace

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Contents

ACRONYMS AND ABBREVIATIONS

BWRs	boiling water reactors
DAE	Department of Atomic Energy
EAR	estimated additional resources
FBTR	fast breeder test reactor
FMCT	fissile material cutoff treaty
GWe	gigawatt (electric)
MWD/MTU	megawatt days per metric ton of uranium
MTHM/yr	metric tons of heavy metal per year
MTU	metric tons of natural uranium
MTPD	metric tons per day
MWe	megawatt (electric)
MWt	megawatt (thermal)
PHWRs	pressurized heavy water reactors
PFBR	prototype fast breeder reactor
RAR	reasonably assured resources
RGPu	reactor-grade plutonium
SR	speculative resources
WGPu	weapons-grade plutonium

Introduction

The U.S.-Indian nuclear cooperation initiative agreed to by President George W. Bush and Prime Minister Manmohan Singh has been criticized for many reasons, but perhaps the most serious charge levied by its opponents is that this agreement would enable India to rapidly expand its nuclear arsenal. For example, Joseph Cirincione of the Center for American Progress asserted that "the deal endorses and assists India's nuclear-weapons program. U.S.-supplied uranium fuel would free up India's limited uranium reserves for fuel that otherwise would be burned in these reactors to make nuclear weapons. This would allow India to increase its production from the estimated six to 10 additional nuclear bombs per year to several dozen a year."[1]

A similar view has been expressed by Daryl G. Kimball of the Arms Control Association who, while indicting the administration for "cav[ing] in to the demands of India's nuclear bomb lobby" in its rush to procure an agreement under pressure of "artificial summit deadlines," charged that the United States had ended up with a deal that permitted India

> *…to keep major existing and future nuclear facilities shrouded in secrecy and use them to manufacture more nuclear weapons.*
>
> *India agreed only to allow international safeguards on 14 of its 20-some nuclear power reactors. The Bush team dropped its demands that India*

> *allow safeguards on its fast breeder reactors, which can produce especially large quantities of bomb-quality plutonium.*
>
> *These gaping loopholes would allow India to increase its capacity to produce nuclear bombs from six to 10 a year to several dozen a year.*
>
> *In addition, the plan would allow India to use the spent nuclear fuel in existing civilian power reactors for weapons purposes. That would allow it to extract the 4,100 pounds of plutonium in those fuel rods and potentially build over 1,000 more nuclear bombs. By opening the spigot for foreign nuclear fuel supplies to India, this deal also could free India's existing limited domestic capacity of uranium for both energy and weapons to be singularly devoted to arms production in the future.*
>
> *It is not in the United States' strategic interests to ignore the expansion of India's current arsenal of 50 to 100 nuclear weapons, which could prompt neighboring Pakistan to increase its nuclear and missile arsenals.*[2]

Variations of this argument, first advanced by Henry Sokolski of the Nonproliferation Education Center, now appear to have acquired the status of gospel truth and are routinely reiterated by many in Congress, the larger nonproliferation community, and, of course, critics of the U.S.-Indian nuclear cooperation accord.[3] In its maximalist formulation, these opponents contend that the U.S.-India nuclear cooperation initiative is deeply dangerous, and perhaps even illegal under Article 1 of the nuclear Non-Proliferation Treaty, because providing India with natural uranium to fuel its safeguarded heavy water reactors for electricity production permits New Delhi to allocate its domestic reserves of natural uranium for purposes of expanding the production of weapons-grade plutonium and, thereby, rapidly increase the size of the Indian nuclear arsenal. The fact that the government of India has withheld eight heavy water reactors outside of safeguards in its March 2006 separation plan only attests, in this view, to its desire to sharply enlarge its nuclear warhead inventory when imported natural uranium becomes available for its safeguarded nuclear reactors. The Bush-Singh nuclear cooperation initiative, accordingly, is doubly pernicious in the eyes of its critics because it would not only provide India with the material wherewithal to speedily increase its nuclear weapons stockpile but would do so—ironically (or malevolently, depending on one's view about the Bush administration)—under the rubric of peaceful nuclear cooperation!

A minimalist version of this argument would take a different form, but leads nonetheless to a similar critique of the Bush-Singh initiative. The minimalist version contends that the administration's effort to renew nuclear cooperation with India would be dangerous and certainly illegal if it permits India to expand its nuclear arsenal in any way beyond that which it is capable of doing through its own resources today. Since the president's proposal to renew peaceful nuclear cooperation with India would purportedly permit New Delhi to enlarge its arsenal, however marginally—if nothing else, by permitting India to import natural uranium, which would have the effect of freeing up at least some of its own indigenous reserves for weapons production activities—his bold new overture must be judged as destabilizing for regional security as well as violative of U.S. obligations under the nuclear Non-Proliferation Treaty.

The maximalist claim that U.S.-Indian civil nuclear cooperation would underwrite the rapid expansion of India's nuclear arsenal hinges on two crucial assumptions: first, that New Delhi seeks the largest nuclear weapons inventory consistent with what its capacity permits and, consequently, its claimed desire for only a minimum deterrent is effectively a charade; and second, that the Indian desire for a large nuclear arsenal has been stymied so far by a shortage of natural uranium, which would now be remedied by the implementation of the proposed nuclear cooperation between the United States and India. The minimalist claim that U.S.-Indian civil nuclear cooperation would be unacceptable if it permits any expansion of India's nuclear arsenal hinges, in turn, on the premise that India does not have the natural resources to develop a nuclear stockpile of the size it may prefer either today or in the future and, consequently, the Bush-Singh initiative must be deemed unacceptable precisely because it makes up for this deficit in some substantive way. Understanding the issues implicated in these assumptions underlying both the maximalist and the minimalist claims is critical if President Bush's strategic overture toward India is to be appreciated for what it really is: an effort to strengthen India's ability to expand its civilian nuclear power program in order to increase the share of nuclear energy's contribution to India's large and rapidly growing electricity needs, rather than a closet "atoms for war" effort that would have the effect of covertly accelerating the growth in India's nuclear arsenal and, by implication, exacerbating a potential arms race with China and Pakistan.

This report uses the maximalist claim as its point of entry to demonstrate that India's ability to develop a larger nuclear arsenal than it currently possesses is not affected by the U.S.-Indian civilian nuclear cooperation initiative proposed by President Bush and Prime Minster Singh. In other words, whether the arsenal consists of the largest stockpile that protagonists of the maximalist claim imagine India would want to build, or whether it consists merely of some incremental addition as the minimalist version would have it, this report concludes that India has sufficient indigenous natural uranium to satisfy both scenarios. This conclusion obtains, in part, because India's weapons program requires only a small fraction of the natural uranium required to sustain its power production efforts. More importantly, however, India has sufficient natural uranium reserves to sustain the largest nuclear weapons program that can be envisaged relative to its current capabilities; it also possesses enough uranium to sustain more than three times its current and planned capacity as far as nuclear power production involving pressurized heavy water reactors (PHWRs) is concerned. This basic reality will not be altered whether the Bush-Singh nuclear cooperation initiative now being reviewed by the U.S. Congress is successfully consummated or not.

The highly publicized Indian "shortage" of natural uranium, therefore, takes on different meanings from that commonly imagined. India does face an energy constraint over the very long term since its currently known uranium deposits will be exhausted after many decades—depending on the rate at which India commissions new PHWRs—if its nuclear power program is restricted to the use of only indigenous technology and if New Delhi is permanently cut off from international nuclear commerce. Assuming for the sake of argument that no technical change occurs in the interim, this energy constraint would materialize simply because India's uranium deposits, like all other physical resources found elsewhere in the world, are finite. The U.S.-Indian civilian nuclear cooperation initiative is expressly intended to address this challenge: As Under Secretary of State R. Nicholas Burns phrased it, "[The civilian nuclear cooperation accord] will help India's economy gain access to the energy it requires to meet its goal of growing at 8% and beyond over the long term, while reducing competition in global energy markets."[4]

There is a different kind of constriction, however, consisting of a transient shortage of natural uranium, which threatens India in the short term. Although it is commonly believed that this deficit derives from the fact that "Indian sources [of natural uranium] are extremely limited, and the quality of natural uranium ores in India is so low," the present insufficiency of uranium fuel arises not so much from a lack of natural uranium reserves as it does from bottlenecks in mining and milling capacity. These hindrances are entirely self-inflicted as a result of decisions made under pressures of fiscal necessity by the government of India in the early 1990s. They are, however, being corrected, and the transient shortages of natural uranium currently facing the country could disappear within the next several years as India brings new uranium milling plants on line and opens new uranium mines at sites that have been explored but not exploited during the last decade. More to the point, however, the U.S.-India civilian nuclear cooperation initiative does not affect India's ability to rectify its deficiencies in uranium mining and milling capacity. The technologies relevant for this purpose already exist abundantly within India, and its national leadership is already committed to upgrading the uranium mining and milling infrastructure irrespective of how the bilateral accord on civilian nuclear cooperation turns out. Consequently, it is specious to conclude that the proposed nuclear cooperation initiative would assist India in resolving its short-term natural uranium shortages in a way that would either run afoul of U.S. obligations to the nuclear Non-Proliferation Treaty or help in expanding New Delhi's nuclear arsenal beyond what already lies within its indigenous capability.

Civilian Nuclear Cooperation and U.S. Non-Proliferation Treaty (NPT) Obligations

Although critics of the U.S.-Indian nuclear cooperation agreement admit that all international nuclear assistance to India will be restricted only to those facilities that are under IAEA safeguards, many commentators have nevertheless argued that the Bush-Singh initiative violates the U.S. obligation under Article I of the nuclear Non-Proliferation Treaty (NPT) "not in any way to assist, encourage, or induce any non-nuclear weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices." This claim is based on the contention that any U.S. fuel supplied to India would free up India's limited uranium reserves, thus permitting New Delhi to build more nuclear weapons than might be possible otherwise. Although this "fungibility" thesis is untenable empirically, because India possesses the requisite uranium reserves to build as many weapons as it might realistically desire, the legal claim advanced by the critics—that any peaceful nuclear cooperation with India would result in a violation of U.S. Article I obligations so long as New Delhi pursues an active nuclear weapons program—deserves scrutiny.

To begin with, even if U.S.-Indian nuclear cooperation were to liberate India's natural uranium reserves for use in weapons production, the claim that such substitution effects would make nuclear cooperation with India illegal under the NPT is based on a novel legal interpretation of U.S. obligations that has never been accepted by the U.S. government since the United States signed the treaty in 1968. In fact, the NPT itself does not require full-scope safeguards as a condition for civil nuclear cooperation with any safeguarded facilities. (The condition of full-scope safeguards is a U.S. innovation that postdates the NPT: it was enacted into U.S. law under the 1978 Nuclear Non-Proliferation Act (NNPA) and became part of the Nuclear Suppliers Group (NSG) guidelines in 1992, but is not a constituent condition in the NPT itself.) What the NPT simply requires is that all state parties undertake not to provide certain nuclear materials and equipment to any non-nuclear weapon state (or non-signatories) for peaceful purposes unless these materials and equipment are subjected to safeguards. This requirement is encoded in Article III (2) of the NPT, and it has guided previous efforts at U.S.-Indian nuclear cooperation just as it has regulated other Chinese, French, and Russian peaceful nuclear cooperation activities with India. If the critics' current claims are therefore taken seriously, China, France, Russia, and the United States have already been in violation of their Article I obligations because of past nuclear cooperation with India—an assertion that no serious jurist has ever advanced previously and that at any rate would be roundly rejected not only by these governments but all other non-nuclear weapon states, such as Canada, which have cooperated with India as well.

The simple fact of the matter is that the NPT does not treat peaceful nuclear cooperation under safeguards as assisting a non-nuclear weapon state to manufacture nuclear weapons. Indeed, Article III (2) establishes the basis under which parties may engage in nuclear cooperation with safeguarded facilities in countries that are not parties to the NPT and do not have full-scope safeguards. Previous practice abundantly confirms this view, as a number of countries—Canada, China, France, Russia, and the United States—have provided fuel to India's safeguarded facilities under facility-specific (INFCIRC/66) safeguards agreements both before and after the NPT entered into force and before and after India first detonated a nuclear explosive device in 1974. The current Russian civilian nuclear cooperation program, involving the construction of two light water reactors at Koodankulam in the southern Indian state of Tamil Nadu, is also occurring under the same understanding. In every case, nuclear cooperation taking place under facility-specific safeguards agreements—a standard form of collaboration under the auspices of the International Atomic Energy Agency—was understood to fully satisfy all the obligations incurred by the state parties under the NPT.

The critics' claims, therefore, that the U.S.-Indian civilian nuclear cooperation initiative violates U.S. Article I obligations insofar as it has the effect of freeing up India's own indigenous natural uranium resources for its weapons program is untenable because it fails to understand that, in a modern economy, all resources are fungible to some degree or another. As elementary textbooks in neoclassical economics have taught for decades, in any economic system characterized by scarcity, all inputs have alternative uses and can be substituted for each other with varying degrees of flexibility. Given this fact, the critics' assertions about a state's Article I obligations leads inexorably to the conclusion that no party to the NPT should have any economic intercourse with India whatsoever, because the resulting gains from trade would inevitably free up some domestic Indian resources that would be of use to New Delhi's weapons program, thereby violating the injunction that forbids states from assisting another's weapons program, as the critics love to emphasize, "in *any* way." Recognizing the absurdity of this position, the leading study on the negotiation of the NPT by Egypt's Ambassador Mohamed Ibrahim Shaker concluded that: "Almost any kind of international nuclear assistance is potentially useful to a nuclear-weapon program. However, the application of safeguards to all peaceful nuclear assistance to non-nuclear weapon States, as required by Article III, provides a means to establish and clarify the peaceful purposes of most international nuclear assistance."*

The argument that foreign fuel supply could allow India to devote its domestic uranium reserves substantially or even exclusively to its weapons program, should India so desire, does not change this legal conclusion. Nothing in the NPT, its negotiating history, or the previous and current practice of the signatories supports the notion that fuel supply to safeguarded reactors for peaceful purposes could be construed as "assisting in the manufacture of nuclear weapons," as that clause is understood in Article I of the treaty. No nuclear material or equipment that would be exported by the United States (or others) under the civil nuclear cooperation initiative with India would be involved in any way in the manufacture of nuclear weapons. In essence, therefore, nuclear cooperation under safeguards does not fundamentally differ from other forms of energy cooperation as, for example, oil sales, transfers of clean coal technology, or provision of alternative fuels. All such transactions would arguably relieve India of its reliance on domestic uranium for energy production. Yet these activities clearly could not be viewed as assisting, encouraging, or inducing India to manufacture or acquire nuclear weapons or other nuclear explosive devices. *Quod Erat Demonstrandum.*

* Mohamed I. Shaker, *The Nuclear Non-Proliferation Treaty: Origin and Implementation, 1959–1979* (New York: Oceana Publications, 1980).

Does India Seek the Largest Nuclear Arsenal Possible?

Because the U.S.-Indian civilian nuclear cooperation agreement does not terminate the production of fissile material for India's nuclear weapons program—an agreement that had such an effect could never have been concluded—there is truly no way of determining *a priori* what the eventual size of India's nuclear arsenal will be. The government of India has repeatedly affirmed its desire for only a "minimum credible deterrent," but has refused to quantify publicly what this concept means in terms of numbers and types of weapons. It is, in fact, entirely possible that not even the government of India itself knows what the notion of minimum deterrence precisely entails, because in a situation where India's rivals, China and Pakistan, are both continuing to build up their nuclear arsenals in the absence of any clearly defined force posture goals, policy makers in New Delhi would want to keep their options open in regards to their own strategic response. No one, therefore, can say with any certainty whether the eventual Indian nuclear arsenal will be large, medium, or small in size, because that magnitude will depend, at least in part, on the eventual—and as yet unknowable—strength and character of the Chinese and Pakistani nuclear inventories. What can be said, however, with reasonable confidence, is that the fundamental assumption inherent in the maximalist version of the critique of U.S.-Indian nuclear cooperation—that India seeks to build the largest possible nuclear weapons inventory it could develop through use of its indigenous resources—is simply not borne out by the record thus far. In fact, as Secretary of State Condoleezza Rice emphasized in her testimony before the Senate Foreign Relations Committee on April 5, 2006, the most interesting feature of the Indian nuclear weapons program historically has been its restraint, not its indulgence.[6]

A few details help to place this judgment in perspective. The Indian nuclear weapons program is not transparent enough to enable analysts on the outside to determine conclusively when its nuclear establishment began producing fissile materials for weapons and with what efficiency, although it is universally agreed that India's two research reactors, the Canadian-supplied CIRUS and the indigenously constructed Dhruva, have been the principal production foundries used for this purpose. Based on the known information about the history, technical characteristics, and fissile material production potential of these two reactors, several analysts have offered educated judgments about the size and quality of India's fissile material stockpile but, in the absence of authoritative data from the government of India, all these assessments are clouded to some degree or another by uncertainty.[7] One of the best Western assessments, produced in the immediate aftermath of India's 1998 nuclear tests, concluded that New Delhi possessed about 370 kilograms of weapons-grade plutonium (WGPu) at the time, and that its weapons-related fissile material stockpile, deriving principally from the output of the Dhruva (and to a lesser extent, CIRUS) reactor, was growing at a rate of some 20 kilograms annually.[8] If India is classified as a country with "low" technical capability as far as nuclear weapons design is concerned, meaning that a weapon with a 20 kiloton yield would require at least something on the order of 6 kilograms of weapons-grade plutonium, the notional Indian nuclear stockpile stood at about 61 weapons in 1998. A well-connected Indian journalist, R. Ramachandran, who reportedly was given access to several confidential government briefings on the subject, concluded that India's inventory of weapons-grade plutonium in the aftermath of its 1998 tests consisted of approximately 280 kilograms—sufficient for about 46 weapons. Furthermore, he reported that this inventory grew traditionally at the rate of about 12–16 kilograms per annum or, in other words, sufficient for slightly less than three new nuclear weapons annually.[9]

In the aftermath of India's 1998 tests, the government of India directed its nuclear establishment to increase the production of fissile materials over historical rates for two reasons: first, to provide Indian policy makers with the option of deploying a larger nuclear arsenal than originally intended, if China and Pakistan were to increase their own nuclear targeting of India in the future; and second, as insurance in case a global fissile material cutoff regime, which could require India to immediately terminate the production of weapons-grade fissile materials, were to unexpectedly materialize. Consistent with this injunction, India's nuclear managers pursued several diverse initiatives concurrently: recognizing the age and increasing inefficiency of the obsolescent CIRUS reactor, they sought its replacement by advocating the construction of a new 100-megawatt Dhruva-type research reactor that would be dedicated to the production of weapons-grade plutonium. Simultaneously, they explored the idea of using at least some of India's power reactors in a "low burnup" mode to increase the production of weapons-grade plutonium and possibly to produce tritium as well. Finally, using their existing research reactors, they increased the rate of production of both weapons-grade plutonium—the primary material for India's nuclear weaponry—and tritium—the boosting agent required for its advanced nuclear weapons—above the previous norm, while paying increased attention to the manufacture of other byproduct materials and nonfissile components required by its nuclear weapon stockpile.[10]

Discussions with Indians familiar with their nuclear establishment indicate that the new post-1998 practices have resulted more or less in a "doubling" of the weapons-grade plutonium production rate known to obtain historically. Although tritium production is believed to have increased as well, no Indian interlocutor could provide any sense of how the current production rate of this byproduct material compares with the past. If David Albright's and R. Ramachandran's data pertaining to weapons-grade plutonium are treated as previous benchmarks, then it must be inferred that India's new production rate has bequeathed the country with between 40 kilograms and 24–32 kilograms of this material annually since 1998. Obviously, these yearly increases are unlikely to have been either consistent or uniform, and every marginal increase in the fissile material stockpile is also unlikely to have been immediately fabricated into cores for usable nuclear weapons; yet, these numbers do provide a point of reference that illustrates the growth in the Indian fissile materials inventory (and, by implication, the size of its notional nuclear weapons stockpile) since New Delhi's last round of nuclear tests. If the conclusion about "doubling" were in fact veracious—as is likely—then the Indian fissile materials inventory in 2006 would range from some 550 kilograms of weapons-grade plutonium (extrapolating from Albright's 1998 estimate) at the high end, to some 388–424 kilograms of weapons-grade plutonium (extrapolating from Ramachandran's 1998 estimate) at the low end.[11] Most knowledgeable Indians suggest that the figures at the low end of these estimates probably convey a more accurate picture of India's current holdings than the data at the high end, but in any event these inventory sizes translate into a notional stockpile of some 91–65 simple fission weapons.[12]

What is remarkable about these numbers is that they repudiate the first key assumption that many critics of the U.S.-India nuclear cooperation agreement holding the maximalist view appear to make, namely that New Delhi seeks the largest possible nuclear arsenal it can lay its hands on. For starters, the relatively slow—even if increased—pace of production of weapons-grade plutonium indicates that the government of India appears to be in no hurry to build the biggest nuclear stockpile it could construct *based merely on material factors alone.* Most observers of the Indian nuclear weapons program, both U.S. and Indian, invariably underscore the conspicuous inefficiencies that still characterize many aspects of India's production regime;

this reality no doubt accounts for some of the languid pace witnessed even in the post-1998 epoch, but it cannot be a sufficient explanation because the production of other byproduct materials and nonfissile components required by India's nuclear devices has apparently increased during this same period.

The best explanation that accounts for the slow accumulation of primary fissile materials required by the weapons stockpile, therefore, is New Delhi's choices—which are driven more by what it believes are necessary to deter its adversaries without unnecessary arms-racing than by some automatic need to maintain the largest possible arsenal simply because technical factors permit it. In other words, it is India's strategic preferences—borne out of its traditional penchant for political moderation—and not simply its infrastructural capacity that defines the size of its extant and prospective arsenal. Other practical considerations appear to play a role as well: conversations with senior Indian military officers involved in the strategic program indicate that the country's immediate priority is not to maximize the production of weapons-grade materials per se even if technical conditions allow it, but rather to successfully integrate the modest capabilities India already possesses into an effective deterrent. This involves, among other things, producing the delivery systems, institutionalizing the procedural systems, and codifying the ideational systems in order to ensure that the weapons New Delhi already has in the stockpile can be used as intended in situations of supreme emergency.

At any rate, and irrespective of what the precise determining influences are, the conclusion remains the same: India appears content to produce less than the maximum quantity of weapons-grade materials it otherwise could based on material constraints alone. Translated, this means India's restraint is rooted in choice, rather than forced upon it by successful foreign strategies of denial. This fact is corroborated incontrovertibly by a simple detail: each of the major Indian reprocessing facilities at Tarapur (PREFRE) and at Kalpakkam (KARP) have a nominal capacity to reprocess at least 100 metric tons of spent fuel per year;[13] the smaller reprocessing plant at the Bhabha Atomic Research Center in Trombay has a nominal capacity to reprocess some 50 metric tons of spent fuel annually.[14] All told, then, India has the nominal capacity to reprocess at least 250 metric tons of heavy metal per year (MTHM/yr) in these three facilities, far more than the quantities it is currently reprocessing to yield the 24–40 kilograms of weapons-grade plutonium now produced annually for its weapons program.[15] The evidence, therefore, repudiates the first assumption made by those who advance the maximalist criticism of the U.S.-Indian civil nuclear agreement: not only is the Indian "nuclear bomb lobby" not in any hurry to produce the largest possible arsenal that it is often accused of desiring, it is in fact separating far less weapons-grade plutonium than it could technically through its current reprocessing facilities—a detail that cannot be explained away simply due to the age and condition of the Trombay reprocessing plant.

Lest it be imagined that the slow pace of plutonium production is justified by some accelerated Indian activity relating to uranium enrichment, nothing could be further from the truth. The Indian Rare Earths uranium enrichment plant at Rattehalli in Mysore has been plagued by technical problems since its inception and represents one of the most sorry stories of mismanagement in the Indian nuclear program. In any event, the enriched uranium produced in this facility is intended primarily for fuelling the reactors associated with India's nuclear submarine program and not for developing a new series of uranium-235-based fission weapons. Enriched uranium would obviously have great utility for thermonuclear weaponry, which India is known to be avidly pursuing, but all the information openly available suggests that India's thermonuclear designs still emphasize plutonium-based devices supplemented as necessary by deuterium, tritium, and lithium deuteride.[16]

The bottom line, therefore, remains unchanged: there is no evidence so far that India is seeking to build the biggest nuclear arsenal possible. The data adduced above suggests that New Delhi is in fact producing far less weapons-grade plutonium than it is capable of, given its current capacity. Consequently, the notion that India seeks to inexorably expand its nuclear arsenal does not stand scrutiny because New Delhi's weapons program even today is not operating at its maximum potential.

Is the Indian Nuclear Arsenal Stymied by a Shortage of Natural Uranium?

It is possible for critics to agree with all the propositions advanced thus far and still contend that the low rate of production of weapons-grade plutonium has less to do with India's political proclivities—as suggested in this report and elsewhere—and more to do with its limited stocks of natural uranium, which Indian policy makers have clearly appreciated since the country's independence. Senator Sam Nunn captured this perspective succinctly when he argued that "India's well-known uranium shortage may have been a significant constraint to India's nuclear weapons potential; however, by removing the barriers so that the U.S. and others can provide fuel for India's civilian reactors, India will no longer be forced to choose whether its own limited uranium stocks should be used to support its civilian nuclear program or its nuclear weapons program."[17] The data, however, do not bear this claim out either and to appreciate this fact, India's constraints regarding natural uranium must be understood in proper perspective.

The official estimate of India's natural uranium reserves provided by the Indian Department of Atomic Energy (DAE) stands at 78,000 tons of uranium. Ideally, such data would be disaggregated by cost ranges, identifying the size of the reserve as a function of the dollar cost per kilogram of uranium. Information at this level of precision is hard to come by in both Indian and international sources. The most authoritative foreign sources, namely the OECD Nuclear Energy Agency–International Atomic

Energy Agency's (IAEA) "red book," classifies India's natural uranium holdings as consisting of 54,636 tons of "reasonably assured resources" (RAR); 25,245 tons in estimated additional resources (EAR-Category I [in situ resources]); 15,488 tons in undiscovered conventional resources (EAR-Category II); and, finally, 17,000 tons in speculative resources (SR), for a grand total of 112,369 tons of uranium reserves without any assigned cost ranges.[18] If, for purposes of analysis, attention is restricted mainly to those reserves that are assumed to be recoverable with high confidence, meaning the RAR and EAR-I categories, then, India's holdings of natural uranium would total 79,881 tons, close to the figure routinely cited in DAE publications. Other international sources, such as the World Energy Council, the World Information Service on Energy (WISE) Uranium Project, and the IAEA's own surveys of India's nuclear industry generally agree with this estimate.[19]

The fact that India's recoverable uranium holdings consist of at least 78–79,000 tons of uranium suggests that a shortage of natural uranium cannot be the reason for why New Delhi has not enlarged the size of its nuclear arsenal in the manner presumed by many of its critics. Table 1 captures the amount of natural uranium that India's two research reactors, CIRUS and Dhruva, would require as inputs if they were to produce weapons-grade plutonium at various capacity factors (or plant load factors, as they are alternatively called) reasonable for the age and the condition of these two reactors and at alternative burnup values relevant to the production of weapons-grade plutonium. Most of the literature suggests that a burnup of 1,000 megawatt days per metric ton of uranium (MWD/MTU) is necessary for producing weapons-grade plutonium, that is, plutonium containing an isotopic content of at least 94 percent plutonium-239, but the table below also includes calculations incorporating higher and lower burnups of 1400 MWD/MTU and 665 MWD/MTU as well for purposes of comparison.

The information revealed by the calculations above is critical: it suggests that both CIRUS and Dhruva, when operating at relatively high capacity factors (0.70 and 0.75 respectively) and at the standard burnup level of 1,000 MWD/MTU necessary for the production of weapons-grade plutonium, do not use more than 38 metric tons of natural uranium (MTU) annually when producing an output of some 33 kilograms of weapons-grade material. If the more realistic capacity factors of 0.50 for CIRUS and 0.65 for Dhruva are assumed with the same burnup levels, then the two reactors combined use only some 31 MTU to produce an output of some 27 kilograms of weapons-grade plutonium annually. Even if, for purposes of argument, it is assumed that CIRUS and Dhruva operate at their highest capacity factors and at the lowest practical burnup levels of 665 MWD/MTU—in order to maximize the purity of the plutonium produced—both reactors would not consume more that 57 MTU, while producing some 35 kilograms of weapons-grade plutonium annually. If the more reasonable capacity factors of 0.50 for CIRUS and 0.65 for Dhruva are assumed with

TABLE 1. *Estimated Amounts of Uranium Required for Producing Weapons-Grade Plutonium at Various Capacity Factors in India's Research Reactors*

Reactor	Capacity Factor (%)	Thermal Power (MW)	Thermal Energy Output (MWD/yr)	Average Discharge Burnup (MWD/MTU)	Fuel Requirement (MTU/yr)	WGPu per year (kg)[a]
CIRUS						
	40	40	5,840	665	8.8	5.4
	40	40	5,840	1,000	5.8	5.1
	40	40	5,840	1,400	4.2	4.9
	50	40	7,300	665	11.0	6.7
	50	40	7,300	1,000	7.3	6.4
	50	40	7,300	1,400	5.2	6.1
	70	40	10,220	665	15.4	9.4
	70	40	10,220	1,000	10.2	9.0
	70	40	10,220	1,400	7.3	8.7
Dhruva						
	65	100	23,725	665	35.7	21.8
	65	100	23,725	1,000	23.7	20.9
	65	100	23,725	1,400	16.9	19.9
	75	100	27,375	665	41.2	25.2
	75	100	27,375	1,000	27.4	24.1
	75	100	27,375	1,400	19.6	23.0

[a] Pu production is calculated at 1 kg/1000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MW, megawatt. MWD/yr, megawatt days per year. MWD/MTU, megawatt days per metric ton of uranium. MTU/yr, metric ton of uranium per year. WGPu, weapons-grade plutonium. Kg, kilogram.

the same low burnup levels of 665 MWD/MTU, then the consumption of natural uranium inputs actually drops to some 47 MTU for both reactors, for an output of some 29 kilograms of weapons-grade plutonium annually.

These data clearly underscore the strength of Secretary Rice's contention when she told the Senate Foreign Relations Committee that "it would need a very small percentage of . . . [India's uranium reserves to support] . . . the military nuclear side [of its program]. And in fact, we do not believe that the absence of uranium is really the constraint on the [Indian] nuclear weapons program."[20] Table 1 establishes conclusively that the amount of natural uranium necessary to produce weapons-grade plutonium at roughly the rates India has been producing it since 1998 is so small relative to India's uranium reserves that the decision to maintain a small weapons stockpile arguably remains primarily a product of New Delhi's political choices rather than the size of its natural resources.

The amount of feedstock necessary to fuel India's pressurized heavy water reactors (PHWRs) only confirms this proposition even more abundantly. India currently has sixteen power reactors operational, of which fourteen are PHWRs fuelled from the country's indigenous reserves of natural uranium. (The remaining two, Tarapur 1 and 2, are boiling water reactors (BWRs) that rely on imported low enriched uranium for fuel.) Ten of the fourteen PHWRs are 220 MWe units, with the remainder of assorted ratings: The oldest, Rajasthan 1, [RAPS-1 IN TABLE 2] although rated at 100 MWe, has for all practical purposes ceased to be operational (the DAE listed its capacity factor in 2005–2006 as 0); the second, Rajasthan 2, [RAPS-2 IN TABLE 2] is rated at 200 MWe; and the newest reactors, Tarapur 3 and 4, which are also the largest indigenous PHWRs constructed in India, are both rated at 540 MWe.[21] These variations in maximum electrical output imply that their thermal power is varied as well, ranging from 690 MWt for the Rajasthan 2 reactor, through 760 MWt for the ten reactors of the 220 MWe series, to 1,860 MWt for the new larger PHWRs at Tarapur. The thermal power in each instance is derived from the reasonable assumption that the thermal efficiency of all these reactors is approximately 29 percent. The fuel requirements for each of these reactors are calculated in Table 2 on the assumption that producing electricity requires an average discharge burnup of 6,700 MWD/MTU. It is also assumed that all these reactors operate at a 0.73 capacity factor, which is the average actual operating performance of the Rajasthan (except RAPS-1), Madras, Narora, Kakrapar, and Kaiga reactors in 2005–2006.

The calculations in Table 2 suggest that compared with the fuel requirements associated with India's research reactors operating at burnup levels of 1,000 MWD/MTU—some 31–38 MTU annually—India's power reactors require some 478 metric tons of indigenous fuel every year—or, in other words, anywhere between thirteen to fifteen times the amount of fuel for producing electricity as that required for the production of nuclear weaponry. It must be noted, however, that these figures are much higher than the actual feedstock annually consumed by India's PHWRs historically: the annual fuel requirement of 478 MTU recorded in Table 2 is substantially influenced by the fact that one of the two largest Indian reactors, TAPS-3, has recently gone critical and is treated as already operational for purposes of analysis here and, furthermore, by the assumption that all Indian PHWRs enjoy a constant 0.73 capacity factor across time and across all facilities. If the past power production of India's 220 MWe reactors is any guide, it is likely that much smaller quantities of fuel were required for their reloading on an annual basis. Few, if any, of the 220 MWe CANDU clones required more than 27–29 MTU per year, for a total of some 324–348 MTU annually (assuming RAPS-1 and RAPS-2 are also included).

TABLE 2. *Estimated Fuel Requirements for Operational Pressurized Heavy Water Reactors*

Reactor	MWe	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)[a]	Annual Fuel Requirement (MTU/yr)	Date of Commercial Operation	Notional Decommissioning Date[b]	Fuel Needed 2006–Decommissioning (MTU)
RAPS-1 Rawatbhata, Rajasthan[c]	100	350	93,258	0.00	December 1973	?	0.00
RAPS-2 Rawatbhata, Rajasthan	200	690	183,759	27.43	April 1981	2011	137.13
RAPS-3 Rawatbhata, Rajasthan	220	760	202,502	30.22	June 2000	2030	725.38
RAPS-4 Rawatbhata, Rajasthan	220	760	202,502	30.22	December 2000	2030	725.38
MAPS-1 Kalpakkam, Tamilnadu	220	760	202,502	30.22	January 1984	2014	241.79
MAPS-2 Kalpakkam, Tamilnadu	220	760	202,502	30.22	March 1986	2016	302.24
NAPS-1 Narora, Uttar Pradesh	220	760	202,502	30.22	January 1991	2021	453.36
NAPS-2 Narora, Uttar Pradesh	220	760	202,502	30.22	July 1992	2022	483.59
KAPS-1 Kakrapar, Gujarat	220	760	202,502	30.22	May 1993	2023	513.81
KAPS-2 Kakrapar, Gujarat	220	760	202,502	30.22	September 1995	2025	574.26
KAIGA-1 Kaiga, Karnataka	220	760	202,502	30.22	November 2000	2030	725.38
KAIGA-2 Kaiga, Karnataka	220	760	202,502	30.22	March 2000	2030	725.38
TAPS-3 Tarapur, Maharashtra[d]	540	1,860	495,597	73.97	May 2006	2036	2,219.09
TAPS-4 Tarapur, Maharashtra	540	1,860	495,597	73.97	September 2005	2035	2,145.12
Total				**478**			**9,972**

[a] Assumes a capacity factor of 73 percent.

[b] Assumes 30-year reactor life.

[c] Reactor virtually non-operational.

[d] TAPS-3 went critical in May 2006, but is treated as operational for calculation purposes in this report.

Notes. Reactors identified in shaded rows have been offered for safeguards in India's March 2006 separation plan. MWe, megawatt-electric. MW, megawatt. MWD/yr, megawatt days per year. MTU/yr, metric ton of uranium per year. MTU, metric ton of uranium.

In any event, if the approximate total fuel requirements from the current year 2006 to the end of the notional 30-year life of every Indian PHWR currently operational is calculated (see Table 2), India is likely to require some 9,972 MTU to keep all its existing nuclear power plants that rely on indigenously mined natural uranium operational. If the total fuel requirements (the initial fuel loading plus the fresh fuel needed over a 30-year notional life cycle) relating to all India's PHWRs currently under construction and reliant upon indigenous uranium is calculated on the same aforementioned assumptions, then India is likely to need an additional 3,730 MTU to sustain its currently envisaged program (Table 3). All told, the Indian nuclear power program will require about 13,702 MTU to ensure uninterrupted production of electricity during the remainder of the notional 30-year lifetime of all the PHWRs currently operational and the full nominal life cycle of those under construction. Admittedly, these figures are still approximations and, most likely, err on the high side, but they nevertheless provide a reasoned estimate of the magnitude of natural uranium feedstock that will be necessary to sustain the PHWRs in the Indian nuclear power program as it is currently configured.

If the fuel requirements of India's two research reactors are added to this total, the number increases marginally. Because CIRUS will be decommissioned in 2010 under the Indian separation plan, it will consume—assuming capacity factors between 0.5–0.7 and a burnup level of 1,000 MWD/MTU—somewhere between 29–41 MTU in total during the next four years. Assuming Dhruva is operational for a total of 30 years, it will consume—assuming capacity factors between 0.65–0.75 and a burnup level of 1,000 MWD/MTU—somewhere between 214–246 MTU in total during this final decade of its operational life. If the government of India were to construct a new 100-MWt research reactor for producing weapons-grade plutonium to replace CIRUS, a reactor that becomes operational hypothetically in 2011, this "Dhruva-II" facility—assuming capacity factors between 0.65–0.75 and burnup levels of 1,000 MWD/MTU similarly hold for this reactor as well—would need between 695–801 MTU in total for its annual throughput over a period of 30 years.[22] The primary weapons-grade plutonium producing facilities in the Indian nuclear estate would thus require a total of some 938–1088 MTU to sustain New Delhi's strategic program during their operational lives. During this period, these facilities would be able to produce some 840–976 kilograms of weapons-grade plutonium that, assuming 6 kilograms for each simple fission device, results in an aggregate inventory of some 200–250 weapons if India's current stockpile is included. An arsenal of this size, which many in India believe would suffice for its deterrence requirements, can therefore be produced through its dedicated research reactors alone using a tiny fraction—about one-fiftieth—of India's reasonably assured reserves of uranium.

These data illustrate several facts that are often overlooked by those adducing even the minimalist critique of the U.S.-India civil nuclear agreement. First, the total

TABLE 3. ***Estimated Fuel Requirements for Pressurized Heavy Water Reactors Currently under Construction***

Reactor	MWe	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)[a]	Annual Fuel Requirement (MTU/yr)	Scheduled Date of Commercial Operation	Notional Decommissioning Date[b]	Total Fuel Needed Until Decommissioning (MTU)[c]
RAPS-5 Rawatbhata, Rajasthan	220	760	202,502	30.22	2007	2037	932.50
RAPS-6 Rawatbhata, Rajasthan	220	760	202,502	30.22	2008	2038	932.50
KAIGA-3 Kaiga, Karnataka	220	760	202,502	30.22	2007	2037	932.50
KAIGA-4 Kaiga, Karnataka	220	760	202,502	30.22	2007	2037	932.50
Total				**121**			**3,730**

[a] Assumes a 73 percent capacity factor.

[b] Assumes 30-year reactor life.

[c] Includes an initial loading of 56 MTU.

Notes. Reactors identified in shaded rows have been offered for safeguards in India's March 2006 separation plan. MWe, megawatt-electric. MW, megawatt. MWD/yr, megawatt days per year. MTU/yr, metric ton of uranium per year. MTU, metric ton of uranium.

inventory of natural uranium required to sustain the PHWRs associated with both the current power program and the weapons program over the entire notional lifetime of the reactors involved—some 14,640–14,790 MTU—is well within even the most conservative valuations of India's reasonably assured reserves of some 54,636 tons of uranium. Even if these reserves are downscaled to account for extraction and processing losses, the resulting value of the reasonably assured assets—some 40,980 tons as estimated by the OECD-IAEA "red book"[23]—more than suffices to sustain the current Indian nuclear program in principle for a long time to come, as far as both its electricity and its weapons components are concerned. If the additional uranium resources in the Category I and II classifications, not to mention the speculative resources, were thrown into the mix, India's ability to meet its nuclear fuel requirements for both electricity and weapons would be even more unquestionable *a fortiori*.

Second, the demands placed on India's indigenous natural uranium deposits by its electricity needs and by its weapons program are simply asymmetrical. Contrary to the fears expressed both by private critics and legislators in the U.S. Congress, the Indian nuclear weapons program is small and the fuel requirements necessary to support that program are commensurately small as well: as previous calculations have established, India's weapons program, which is based principally on its two research reactors, characteristically requires some 31–38 MTU annually (or 57 MTU at most), in contrast to its power reactors, which require somewhere around 478 MTU every year for the production of electricity. Equally important, however, is the fact that even if additional fuel supplies were available freely—as, for example, even critics who hold the minimalist view argue would be the case if the U.S.-Indian nuclear cooperation agreement were consummated—they would be of no effective use to India's research reactors because both CIRUS and Dhruva, in their fuel requirements calculated above, are assumed to be operating at high capacity, given their age, their maintenance needs, and the inherent operational limitations imposed by their design.

Third, the only circumstances under which India's natural uranium reserves approach insufficiency for its national purposes are when it is assumed that many of its PHWRs will be used for the production of weapons-grade plutonium. Consider the following example, which presumes that a single 220 MWe PHWR is committed to the production of weapons-grade plutonium rather than the production of electricity. As noted previously (with all the appropriate caveats), it will be assumed that this 220 MWe PHWR has already begun its commercial life with an initial fuel load of 56 MTU. Furthermore, assuming that such a reactor is used exclusively for the production of electricity, it would require an average assembly discharge burnup of some 6,700 MWD/MTU. Although burnups at this level are appropriate for producing power, the production of weapons-grade plutonium requires considerably lower burnup, which for purposes of analysis here is assumed to take three alternative values: 665 MWD/MTU, 1,000 MWD/MTU, and 1,400 MWD/MTU. These burnup levels are mapped in Table 4 against two different capacity factors, 0.73 and 0.79—the former deriving from the actual performance of Indian 220 MWe units referred to earlier, and the latter merely a fictional value that presumes much better than historical performance—to assess the amount of natural uranium needed for both the production of weapons-grade plutonium and the production of electricity.

The results in this table corroborate the expectation that producing weapons-grade plutonium *in a 220 MWe PHWR* requires much larger quantities of natural uranium fuel than would be required by the same reactor when used to produce electricity. Thus, for example, if the reactor is assumed to operate at a capacity factor of 0.73 and at a 1,000 MWD/MTU burnup level appropriate to producing weapons-grade plutonium, it would require 203 MTU per year compared with the approximately 30 metric tons of natural uranium required to produce electricity. Similarly, if the reactor is assumed to operate at the better-than-average capacity factor of 0.79 but at the same 1,000 MWD/MTU burnup level, it would require some 219 MTU annually compared with the mere 33 MTU or so necessary to produce electricity. If the

TABLE 4. ***Comparison of Notional 220 MWe Reactor Fuel Requirements in Production of Weapons-Grade Plutonium versus Electricity***

Weapons-Grade Plutonium					
Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Average Discharge Burnup (MWD/MTU)	Fuel Requirement (MTU/yr)	WGPu per year (kg)[a]
73	760	202,502	665	304.51	186.30
73	760	202,502	1,000	202.50	178.20
73	760	202,502	1,400	144.64	170.10
79	760	219,146	665	329.54	201.61
79	760	219,146	1,000	219.15	192.85
79	760	219,146	1,400	156.53	184.08
Electricity					
Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Average Discharge Burnup (MWD/MTU)	Fuel Requirement (MTU/yr)	WGPu per year (kg)
73	760	202,502	6,700	30.22	NA
79	760	219,146	6,700	32.71	NA

[a] Plutonium production is calculated at 1 kg/1,000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MWe, megawatt-electric. WGPu, weapons-grade plutonium. MW, megawatt. MWD/yr, megawatt days per year. MWD/MTU, megawatt days per metric ton of uranium. MTU/yr, metric ton of uranium per year. Kg, kilogram. NA, not applicable.

eight PHWRs that India has currently kept outside of safeguards were thus used to produce weapons-grade plutonium exclusively, then, depending on the capacity factors involved and the burnup levels, they could require anywhere from 2,206 MTU to 3,590 MTU annually for many years to come (Table 5).

Calculations earlier in this report had suggested that if all Indian PHWRs were used solely for power production, with its two research reactors alone (two currently operational reactors, CIRUS and Dhruva, plus one other hypothesized 100-MWt replacement for CIRUS) restricted to the production of weapons-grade plutonium, the total inventory of natural uranium required to sustain both the power and the weapons program over the entire notional lifetime of the reactors involved—some 14,640–14,790 MTU—would lie well within the reasonably assured Indian uranium reserve of 54,636 tons (or some 40,980 tons net). If, however, the eight PHWRs withheld by India from safeguards were committed solely to the production of weapons-grade plutonium for the duration of their entire lives, in addition to the two research reactors already dedicated to this task, then, the Indian requirement for natural uranium would increase to 56,098–90,854 MTU, depending on the assumptions made about capacity factors and burnup levels. These totals are derived by adding the fuel requirements associated with the three research reactors referred to earlier in this paragraph (938–1,088 MTU) with the fuel requirements associated with the eight unsafeguarded PHWRs over the duration of their remaining lives (55,160–89,766 MTU, the totals calculated in Table 5). This enormous figure of 56,098–90,854 MTU implies that India's uranium requirements for weapons production would compete, for the first time in this analysis, with its requirements for electricity production but, because these needs would materialize over a period of three decades, the tradeoff between electricity and weapons production would still not be manifest for many years. In any case, these data suggest that India's total natural uranium feedstock needs reach levels that exceed its reasonably assured uranium deposits only *on the fantastic assumption that India would commit all its unsafeguarded PHWRs exclusively to the production of weapons-grade plutonium for the entire duration of their operational lives.*

Critics of the U.S.-India civil nuclear agreement who are concerned about the "fungibility" of fuel—meaning that imported fuel for India's safeguarded reactors would liberate its domestic natural uranium reserves to be used in its unsafeguarded PHWRs to expand the size of its nuclear arsenal—ought to be paid heed only if it is believed that India would in fact use its eight unsafeguarded PHWRs to produce weapons-grade plutonium in the manner suggested by the calculations in Table 5 *because this scenario alone represents a nuclear weapons option that would otherwise be beyond India's reach in the absence of the U.S.-Indian civilian nuclear cooperation agreement.* There are at least three important reasons, however, why this scenario is unlikely to materialize.

To begin with, using PHWRs to produce weapons-grade plutonium imposes much higher costs and considerably more complex technical burdens on India. The fuel elements used in India's PHWRs consist of uranium dioxide pellets in zircalloy tubes, which are costlier to produce than the aluminum clad fuel tubes used in its research reactors. Separating weapons-grade plutonium from uranium oxide in zircalloy tubes is also technically more burdensome than reprocessing aluminum clad metallic uranium fuel elements. Using CANDU-type power reactors to produce weapons-grade plutonium would thus require India to bear the higher front-end costs of using expensive uranium dioxide fuel bundles to begin with, and then absorb the higher back-end technical (and cost) burdens associated with reprocessing these elements. It is, of course, possible to argue that an India determined to increase its weapon stockpile would bear any cost necessary, but the previous record of the Indian DAE fails to bear this assertion out either. If anything, DAE operators have been highly cost conscious, and operating on tight budgets and narrow margins, they have consistently focused on maximizing power production at the lowest possible expense. This is because India's national leadership, in the face of the country's great

TABLE 5. *Estimated Uranium Requirements for Pressurized Heavy Water Reactors Used Exclusively to Produce Weapons-Grade Plutonium*

Reactor	MWe	Date of Commercial Operation	Notional Decommissioning Date[a]	MWt	Capacity Factor (%)	Fuel Requirements for Average Discharge Burnup 1,000 MWD/MTU per Year (MTU)	Fuel Requirements for Average Discharge Burnup 1,000 MWD/MTU over Remaining Life of the Reactor (MTU)	Fuel Requirements for Average Discharge Burnup 665 MWD/MTU per Year (MTU)	Fuel Requirements for Average Discharge Burnup 665 MWD/MTU over Remaining Life of the Reactor (MTU)
MAPS-1 Kalpakkam, Tamilnadu	220	January 1984	2014	760	73	202.50	1,620.02	304.51	2,436.11
			2014	760	79	219.15	1,753.17	329.54	2,636.34
MAPS-2 Kalpakkam, Tamilnadu	220	March 1986	2016	760	73	202.50	2,025.02	304.51	3,045.14
			2016	760	79	219.15	2,191.46	329.54	3,295.43
KAIGA-1 Kaiga, Karnataka	220	November 2000	2030	760	73	202.50	4,860.05	304.51	7,308.34
			2030	760	79	219.15	5,259.50	329.54	7,909.03
KAIGA-2 Kaiga, Karnataka	220	March 2000	2030	760	73	202.50	4,860.05	304.51	7,308.34
			2030	760	79	219.15	5,259.50	329.54	7,909.03
KAIGA-3 Kaiga, Karnataka	220	2007	2037	760	73	202.50	6,277.56	304.51	9,439.94
			2037	760	79	219.15	6,793.53	329.54	10,215.83
KAIGA-4 Kaiga, Karnataka	220	2007	2037	760	73	202.50	6,277.56	304.51	9,439.94
			2037	760	79	219.15	6,793.53	329.54	10,215.83
TAPS-3 Tarapur, Maharashtra	540	May 2006	2036	1,860	73	495.60	14,867.91	745.26	22,357.76
			2036	1,860	79	536.33	16,089.93	806.51	24,195.38
TAPS-4 Tarapur, Maharashtra	540	September 2005	2035	1,860	73	495.60	14,372.31	745.26	21,612.50
			2035	1,860	79	536.33	15,553.60	806.51	23,388.87
Total fuel requirements for all 8 unsafeguarded PHWRs operating at 73 percent capacity factor producing only WGPu						**2,206**	**55,160**	**3,318**	**82,948**
Total fuel requirements for all 8 unsafeguarded PHWRs operating at 79 percent capacity factor producing only WGPu						**2,388**	**59,694**	**3,590**	**89,766**

[a] Assumes 30-year reactor life.

Notes. MWe, megawatt (electric). MWt, megawatt (thermal). MTU, metric ton of uranium. MWD/MTU, megawatt days per metric ton of uranium. PHWR, pressurized heavy water reactors. WGPu, weapons-grade plutonium.

poverty and steep electricity deficits, demand no less, and equally importantly, because the DAE's own institutional interests require maximization of electricity production at the lowest possible cost, if for no other reason than to prove the attractiveness of nuclear electricity vis-à-vis other indigenous sources of energy for reasons of bureaucratic politics.

Furthermore, since producing weapons-grade plutonium in a PHWR *necessarily* requires a reduction in the average discharge burnup level, there is a consequential tradeoff between the production of weapons-grade materials and the production of electricity—*assuming normal refueling rates.* If, for example, a PHWR that is ordinarily dedicated to the production of electricity were used for the production of weapons-grade plutonium instead, its average discharge burnup must be reduced from some 6,700 MWD/MTU to about the 1,000 MWD/MTU necessary to produce the appropriate weapons-grade materials. Assuming normal refueling rates, such an operating regime would result in a reduction in electricity production by about 85 percent. If a PHWR is used to produce weapons-grade plutonium at even lower burnup levels—for example, the 665 MWD/MTU necessary to produce higher quality weapons-grade materials—and on the assumption that normal refueling rates continue to obtain, electricity production drops by 90 percent, meaning that the reactor produces little or no power for all practical purposes.[24] The sharp diminution in electricity production that occurs when a PHWR is dedicated to the production of weapons-grade materials is not difficult to understand: producing weapons-grade plutonium requires reactor operators to sharply reduce the thermal output of the system, which in turn affects the production of steam and, by implication, the amount of electricity that can be produced. Given India's acute power shortages, this is a tradeoff that the nation's political leadership has judged it cannot afford and, consequently, the Indian DAE has never countenanced the idea of dedicating its unsafeguarded PHWRs to the full-bore production of weapons-grade plutonium in the manner imagined by the most fervid critics of the U.S.-India civil nuclear agreement.

Finally, and perhaps most importantly, the critics' fears that India's eight unsafeguarded PHWRs would be used exclusively for the production of weapons-grade plutonium can be discounted for weighty technical reasons. A quick perusal of Table 4 indicates that using a 220 MWe PHWR to produce weapons-grade plutonium (*versus* producing electricity) requires close to five times the amount of fuel for the former task, if a discharge burnup of 1,400 MWD/MTU and a capacity factor of 0.73 is assumed; if even lower burnup levels are postulated (while varying the capacity factors), the amount of fuel consumed could increase to between more than six to more than ten times that required for the production of electricity. Refueling the reactor at these rates—in accordance with a fast fuelling regime necessary to produce weapons-grade plutonium in a PHWR—would be infeasible, given the complex electromechanical character of the two refueling machines that are normally operational in a CANDU-type facility. When dedicated to the production of electricity, the two refueling machines in a 220 MWe CANDU reactor on average "visit" two of the reactor's 306 fuel channels daily, where they do a "four-bundle shift" inserting four fresh fuel bundles, while removing an identical number of spent bundles each day. Even at these routine levels of performance, the refueling machines, which operate in zones of high radioactivity, often break down, which is why every reactor is equipped with a built-in spare refueling machine.

If an Indian CANDU-type power reactor is now dedicated entirely to the production of weapons grade-plutonium—the scenario feared by many critics of the U.S.-India nuclear agreement—the refueling machines would have to operate at nearly *five* times their normal intensity, levels for which they were never designed.[25] This limitation is not surprising, because CANDU reactors of the kind operated by India are intended for the production of electricity where slow refueling, involving relatively small quantities of fuel inputs, are the norm. Committing these reactors to a different operating regime, where fast fueling involving large amounts of natural uranium is necessary, would tax the refueling machines beyond their design limits, sharply increasing their probability of breakdown, and rendering the reactor itself inutile both for the production of weapons-grade materials and the production of electricity. There is another problem as well: manufacturing the large quantities of power reactor fuel that would be required if India's PHWRs were employed for the production of weapons-grade plutonium would exceed the current capacity of India's Nuclear Fuel Complex and would, therefore, require the construction of a costly new facility.[26] The strategy of using PHWRs to produce weapons-grade plutonium in the manner imagined by many opponents of the civil nuclear cooperation agreement would consequently be very burdensome for India. Not surprisingly, then, the Indian DAE has advocated, and continues to advocate, the construction of a new 100-MWt research reactor, which can be dedicated to the production of weapons-grade plutonium after CIRUS is decommissioned, rather than adopting the counterproductive regime feared by critics of the U.S.-India nuclear agreement, namely using unsafeguarded PHWRs for the production of weapons-grade materials required by the country's nuclear arsenal.[27]

Confronted by the problems discussed here, the critics of the U.S.-India nuclear agreement could postulate that India's unsafeguarded reactors could be used with less than the full core devoted to the production of weapons-grade plutonium. Such an operating regime is technically possible, but it may not be very appealing to Indian nuclear operators because it again confronts them with unpalatable alternatives: If the managers of a 220 MWe reactor seek to avoid a fast fuelling regime that causes fuelling machine breakdowns and thus settle for less-than-full core production of weapons-grade materials, they would be confronted by a steep, albeit less than proportionate, decline in electricity production; if they seek to compensate for the shortfall in electricity production—which remains India's crying need and the *raison d'etre* justifying the country's large investment in nuclear power generation—by increasing the refueling rate, they return full circle to the problems caused by fast fuelling, namely the risk to the fueling machines, which could not only undermine the output of weapons-grade materials and electricity production but also endanger the safe operation of the reactor itself. Because minimizing cost and maximizing electricity production remain the holy grail of the Indian nuclear power program, the DAE is unlikely to view partial core production of weapons-grade plutonium in its PHWRs as the solution to its strategic goals. These objectives, which require a modest inventory of fissile materials to begin with, are best served by small research reactors dedicated to the production of weapons-grade plutonium, such as Dhruva, and so it is very likely that Indian nuclear managers will continue to push for a replacement "Dhruva-II" reactor for CIRUS, rather than use their existing PHWRs to produce weapons-grade materials in either a full core or a partial core mode at the cost of a substantial decline in electricity production.[28]

Despite this conclusion, Table 6 calculates the fuel requirements for a notional 220 MWe reactor operated at the same capacity factors as before, but assuming only one-fourth of the core is used for the production of weapons-grade plutonium, to test whether the use of PHWRs in such a regime would impose unacceptable burdens on India's existing natural uranium reserves. The data indicate that when a 220 MWe PHWR is operated in this manner, the amount of uranium required to fuel its operations drops dramatically compared with the results detailed in Table 4. When operated at a 0.73 capacity factor with a discharge burnup of 1,000 MWD/MTU in the one-fourth of the core used to produce WGPu, the reactor uses some 73 MTU per year; if operated at the higher capacity factor of 0.79, but at the same burnup levels, the reactor requires some 79 MTU annually. Operating a PHWR with even this small fraction of the core dedicated to producing WGPu would require the refueling machines to operate at about two and a half times their normal operating intensity. It would be surprising if the refueling machines in India's CANDU-type reactors can operate at such levels continuously.

This fact notwithstanding, if India sought to produce weapons-grade plutonium in a PHWR, using one-fourth of the reactor core to do so would appear to be the most attractive option technically compared with many other alternatives. For one thing, the shape of the Indian 220 MWe PHWR's core elegantly lends itself to the production of weapons-grade plutonium in the outer periphery: the 309 pressure tubes are arranged in a roughly circular array that has a square, 15 x 15 center and then, on each side of the square, a row of 11, a row of 7, and finally a row of 3 tubes. Thus there are 84 (that is, 4 x [11+7+3]) tubes on the edge of the core—roughly one-fourth of the total—that could be used to produce weapons-grade plutonium in a region where the neutron flux and, consequently, the power density is lowest.

Using one-fourth of the core to produce weapons-grade plutonium avoids many of the distortions in reactivity distribution that could materialize in other scenarios, which posit higher fractions of the core being used to produce weapons-grade materials. Furthermore, the stress on the refueling machines, although still significant, is lowest in this scenario compared with alternatives that involve one-third or one-half of the core being used for purposes of producing weapons-grade plutonium. Finally, although the trade-off in electric power sacrificed for the production of weapons-grade materials is noteworthy in this regime, it is lower than in alternative regimes, which presume the use of, for example, one-third of the reactor's core for producing weapons-grade plutonium. For all these reasons, *if* India's nuclear managers decided to produce weapons-grade plutonium in their 220 MWe PHWRs, they are most likely to use the one-fourth core option because it represents the technically optimal choice despite its attendant drawbacks. Assessing the fuel consumption of the reactor in this scenario, therefore, becomes the best test of whether the fungibility argument bandied by the critics of the U.S.-India nuclear cooperation agreement has any merit. Table 6 provides the critical pieces of information necessary to answer this question, whereas Table 7 extends the analysis to the one-third core scenario for comparison.

These results offered in Table 6 and extended in Table 8 have enormous significance insofar as they undermine the plausibility of the fungibility argument advanced by the critics of the U.S.-India nuclear agreement. Table 8 shows that if all the eight unsafeguarded Indian reactors were used in the most reasonable regime imaginable for the production of weapons-grade plutonium—meaning that, for the sake of argument, one-fourth of their cores were allocated to producing materials for bomb-making at capacity factors of 0.73 and 0.79 and at discharge burnup equivalents of 1,000 and 665 MWD/MTU respectively—the total amount of natural uranium required to run these facilities for the remaining duration of their notional 30-year lives would be somewhere between 19,965 and 29,124 MTU. If this total is added to the entire natural uranium fuel load required to run India's two research reactors dedicated to the production of weapons-grade plutonium over their entire life cycle—some 938–1088 MTU—the total amount of natural uranium required by India's dedicated weapons reactors and all its unsafeguarded PHWRs does not exceed 20,903–30,212 MTU over the remaining lifetime of these facilities. These results, when compared with the lowest estimates of India's known uranium reserves—40,980 tons net—should be sobering for those who articulate even minimalist versions of the critique of the U.S.-India civil nuclear agreement, because the calculations affirm clearly that if India chose to expand its nuclear arsenal in the most realistic way conceivable through the use of its PHWRs, *it would be able to do so entirely on the strength of its own resources and without relying on the supposed benefits of fungibility afforded by the Bush-Singh initiative.* Operating India's eight unsafeguarded PHWRs in such a regime would bequeath New Delhi with some 12,135–13,370 kilograms of weapons-grade

TABLE 6. *Comparison of Notional 220 MWe Reactor Fuel Requirements in Production of Weapons-Grade Plutonium Using One-Fourth Core versus Electricity*

Weapons-Grade Plutonium

Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Discharge Burnup in Fraction of Core Used to Produce WGPu (MWD/MTU)	Average Discharge Burnup in Remainder of Core (MWD/MTU)	Total Annual Fuel Requirement with 1/4 of Core Used for WGPu Production (MTU/yr)	WGPu Production in 1/4 of Core Used for WGPu Production (kg/yr)[a]	RGPu Production in Remainder of Core (kg/yr)
73	760	202,502	665	6,700	98.80	46.58	83.53
73	760	202,502	1,000	6,700	73.29	44.55	83.53
73	760	202,502	1,400	6,700	58.83	42.53	83.53
79	760	219,146	665	6,700	106.92	50.40	90.40
79	760	219,146	1,000	6,700	79.32	48.21	90.40
79	760	219,146	1,400	6,700	63.66	46.02	90.40

Electricity

Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Average Discharge Burnup in Entire Core (MWD/MTU)		Fuel Requirement (MTU/yr)		
73	760	202,502	6,700		30		
79	760	219,146	6,700		32.7		

[a] Plutonium production is calculated at 1 kg/1000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MWe, megawatt (electric). WGPu, weapons-grade plutonium. MW, megawatt. MWD/yr, megawatt days per year. MWD/MTU, megawatt days per metric ton of uranium. MTU/yr, metric ton of uranium per year. Kg/yr, kilograms per year. RGPu, reactor-grade plutonium.

TABLE 7. *Comparison of Notional 220 MWe Reactor Fuel Requirements in Production of Weapons-Grade Plutonium Using One-Third Core versus Electricity*

Weapons-Grade Plutonium							
Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Discharge Burnup in Fraction of Core Used to Produce WGPu (MWD/MTU)	Average Discharge Burnup in Remainder of Core (MWD/MTU)	Total Annual Fuel Requirement with 1/3 of Core Used for WGPu Production (MTU/yr)	WGPu Production in 1/3 of Core Used for WGPu Production (kg/yr)[a]	RGPu Production in Remainder of Core (kg/yr)
73	760	202,502	665	6,700	121.65	62.10	74.25
73	760	202,502	1,000	6,700	87.65	59.40	74.25
73	760	202,502	1,400	6,700	68.36	56.70	74.25
79	760	219,146	665	6,700	131.65	67.20	80.35
79	760	219,146	1,000	6,700	94.85	64.28	80.35
79	760	219,146	1,400	6,700	73.98	61.36	80.35
Electricity							
Capacity Factor (%)	Thermal Power (MW)	Annual Thermal Energy Output (MWD/yr)	Average Discharge Burnup in Entire Core (MWD/MTU)		Fuel Requirement (MTU/yr)		
73	760	202,502	6,700		30		
79	760	219,146	6,700		32.7		

[a] Plutonium production is calculated at 1 kg/1000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MWe, megawatt (electric). WGPu, weapons-grade plutonium. MW, megawatt. MWD/yr, megawatt days per year. MWD/MTU, megawatt days per metric ton of uranium. MTU/yr, metric ton of uranium per year. Kg/yr, kilograms per year. RGPu, reactor-grade plutonium.

TABLE 8. *Estimated Fuel Requirements for Pressurized Heavy Water Reactors Using One-Fourth Core for the Production of Weapons-Grade Plutonium*

Reactor	MWe	Date of Commercial Operation	Notional Decommissioning Date[a]	Thermal Power (MW)	Capacity Factor (%)	Fuel Requirement with 1/4 of Core Used for WGPu Production at 1,000 MWD/MTU over Remaining Life of the Reactor (MTU)	WGPu Produced in 1/4 Core at 1,000 MWD/MTU burnup over Remaining Life of Reactor (kg)[b]	Fuel Requirement with 1/4 of Core Used for WGPu Production at 665 MWD/MTU over Remaining Life of the Reactor (MTU)	WGPu Produced in 1/4 Core at 665 MWD/MTU burnup over Remaining Life of Reactor (kg)[b]
MAPS-1 Kalpakkam, Tamilnadu	220	January 1984	2014	760	73	586.35	356.40	790.37	372.60
			2014	760	79	634.54	385.70	855.34	403.23
MAPS-2 Kalpakkam, Tamilnadu	220	March 1986	2016	760	73	732.94	445.50	987.97	465.75
			2016	760	79	793.18	482.12	1069.17	504.04
KAIGA-1 Kaiga, Karnataka	220	November 2000	2030	760	73	1,759.05	1,069.21	2,371.12	1,117.81
			2030	760	79	1,903.63	1,157.09	2,566.01	1,209.69
KAIGA-2 Kaiga, Karnataka	220	March 2000	2030	760	73	1,759.05	1,069.21	2,371.12	1,117.81
			2030	760	79	1,903.63	1,157.09	2,566.01	1,209.69
KAIGA-3 Kaiga, Karnataka	220	2007	2037	760	73	2,272.10	1,381.06	3,062.70	1,443.84
			2037	760	79	2,458.85	1,494.58	3,314.43	1,562.51
KAIGA-4 Kaiga, Karnataka	220	2007	2037	760	73	2,272.10	1,381.06	3,062.70	1,443.84
			2037	760	79	2,458.85	1,494.58	3,314.43	1,562.51
TAPS-3 Tarapur, Maharashtra	540	May 2006	2036	1,860	73	5,381.30	3,270.94	7,253.76	3,419.62
			2036	1,860	79	5,823.59	3,539.78	7,849.96	3,700.68
TAPS-4 Tarapur, Maharashtra	540	September 2005	2035	1,860	73	5,201.92	3,161.91	7,011.97	3,305.63
			2035	1,860	79	5,629.47	3,421.79	7,588.29	3,577.33
Totals for all 8 unsafeguarded PHWRs operating at 73 percent capacity factor producing WGPu in 1/4 of the core						**19,965**	**12,135**	**26,912**	**12,687**
Totals for all 8 unsafeguarded PHWRs operating at 79 percent capacity factor producing WGPu in 1/4 of the core						**21,606**	**13,133**	**29,124**	**13,730**

[a] Assumes 30-year reactor life.

[b] Plutonium production is calculated at 1 kg/1000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MWe, megawatt (electric). MW, megawatt. MTU, metric ton of uranium. WGPu, weapons-grade plutonium. MWD/MTU, megawatt days per metric ton of uranium. MTU, metric ton of uranium. Kg, kilograms. PHWR, pressurized heavy water reactors.

TABLE 9. *Estimated Fuel Requirements for Pressurized Heavy Water Reactors Using One-Third Core for the Production of Weapons-Grade Plutonium*

Reactor	MWe	Date of Commercial Operation	Notional Decommissioning Date[a]	Thermal Power (MW)	Capacity Factor (%)	Fuel Requirement with 1/3 of Core Used for WGPu Production at 1,000 MWD/MTU over Remaining Life of the Reactor (MTU)	WGPu Produced in 1/3 Core at 1,000 MWD/MTU burnup over Remaining Life of Reactor (kg)[b]	Fuel Requirement with 1/3 of Core Used for WGPu Production at 665 MWD/MTU over Remaining Life of the Reactor (MTU)	WGPu Produced in 1/3Core at 665 MWD/MTU burnup over Remaining Life of Reactor (kg)[b]
MAPS-1 Kalpakkam, Tamilnadu	220	January 1984	2014	760	73	701.20	475.20	973.23	496.80
			2014	760	79	758.83	514.26	1,053.23	537.64
MAPS-2 Kalpakkam, Tamilnadu	220	March 1986	2016	760	73	876.50	594.01	1,216.54	621.01
			2016	760	79	948.54	642.83	1,316.53	672.05
KAIGA-1 Kaiga, Karnataka	220	November 2000	2030	760	73	2,103.60	1,425.61	2,919.70	1,490.41
			2030	760	79	2,276.50	1,542.79	3,159.68	1,612.91
KAIGA-2 Kaiga, Karnataka	220	March 2000	2030	760	73	2,103.60	1,425.61	2,919.70	1,490.41
			2030	760	79	2,276.50	1,542.79	3,159.68	1,612.91
KAIGA-3 Kaiga, Karnataka	220	2007	2037	760	73	2,717.15	1,841.42	3,771.28	1,925.12
			2037	760	79	2,940.48	1,992.77	4,081.25	2,083.35
KAIGA-4 Kaiga, Karnataka	220	2007	2037	760	73	2,717.15	1,841.42	3,771.28	1,925.12
			2037	760	79	2,940.48	1,992.77	4,081.25	2,083.35
TAPS-3 Tarapur, Maharashtra	540	May 2006	2036	1,860	73	6,435.36	4,361.25	8,931.98	4,559.49
			2036	1,860	79	6,964.30	4,719.71	9,666.12	4,934.25
TAPS-4 Tarapur, Maharashtra	540	September 2005	2035	1,860	73	6,220.85	4,215.88	8,634.25	4,407.51
			2035	1,860	79	6,732.15	4,562.39	9,343.91	4,769.77
Totals for all 8 unsafeguarded PHWRs operating at 73 percent capacity factor producing WGPu in 1/3 of the core						**23,875**	**16,180**	**33,138**	**16,916**
Totals for all 8 unsafeguarded PHWRs operating at 79 percent capacity factor producing WGPu in 1/3 of the core						**25,838**	**17,510**	**35,862**	**18,306**

[a] Assumes 30-year reactor life.

[b] Plutonium production is calculated at 1 kg/1000 MWD of thermal energy output multiplied by a correction factor based on burnup level.

Notes. MWe, megawatt (electric). MW, megawatt. WGPu, weapons-grade plutonium. MWD/MTU, megawatt days per metric ton of uranium. MTU, metric ton of uranium. Kg, kilograms. PHWR, pressurized heavy water reactors.

plutonium, which is sufficient to produce between 2,023–2,228 nuclear weapons over and above those already existing in the Indian arsenal. Although no Indian analyst, let alone a policy maker, has ever advocated any nuclear inventory that even remotely approximates such numbers, this heuristic exercise confirms that New Delhi has the capability to produce a gigantic nuclear arsenal while subsisting well within the lowest estimates of its known uranium reserves.

Even if the most skeptical critics of New Delhi's strategic intentions were to be accommodated on the presumption that "India's nuclear bomb lobby" had no other objectives but to maximize the production of weapons-grade materials through its unsafeguarded power reactors—a presumption that requires us to assume that India would use a more significant fraction of the cores (say, for purposes of illustration, one-third of the core in this instance) of its eight unsafeguarded reactors for producing weapons-grade plutonium—the total amount of natural uranium that would be needed for this purpose, assuming the same capacity factors and equivalent discharge burnups as before, would not exceed 23,875–35,862 MTU over the lifetime of all these facilities, as calculated in Table 9. When the fuel requirements of the two research reactors are added to these numbers, the total amount of fuel necessary to support the grandest Indian weapons production capacity imaginable is somewhere on the order of 24,818–36,950 MTU.[29] Not only is this well within the most conservative estimates of India's reasonably assured natural uranium reserves of 54,636 tons, it could even be satisfied by those lesser resources available—some 40,980 tons net—after extraction and processing losses are accounted for. Despite this fact, however, it would be virtually impossible for India's nuclear managers to overcome the refueling problems inherent in this operating regime since it assumes that the refueling machines operate at a significantly higher rate—three times faster than normal—continuously. If this problem could actually be overcome, and weapons-grade materials are produced according to the assumptions in this iteration, then India would be able to generate between 16,180 and 18,306 kilograms of weapons-grade plutonium, sufficient to add some 2,697–3,051 nuclear weapons to those modest numbers already existing in the Indian inventory. This excursus confirms once again that New Delhi has the capability to produce an enormous nuclear arsenal while still staying within the lowest estimates of its known uranium reserves.

Finally, and most devastatingly for the critics of the U.S.-India agreement and their shibboleths about fungibility, the grand total of India's natural uranium needs on even the most generous assumptions lie well within its known reserves of natural uranium: Assume, for instance, that the eight PHWRs India has withheld from safeguards are dedicated to producing weapons-grade plutonium at one-fourth core and that two research reactors are also used for exactly the same purpose, with only the remaining ten PHWRs (which have been offered up for safeguards) used for the production of electricity, the total natural uranium required to fuel all these reactors would be crudely speaking somewhere between 26,381 and 35,690 MTU over the remaining lives of all these facilities—a requirement that lies well within India's assured uranium reserves howsoever these are disaggregated.

The bottom line, therefore, is as simple as it is transparent: India has the indigenous reserves of natural uranium necessary to create the largest possible nuclear arsenal it may desire and, consequently, the U.S.-Indian civilian nuclear cooperation initiative will not materially contribute toward New Delhi's strategic capacities in any consequential way either directly or by freeing up its internal resources. This conclusion holds despite the fact that the foregoing calculations probably overstate India's uranium requirements for both electricity and weapons production. In any event, the thrust of the argument undermines not only the maximalist but also the minimalist critique of renewed U.S.-Indian civilian nuclear cooperation because it affirms the proposition that New Delhi can develop a nuclear arsenal of any realistic size through its native resources alone.

Making Sense of U.S.-Indian Civilian Nuclear Cooperation

If all elements of the foregoing discussion are true, it is reasonable for an observer to ask whether the heavily touted shortage of India's natural uranium has any significant meaning. After all, the analysis thus far clearly indicates that New Delhi faces no deficit of natural uranium feedstock in at least the two most realistic scenarios of relevance to India: (1) when India uses all its PHWRs to produce electricity, with the two research reactors dedicated solely to producing weapons-grade plutonium; and (2) when India uses its eight unsafeguarded PHWRs to produce weapons-grade plutonium using one-fourth of the core, in addition to the two research reactors dedicated solely for that purpose, with the ten remaining PHWRs used entirely for the production of electricity. In both these scenarios, India can produce a much larger number of nuclear weapons than it is currently accumulating fissile materials for, while still remaining well within the most conservative estimates regarding its natural uranium reserves.

If other analytical excursions were undertaken, such as postulating that only two unsafeguarded 220 MWe PHWRs were dedicated full core to the production of weapons-grade materials, notwithstanding the technical problems involved, (in effect, supplementing the two research reactors used for this purpose), with all other reactors used for producing electricity, the same result would obtain: India could produce a much, much larger stockpile of nuclear weapons than it does currently and still sustain all the existing and prospective reactors over the duration of their notional lives entirely through its extant reserves of assured uranium.[30] Given these conclusions, does India face a shortage of natural uranium at all and, if it does not, why is India interested in nuclear cooperation with the United States to begin with? Both these are reasonable queries and must be addressed if the nature of the true constraints in the Indian nuclear program is to be properly appreciated.

As a first approximation, it is accurate to say that India possesses a limited quantity of natural uranium. Like all physical resources found anywhere in the world, New Delhi's terrestrial deposits of uranium are finite; these limits, accordingly, define a certain "production possibility frontier" that shapes the total amount of nuclear electricity that can be produced on an inter-generational basis over the long term. In other words, at some point in the very distant future, India's currently known uranium reserves will be exhausted if exploration fails to reveal new deposits: depending both on the rate at which India commissions new PHWRs and its access to international nuclear commerce, this exhaustion point would not arrive before many decades elapse and may even be postponed further, depending on the march of technology in the interim. This issue, which is much discussed within India and elsewhere, acquires special relevance from the fact that India—for the size of its landmass—has much smaller quantities of uranium ore than that possessed by some other countries of comparable size such as Australia or Canada. Thus, for example, in contrast to the 112,369 tons of uranium, which constitute India's total reserves without any assigned cost ranges, Australia possesses some 689,000 tons of uranium that are recoverable at less than U.S. $40 per kilogram. At price levels of less than U.S. $130 per kilogram, Australia's reasonably assured resources alone are estimated at some 735,000 tons. If the Category I—Estimated Additional Resources are thrown into the mix, the size of Australia's natural uranium reserve increases by an additional 276,000–323,000 tons at cost ranges of less than U.S. $40 and less than U.S. $130 per kilogram respectively. Although Canada's uranium deposits are smaller than Australia's in some categories, the overall size of the Canadian reserve nonetheless is considerably larger than India's by some eleven times, when the total endowments are accounted for across all reporting categories.[31] Where the size of deposits is concerned, therefore, India shares greater similarities with its larger northern neighbor, China, which is assessed as having an even smaller reserve of some 85,000 tons of uranium.

Given such comparisons, it becomes obvious that India's known reserves of uranium are simply not so abundant as to support the largest possible expansion of nuclear power as might be necessary for a country of India's size and population over the secular period. The Indian DAE, for example, estimates that its reasonably assured reserves of 78,000 MTU suffice to produce only 420 gigawatt-electric-years (GWe-years) of electricity when used solely in PHWRs. This implies that India could have approximately 3.1 times the current and planned installed capacity in PHWRs (4,460

MWe) before it runs out of its reasonably assured reserves of natural uranium; it would, however, reach the limits of these reserves at that point—likely several decades into the future—after which nuclear energy could play no further role in national development *if the country were to be restricted solely to the use of PHWRs and enjoyed no access to natural uranium from international markets.*

This fact has been known since the time of India's independence and it is precisely the *relative* poverty of India's uranium reserves, for example, compared with Australia, Canada, Kazakhstan, or South Africa, that inspired the founder of its nuclear program, Homi Bhabha, to devise his famous three-stage plan, which guides the strategy underlying Indian investments in nuclear power to this day. New Delhi's continued pursuit of this three-stage plan implies that, if successful, India's poor natural uranium endowments would have no strategic significance over the very long term: this is because Bhabha's vision ingeniously exploited the technical properties of various fissionable raw materials found within India to create a nuclear power production regime that would in essence function as a postmodern version of medieval alchemy. Described in its simplest form, Bhabha's approach focused on transmuting India's relatively small holdings of natural uranium to produce plutonium in PHWRs in the first stage; this plutonium would then be used to breed uranium-233 in fast neutron reactors in the second stage; the resulting uranium-233 would finally be combined with thorium in advanced heavy water reactors in the third stage, to generate about two-thirds of that reactor's output from thorium itself, an element that India has in vast abundance. Over the very long term, therefore, India's natural uranium constraints would lose much of their salience, if the second and third stage technologies inherent in Bhabha's vision came to maturity. The Indian nuclear establishment is currently in the process of beginning the implementation of its second stage program with the construction of the first of five commercial fast breeder reactors, even as it completes the design validation and safety reviews of the advanced heavy water reactor required for the third stage.

Completing this ambitious plan successfully will be neither easy nor inexpensive but India's vast and growing energy needs, coupled with its exclusion from international nuclear commerce since about the 1970s, has strengthened the perception within India that its government has no choice but to support all the investments required by Bhabha's three-stage plan if the country is to stand a chance of realizing its dream of energy security. There is by now sufficient data, however, suggesting that implementing Bhabha's plan in the manner initially envisaged by him will be inordinately expensive and possibly very slow. This is because the fast breeder reactors that are central to the second stage of Bhabha's vision breed plutonium very slowly.[32] Moreover, the thorium cycle that India plans to develop in the third stage of the plan will be commercially viable only if the price of uranium increases by several orders of magnitude. As the World Nuclear Association therefore concluded somewhat laconically, "much development work is still required before the thorium fuel cycle can be commercialized, and the effort required seems unlikely while (or where) abundant uranium is available."[33] Because India is currently excluded, however, from the international nuclear fuel market, its nuclear managers have argued, perhaps with some justification, that they are left with no options but to pursue even technological will-o'-the-wisps if these are seen to offer some promise of advancing energy security.[34] Given the powerful motivations underlying this effort, and the DAE's remarkable record of achievement in the face of concerted international isolation, it is possible—the devotees would say probable—that India will succeed in implementing its three-stage plan eventually, despite what are likely to be extraordinarily high costs.

From the U.S. perspective, three important consequences flow from this fact:

- First, the limited Indian reserves of natural uranium, which many in the United States perceive to be New Delhi's Achilles' heel, could cease to have significant operational meaning over the distant future.

- Second, the ongoing Indian effort to implement its three-stage plan amidst its continued segregation from the international nuclear energy cooperation and non-proliferation regimes—which would inevitably be the case if the U.S. Congress does not ratify the Bush-Singh civil nuclear initiative—would place India in a situation where it was not bound by strong global nonproliferation obligations at a time when it not only will have become a true great power internationally but also will have acquired considerable mastery over the plutonium and thorium fuel cycles as well as all the sophisticated technologies required to separate uranium-233 on a commercial scale.

- Third, the United States will have lost the most propitious opportunity to demonstrate that it is a true friend and ally responsive to the deepest aspirations of the Indian people if it either condemns New Delhi to the costly implementation of Bhabha's three-stage plan under conditions of continued isolation or seeks to exploit the current transitory difficulties in India's nuclear electricity production regime to extort concessions relating to the nuclear weapons program, which Indian policy makers of all stripes are determined to protect because of its vital importance to their country's core national security interests.

These considerations remain another way of saying that the present moment represents a great opportunity. Reaching out to India and assisting it with nuclear cooperation at a time when it is a relatively weak state geopolitically bequeaths the United States with greater dividends than would be the case if such cooperation were offered after India had already become a true great power and a repository of sophisticated nuclear technologies—when New Delhi presumably would have lesser need for such cooperation. A civilian nuclear partnership with India today would also bestow on its policy makers the advantages of possessing truly meaningful technical alternatives to their three-stage plan. An India that was fully integrated into the international nuclear fuel market would have less pressing need to reach for extravagant technological remedies to its energy security problems, such as the thorium cycle, which is heavily dependent on the success of an intermediate stage involving fast neutron reactors. In other words, providing India with unfettered access to the global natural uranium market would simply turn out to be the most cost- and technology-effective solution to India's clean energy requirements compared with Bhabha's problematical strategy. Although New Delhi may still persist with this effort as a research and development exercise to validate the thorium economy (and as a hedge against being cut off in the future from the international uranium market), it would nevertheless be better off if it possessed alternative options when making its final investment decisions, rather than be simply condemned to the original three-stage plan merely because it could not supplement its own natural uranium reserves through open commerce in nuclear fuel.

If India's long-term constraints regarding natural uranium can thus be mitigated either through its own ingenuity—as exemplified by Bhabha's three-stage plan—or by access to the international fuel market—as envisaged by President Bush's proposal for renewed civilian nuclear cooperation with India—the question of whether New Delhi is confronted by any near-term shortage of uranium still persists. Despite the fact that uranium production and nuclear fuel availability data in India remains one of the country's most highly prized secrets—information that is not available even to the auditors of the Uranium Corporation of India Limited (UCIL)—the Indian Planning Commission has publicly admitted that "the PLF [plant load factors] for nuclear plants has gone down to 73.70 per cent in 2003-04, after reaching a high of 79.40 per cent in 2001-02." The Commission concluded, "This is primarily due to non-availability of nuclear fuel because the development of domestic mines has not kept pace with addition of generating capacity."[35] What can be said with high confidence, therefore, is that the much-touted Indian deficit of natural uranium cannot be attributed to the fact that India does not possess the requisite natural uranium reserves to begin with or that its routine consumption rates associated with electricity and weapons production exceed those of its natural uranium deposits "in the ground." Rather, the near-term shortage of natural uranium can be attributed primarily to the constraints in uranium production capacity relative to the grade of ores found in the eastern half of the Indian landmass.

India began domestic uranium exploration in a serious way in 1949, a few years before Bhabha unveiled his three-stage plan in 1954. Most Indian efforts in this regard have thus far concentrated on deposits in Rajasthan (which are still uncertain); Andhra Pradesh (which has medium-sized deposits of moderate grade); Karnataka (where some boreholes have discovered deposits with more than 1 percent ore assays); and Meghalaya (where low tonnage, medium-grade deposits have been discovered). India's active operating uranium mines, however, are concentrated at Jaduguda, Narwapahar, and Bhatin in the eastern part of the Singhbhum district of the state of Jharkhand. Additional mines are being developed at Turamdih, Bandugurang, Baghjanta and Mohuldih (all in Jharkhand) and even further afield, such as the promising Domiasiat project in Meghalaya, the Lambapur-Peddagattu and Pulivendula projects in Andhra Pradesh, and the Gogi project in Karnataka.[36] In general, the ore assays of Indian natural uranium deposits are unexceptional, ranging in grade from 0.034 percent to 0.085 percent uranium per metric ton. While such levels are admittedly comparable to the ore assays found in most mines internationally, including in Australia, they do match up unfavorably to the richest "high-grade" deposits discovered in a few places elsewhere in the world, such as the 14.2 percent and 17.5 percent ore assays found at the Cigar Lake and McArthur River mines, respectively, in Canada.[37]

The main implication of possessing an undistinguished ore assay is that it requires the milling facilities to process a much larger quantity of natural ore to concentrate the amount of uranium required to satisfy the feedstock load of a nuclear reactor. Thus, for example, if the ore assay of the Jaduguda vein is assumed to be 0.06 percent as is commonly believed—meaning that each metric ton of ore contains about 0.6 kilograms of uranium—the Jaduguda uranium production facility, currently India's only uranium ore concentration plant, would have to process more than 50,000 metric tons of ore if it is to produce the approximately 30 MTU that are nominally required to refuel a 220 MWe PHWR annually. If, in contrast, uranium ores of a higher grade—say, 0.8 percent—were to become suddenly available to the concentration plant, the quantity of ore that must be processed to produce the 30 MTU referred to in the above example drops sharply to some 3,750 metric tons, thus easing considerably the burdens imposed on the processing capability as well as the overall cost of the fuel inputs involved.[38]

Previous calculations in this report had established that, crudely speaking, India's currently operating PHWRs require some 478 MTU annually for refueling, an estimate that is probably somewhat higher than what their actual consumption entails but is nonetheless an acceptable benchmark. If the fuel requirements associated with the weapons-grade plutonium-producing reactors, CIRUS and Dhruva (operating at the realistic capacity factors of 50 percent and 65 percent respectively and at a burnup level of 1000 MWD/MTU) are added to mix, these facilities, requiring some 31 MTU annually, bring the grand total of natural uranium fuel necessary to support the Indian nuclear program to some 509 MTU every year. The DAE has reported the current processing capacity of the Jaduguda ore concentration plant to be some 2,090 metric tons per day (MTPD).[39] If the mill therefore operated for about 300 days each year, extracting some 80 percent of the 0.06 percent uranium in the ore, the Jaduguda plant should be able to produce about 301 MTU per year. If the ore assay stands at about 0.08 percent, as the ores present at the Domiasiat site apparently are, the Jaduguda plant should be able to produce some 401 MTU per year, if all other assumptions are presumed to remain the same.[40]

In practical terms, this means that the reputed shortage of uranium fuel that is much discussed in Congress and in the press refers to the 108–208 MTU that the figures above suggest India needs annually for its nuclear estate, a number that denotes the deficit *caused by the constrictions in India's milling capacity and not its natural uranium reserves in the first instance.* To date, India has managed this deficit through a combination of strategies: using its stockpile of uranium ore concentrate that had been built up over the years, in part, through the accumulation of unused fuel allocated to power reactors that did not operate at full capacity; recycling uranium recovered from spent fuel; and, producing as much uranium as is feasible as a by-product of processing monazite (a thorium ore that typically contains 0.30 percent uranium) and copper mine tailings at the two uranium recovery plants in the state of Jharkhand. These strategies in combination permitted the DAE to sustain reasonably high capacity factors for electricity production, although these have dropped in recent years, while maintaining its desired level of weapons production.[41] Indian security managers are fully cognizant of the fact, however, that as their new indigenously built PHWRs come on line, the demand for natural uranium as a fuel input will only increase, further widening the deficit caused by the constraints in milling capacity (and, to the degree relevant, mining capacity as well). If the future fuel requirements for each nuclear reactor currently under construction were to be added to the 509 MTU currently required annually, India's total natural uranium fuel needs could run somewhere on the order of some 654 MTU per year. This figure does not include the initial fuel loading of the four PHWRs yet to come on line (only the fresh fuel required on an annual basis), but it does assume that India commissions a second 100 MWt research reactor and that the CIRUS reactor is still operational. Given these assumptions, it would not be surprising if the near-term total annual shortfall of natural uranium needed to run the entire Indian nuclear estate turns out to be anywhere from some 253 to 353 MTU per year (based on differing values of the ore assay assumed to be available to the country's uranium processing plants).

This fact, however, cannot provide any solace to the critics of the U.S.-India civil nuclear agreement because the roots of the uranium fuel deficit currently experienced by India lie not in the permanent shortage of natural uranium reserves—except in the truly long-term sense described earlier—but in the previous failures of the government of India to expand commercial mining and, more importantly, to build up the milling capacity necessary to transform its reserves of ore into the uranium dioxide that is fabricated into fuel pellets, fuel rods, and fuel assemblies used in India's nuclear reactors. These constraints will be rectified within the next several years. The government of India, recognizing the consequences of the decisions made under painful fiscal pressures in the early 1990s, has now sharply increased the budgetary allocations for deepening existing mines and commissioning new sites, many of which were delayed because of disputes over compensation and land rights.[42]

The constraints in milling capacity are also being expeditiously redressed: A new ore concentration plant with a 3,000 MTPD capacity is currently under construction at Turamdih. When completed, it will initially process ores from the Turamdih and Bandugurang mines and, after further expansion, ores from the Mohuldih mine as well. This distention in total capacity—to 5,090 MTPD—represented by the Turamdih facility will enable India, on the same assumptions used earlier (300 days of operation, 80 percent recovery efficiency, and 0.06 percent ore assays), to produce some 733 MTU annually, well above the 654 MTU required to fuel the entire Indian nuclear power and weapons program every year.

As additional insurance however, and to minimize the costs of transporting uranium ores to distant processing plants, the government of India is also contemplating the construction of two more facilities, one with a 1,250 MTPD capacity at Seripally (which will process ores from the Lambapur-Peddagattu, Pulivendula, and Gogi mines in southern India), and another with a 1,370 MTPD capacity at Domiasiat in the northeast Indian state of Meghalaya. When these facilities are completed, India will have a total ore processing capacity of some 7,710 MTPD, sufficient—on the same assumptions used earlier—to produce some 1,110 MTU annually. This output would far exceed the currently assessed feedstock levels required to power all of India's indigenous nuclear reactors, but developing such a processing capacity is essential if the growth of India's nuclear power program in the post-2020 period is to continue apace.[43]

It should be kept in mind that the U.S.-Indian nuclear cooperation agreement proposed by President Bush does not in any way affect the government of India's ability to upgrade its uranium mines and milling facilities to meet its annual requirements for natural uranium fuel. If the U.S. Congress were to reject this initiative—which would be unfortunate—such a rebuff would not by any means impede the Indian activities currently underway to improve its mining and milling facilities and, if anything, would only accelerate them. Furthermore, the technologies used for this purpose are those found routinely in the mining, chemical, and heavy machinery industries, all of which remain entirely within India's domestic competencies. Consequently, New Delhi possesses the wherewithal necessary to correct the problems known to afflict its mining and milling infrastructure, whether or not the U.S.-India civil nuclear cooperation agreement is realized in the manner desired by President Bush and Prime Minister Singh. All this implies that the shortages of uranium fuel experienced by India presently are a near-term aberration caused by constraints in productive capacity due to tragic decisions made by the government of India in the past decade, and not an enduring limitation resulting from the dearth of physical resources, at least in the policy-relevant timeframe. As such, these shortages do not offer a viable basis for Congress to extort any concessions from India regarding its weapons program—for example, by demanding a lasting cap on the production of fissile materials or a permanent moratorium on nuclear testing—as is demanded by many opponents of the U.S.-Indian civil nuclear cooperation initiative.

If confronted by such demands, India would simply forego the benefits of international nuclear commerce. Such an outcome would no doubt satisfy the votaries of the "punish India for its nuclear weapons" school of thought, but it should offer no consolation to Congress or to U.S. policy makers more generally, because the United States as a country would lose on multiple counts: if denied the natural uranium required to overcome its transient shortage of nuclear fuel, Indian policy makers will further reduce the operating factors governing the performance of their nuclear power reactors, and compensate for this reduction in nuclear electricity production by simply burning more dirty coal that pollutes the global environment even more consequentially, all while continuing to allocate the same amount of uranium feedstock as before to the production of nuclear weaponry. Because natural uranium can be substituted by coal, oil, hydropower, and biomass as a resource for electricity production, but cannot be replaced in any comparable way as a raw material for producing nuclear weapons, the United States might find itself—in the absence of nuclear cooperation with India—in a situation where it facilitated New Delhi's accelerated decimation of the global environment, even as India continued to maintain, and perhaps even to expand, its nuclear weapons program. A Congressional rejection of the president's proposal for renewed nuclear cooperation with India—as advocated by its many detractors—therefore fails to advance some of the very nonproliferation goals upheld by these same critics; moreover, it would contribute toward a further deterioration of the planet's environment, while simultaneously dealing a potential death blow to the continuing transformation of the U.S.-Indian relationship.

These outcomes would be realized, in the final analysis, because of the simple fact that India *has* all the natural uranium it needs to produce as many nuclear weapons it may wish without any assistance from the outside, while being able to generate up to 480 GWe-years of electricity. Its principal constraints currently derive from its limitations in mining and milling capacity, but these constrictions are likely to be at most passing perturbations because the government of India has already expanded the resources allocated not only to milling but also to uranium mining and exploration as well.[44] Because the gross consumption of natural uranium for weapons production is so small relative to the gross consumption of natural uranium for purposes of producing electricity in the existing Indian nuclear program, the shortage of natural uranium for feedstock—irrespective of its genesis or its magnitude—will disproportionately affect power production rather than New Delhi's nuclear arsenal. The Bush administration is, therefore, entirely correct when it claims that India has the requisite natural uranium reserves to develop the largest possible nuclear arsenal it may desire, but not the largest possible clean power program it would need over the long term. Precisely because Homi Bhabha reached exactly the same conclusion fifty years earlier, he set his country along the path of his ambitious but technically challenging three-stage plan, which promised to provide India with all the nuclear fuel needed for plentiful electricity even as it conferred the requisite capabilities necessary to produce all the plutonium required for the production of nuclear weaponry.

Parenthetically, it is worth noting that precisely because Bhabha's "magnificent obsessions"[45] remain the lodestar for the Indian power program, the Indian separation plan unveiled during President Bush's March 2006 visit to India withheld eight PHWRs from international safeguards. Although critics of the U.S.-Indian civil nuclear agreement have repeatedly claimed that this act indicates India's desire to construct a huge nuclear arsenal, the reason for withholding these reactors from safeguards was far more prosaic: once New Delhi had determined that it would not offer its breeder reactors for safeguards, at least initially, because of concerns about protecting its proprietary technologies, it needed to preserve a source of unsafeguarded reactor-grade plutonium for feeding its breeder component. This, in turn, required that New Delhi also withhold the appropriate reprocessing capacity necessary from safeguards. Accordingly, eight PHWRs were withheld from safeguards along with the PREFRE and KARP plants, which are intended to reprocess spent fuel from the sequestered power reactors.[46] These eight PHWRs are likely to be committed primarily to the task of producing the unsafeguarded reactor-grade plutonium necessary to fuel India's prospective and future breeders throughout their operational lives. To the degree that these reactors are relevant to the weapons program, they are more likely to be used for tritium production, either as receptacles for the irradiation of lithium or through harvesting from their heavy water moderators, rather than for primarily producing weapons-grade plutonium. As previous analysis in this report has demonstrated, the diminution in electricity generation that occurs when PHWRs are committed—at whatever fraction—to the production of weapons-grade plutonium ensures that India's eight unsafeguarded reactors are unlikely to be used for such a purpose so long as India's vast demand for power continues to remain unsatisfied, as it will be for some time to come.

In this context, the fact that some of India's breeder reactors will remain unsafeguarded ought to be welcomed by nonproliferation hawks in the United States because it implies that, far from diverting the "spent nuclear fuel in existing civilian power reactors for weapons purposes," as Daryl Kimball and others have misleadingly alleged, India's inventory of reactor-grade plutonium would now be committed in magnitudes averaging tons—not kilograms—to fuelling the multiple breeders that are likely to become operational over the next few decades.[47] Because these breeders are fast neutron reactors, the doubling time—that is, the time to produce twice as much plutonium as is consumed by the reactor—is extremely slow, on the order of some 10–15 years, thus making them virtually useless to any Indian strategist in a hurry to increase his present and prospective inventory of weapons-grade materials. Finally, the irrelevance of fast breeder reactors to the current Indian weapons program is confirmed by the fact that no commercial-sized breeder is actually operational within India presently. The extremely small, 39 MWt, Fast Breeder Test Reactor (FBTR) that is currently on-line is used primarily for experimentation and familiarization with breeder operations as well as to test the viability of plutonium-uranium carbide as a fuel source. The commercial-sized 500 MWe Prototype Fast Breeder Reactor (PFBR) that India has declined to put under safeguards (at least initially), and that remains the source of consternation for many critics of the U.S.-Indian civilian nuclear cooperation initiative, will not become operational for many more years to come, and it will probably be at least two decades before it actually starts producing any super-grade plutonium of (potential) value to the Indian weapons program. Given the threat posed by a global fissile material cutoff treaty (FMCT)—already viewed in India as the sword of Damocles hanging over its weapons program—the idea that security managers in New Delhi would treat the PFBR—which will not become operational in this decade and will become a net producer of plutonium only a few decades thereafter—as a reliable source of fissile materials for their strategic activities borders on sheer fantasy.

In any event, if the shortage of natural uranium that currently afflicts the Indian nuclear program is attributable principally to mining and milling limitations as opposed to an absence of uranium reserves per se—and therefore, by implication, is both potentially transitory and of little strategic consequence to the nuclear electricity sector if India's three-stage program bears fruit over time (not to mention its irrelevance to the weapons effort in general)—why does the Singh government appear so eager to consummate the civil nuclear agreement in the first place? Many commentators in the United States and abroad have concluded that the Indian desire for renewed civilian nuclear cooperation with the international community is driven entirely, as Senator Sam Nunn argued, by its "well-known uranium shortage [which] may have been a significant constraint to India's nuclear weapons potential."[48] The analysis in this report demonstrates the fallacy of this proposition, but it has not yet offered any positive explanation of why the Singh government has invested so much capital—just as the Bharatiya Janata Party government before it might have, if it were offered this same deal—in implementing the U.S.-India civil nuclear agreement despite great domestic opposition.

In other words, if India really does not need natural uranium as fuel over the distant future because of the alternatives embodied in its three-stage plan, and if its current reserves are sufficient for both its contemporary PHWR-centered power program and its weapons program at whatever size it may desire, why should New Delhi assume the onerous burdens of implementing the July 18, 2005, agreement when all it needs for its energy security is to concertedly accelerate the development of its mining and milling infrastructure? Many Indian analysts, asking exactly this question, have reached the conclusion that India does in fact have "the wherewithal to forge on on its own … rather than [tying] itself down to commitments with the U.S. and the Nuclear Suppliers Group (NSG), where it proceeds from a level of inferiority."[49] When other Indian and U.S. analysts more supportive of the nuclear cooperation agreement have attempted to answer this question, they have couched their responses primarily in geopolitical, strategic, or diplomatic terms. Thus, for example, they have asserted variously that completing the bilateral commitments encoded in the July 18, 2005, agreement would remove the last great impediment to the transformation of U.S.-Indian relations and the creation of a new global partnership between the two countries; or that it would provide India with access to a range of controlled technologies that New Delhi was hitherto denied; or that it would ineluctably be part of the process of aiding economic development and, by implication, the growth of Indian strength which, in turn, would stabilize the balance of power in Asia to the common benefit of Washington and New Delhi.

All these justifications are accurate and noteworthy, but they do not address the critical reasons why the government of India has judged implementing the U.S.-Indian civil nuclear agreement to be of vital importance to India's energy security, even though it is fully aware of—and appears committed to—the DAE's own efforts to bring Bhabha's three-stage plan to fruition. If distracting asides, such as the desire to secure India's status as a nuclear weapon state or the Indian leadership's distrust of its atomic energy managers to deliver on their promises, are disregarded, it is possible to discern seven distinct reasons why consummating the U.S.-Indian civilian nuclear cooperation agreement is important *for the success of the DAE's own contributions* in regards to ensuring India's energy security.

- First, the agreement promises to provide India regularized access to imported natural uranium fuel which, if nothing else, helps the country tide over the transient difficulties caused by the bottlenecks in its mining and milling infrastructure, while the DAE continues to bring new mines and new ore processing plants into operation and prosecutes its longer-term three-stage plan designed to overcome whatever limitations inhere in India's finite natural uranium reserves.

- Second, it permits the National Power Corporation of India, the DAE's commercial operating arm, to simply import higher unit output reactors than can be constructed by simply scaling up India's original 220 MWe CANDU designs. The high capital costs of constructing nuclear power plants implies that it is simply more economical to build high unit output designs (1000 MWe or higher) of the kind constructed elsewhere in the world rather than the low unit output (approximately 220 MWe) facilities traditionally built in India.

- Third, the ability to legally import new high output reactors built by the United States, France, Russia, and others brings with it the prospect of foreign financing, which in turn reduces the burdens of raising domestic resources for underwriting the vast new investments required in nuclear power.

- Fourth, the opportunity to import new nuclear reactors from abroad provides new benefits in terms of modern safety technologies, which have improved dramatically since the original CANDU and BWR designs were first introduced into India in the early 1970s. A large-scale expansion of nuclear electricity of the kind contemplated by the DAE in the future makes it imperative, both from an economic and a political point of view, that every reactor operating in India be equipped with the latest safety technology if nuclear energy is to remain a viable source of power over the long term.

- Fifth, the access to new reactor technology from abroad promises to give India's nuclear engineers exposure to new advanced designs that maximize efficiency, output, and safety and which could in principle be applicable to future designs developed by India's own indigenous nuclear industry over time.

- Sixth, India's integration into the global nuclear industry's research and development network would enhance the efforts of the country's own domestic research and development community through information flows over the relevant backward linkages, thereby maximizing the DAE's own ability to contribute toward the new global initiatives already underway in the areas of fusion research, waste management, and advanced and unconventional reactor designs.

- Seventh, finally and perhaps most importantly, the U.S.-Indian civil nuclear cooperation agreement provides India with a structural hedge in case Bhabha's three-stage program runs into either irresolvable technical problems—which are possible (the critics would say likely)—or serious implementation delays, unacceptable price overruns, economic infeasibility, or higher than anticipated start-up troubles, some of which are almost certain to occur when a nation sets out upon such a risky and challenging path not trod by others. The U.S.-Indian civil nuclear cooperation agreement would, in this context, provide India with the option of simply staying with the first phase of its three-stage plan indefinitely or, more interestingly, open the door for India to access advanced new technologies, such as the high-temperature gas-cooled reactor, the molten salt reactor, and various accelerator driven systems, all of which exploit thorium for the production of electricity, but without the need for any intermediate-stage fast neutron reactors, which are technologically risky and probably uneconomical.

On balance, therefore, Manmohan Singh's desire for nuclear cooperation with the United States in particular and with the international community more generally has less to do with the immediate challenges of overcoming a transient scarcity of natural uranium caused by bottlenecks in his country's nuclear fuel production infrastructure. Overcoming these impediments, the prime minister well knows, is important, but he also realizes that they can be surmounted—if not immediately, certainly well within the decade—by relatively small changes in India's domestic resource allocation decisions. Even the larger problem of circumventing India's limited natural uranium endowments can be arguably resolved in theory through Bhabha's three-stage plan, albeit at horrendous cost and at substantial technical risk, although there is no evidence whatsoever that the size of these endowments per se has in any way constrained either India's nuclear weapons program or its PHWR-based first-stage of nuclear power production.

What Manmohan Singh, therefore, appears to be after is looking for some means of assuring India's energy security on the grandest scale imaginable so that, regardless of what happens in global energy markets over time, India and its teeming millions will always have access to the only practically inexhaustible source of clean energy now known to man—and, given the vagaries of Asian geopolitics, will have reliable access to this technology and others in partnership with the most powerful entity heretofore seen in the international system, namely the United States. Such opportunities to forge a critical geopolitical relationship do not come often in a lifetime. It would indeed be unfortunate, therefore, if the prospect now confronting Washington regarding a new global partnership with New Delhi were to be sacrificed because of some petty canard regarding the effect of imported natural uranium on India's nuclear weapons program.

Endnotes

1. Joseph Cirincione, "Nuclear Cave In," *PacNet*, no. 8A, Pacific Forum CSIS, March 2, 2006.
2. Daryl G. Kimball, "Dangerous Deal with New Delhi, *Baltimore Sun*, March 9, 2006.
3. Henry Sokolski, "Backing the U.S.-India Nuclear Deal and Nonproliferation: What's Required," testimony before a Hearing of the Senate Foreign Relations Committee, *The Nonproliferation Implications of the July 18, 2005 U.S.-India Joint Statement*, Washington, D.C., November 3, 2005.
4. R. Nicholas Burns, Under Secretary of State for Political Affairs, Remarks as Prepared for the House International Relations Committee Hearing, *The U.S. and India: An Emerging Entente?* Washington, D.C., September 8, 2005. At this same hearing, Robert G. Joseph, Under Secretary of State for Arms Control and International Security, elaborating this theme further, noted that, "India believes, and our Administration agrees, that it needs nuclear power to sustain dynamic economic growth and address its growing energy requirements in an affordable and environmentally-responsible manner. Our intent—in the context of the July 18 Joint Statement by the President and Prime Minister—is to provide India access to the technology it needs to build a safe, modern and efficient infrastructure that will provide clean, peaceful nuclear energy, one of the few proven sources of emissions-free energy that can provide the energy needed for a modern economy."

5. George Perkovich, "Faulty Promises: The U.S.-India Nuclear Deal," *Policy Outlook*, Carnegie Endowment for International Peace, September 2005, 12.
6. Secretary of State Condoleezza Rice, testimony before the Senate Foreign Relations Committee, *Hearing on United States-India Atomic Energy Cooperation: The Indian Separation Plan and Administration's Legislative Proposal*, Washington, D.C., April 5, 2006. For a superb historical investigation of the sources of India's ambivalence and restraint with respect to nuclear weapons, see George Perkovich, *India's Nuclear Bomb* (Berkeley: University of California Press, 1999).
7. An assessment of various analyses regarding the size of India's inventory of weapons-grade fissile materials can be found in Ashley J. Tellis, *India's Emerging Nuclear Posture* (Santa Monica: RAND, 2001), 479–496. See also, A. H. Nayyar, A. H. Toor, and Zia Mian, "Fissile Material Production Potential in South Asia," *Science & Global Security, 6* (1997), 189–203.
8. David Albright, *Fact Sheet: India and Pakistan—Current and Potential Nuclear Arsenals*, Institute for Science and International Security, May 13, 1998.
9. Tellis, *India's Emerging Nuclear Posture*, 484, 493.
10. CIRUS and Dhruva have also been used to produce a variety of radioisotopes for medical, agricultural, and industrial purposes, in addition to producing weapons-grade materials for the Indian nuclear arsenal. The civilian products produced by the facilities are marketed by the Board of Radioisotope Technology (BRIT) in New Bombay and can be found at www.britatom.com.
11. David Albright's estimate of India's fissile material inventory at the end of 2004, some 345–510 kilograms, is in the same range as Ramachandran's. See David Albright, *India's Military Plutonium Inventory, End 2004*, Institute for Science and International Security, May 7, 2005.
12. Because India is known to be energetically pursuing advanced nuclear weapons as well, it is intriguing to speculate about how its inventory of weapons-grade fissile material translates into numbers pertaining to such devices. On the heuristic assumption that India uses all its fissile material to build either thermonuclear devices or boosted fission weapons, and on the further assumption that these devices are based *entirely* on some modification of India's basic fission design described in open sources, it is possible to suggest that India's potential thermonuclear weapon stockpile would be some number greater than 46-33 weapons, while its potential boosted fission stockpile would be some number marginally greater than the 91-65 simple fission weapons believed to populate its standard notional stockpile. For the logic underlying this calculation, see Tellis, *India's Emerging Nuclear Posture,* 487–490.
13. David Albright and Susan Basu, *Separating Indian Military and Civilian Nuclear Facilities*, Institute for Science and International Security, December 19, 2005, 4.

14. Nuclear Threat Initiative, "India: Nuclear Facilities, Plutonium Reprocessing Plant," available at www.nti.org/e_research/profiles/India/Nuclear/2103_2497.html.

15. India has traditionally used the PREFRE and KARP facilities for reprocessing uranium dioxide fuel from its power reactors, fuel that is not used to produce weapons-grade plutonium. These two facilities, however, could be used to reprocess spent fuel containing weapons-grade plutonium if New Delhi chose either to use its power reactors for this purpose—an unlikely prospect, as this report discusses subsequently—or to reprocess spent fuel from its research reactors. The Indian nuclear weapons program historically, however, had never felt the need to exercise this latter option because the relatively small quantities of spent fuel used by the program could be reprocessed entirely at the Trombay plant. All of this confirms the conclusion asserted in this paragraph, namely that India, pursuing a small nuclear arsenal, continues to produce less weapons-grade material than it is technically capable of.

16. Tellis, *India's Emerging Nuclear Posture*, 478–481, 487–490.

17. Senator Sam Nunn, "Nuclear Pig in a Poke," *Wall Street Journal*, May 24, 2006. This argument finds reflection in other sources as well: see, for example, Henry Sokolski, "The India Syndrome: U.S. Nuclear Nonproliferation Policy Melts Down," *The Weekly Standard*, 10: 43 (2005); "The U.S.-India Nuclear Deal," Robert J. Einhorn, senior adviser, Center for Strategic and International Studies, statement before the House International Relations Committee Hearing, *The U.S.-India "Global Partnership": The Impact on Nonproliferation*, Washington, D.C., October 26, 2005; and Sharon Squassoni, *U.S. Nuclear Cooperation with India: Issues for Congress*, CRS Report for Congress, RL33016, March 3, 2006, 13.

18. OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), *Uranium 2003: Resources, Production and Demand* (Paris: OECD/IAEA, 2004), 146-147. The most recent edition, OECD Nuclear Energy Agency and the International Atomic Energy Agency, *Uranium 2005: Resources, Production and Demand* (Paris: OECD/IAEA, 2005), 188, marginally increases the size of the total reserve to some 113,700 tons, mainly as a result of new confirmation of some previously designated EAR-Category II sources.

19. World Energy Council, *Survey of Energy Resources 2001*, available at www.worldenergy.org/wec-geis/publications/default/online.asp; World Information Service on Energy (WISE) Uranium Project, available at www.wise-uranium.org/; and IAEA, "Country Nuclear Power Profile: India," available at www-pub.iaea.org/MTCD/publications/PDF/cnpp2003/CNPP_Webpage/PDF/2002/Documents/Documents/India%202002.pdf, 371.

20. Secretary of State Condoleezza Rice, response to Senator Biden, Senate Foreign Relations Committee, *Hearing on United States-India Atomic Energy Cooperation: The Indian Separation Plan and Administration's Legislative Proposal*, Washington, D.C., April 5, 2006.

21. There is conflicting information about the true rating of the MAPS-1 and MAPS-2 reactors. The IAEA document, *Heavy Water Reactors: Status and Projected Development*, Technical Reports Series Number 407 (Vienna: IAEA, 2002), 664, and the Nuclear Power Corporation of India website list both as 170 MWe reactors, although it is unclear whether they were ever de-rated to these levels. Both MAPS reactors were known to have significant problems with their pressure tubes, and the MAPS-1 underwent extensive rebuilding and re-tubing before being re-started as a 220 MWe plant. See, T.S. Subramanian, "Reborn reactor," *Frontline*, January 28–February 10, 2006. The calculations in this report, therefore, treat both MAPS facilities as 220 MWe reactors. Although all published sources indicate that the Tarapur 3 reactor is not yet operational and will not be before 2007, this reactor has already gone critical earlier than scheduled: see, Arunkumar Bhatt, "Unit 3 of Tarapur project goes critical," *The Hindu*, March 10, 2006. Also see, T.S. Subramanian, "This is what we were looking for: Kakodkar," *The Hindu*, May 22, 2006. For purposes of analysis, therefore, this report treats the Tarapur-3 reactor as an operational reactor, even though it will be many months before it starts producing electricity and is actually connected to the grid. Because the purpose of this report, however, is to examine the effects of U.S.-Indian civil nuclear cooperation on the Indian weapons program (and, by implication, on India's reserves and consumption of natural uranium), treating the MAPS-1 and -2 and Tarapur-3 reactors in the aforementioned manner is more favorable to the critics of the U.S.-Indian civil nuclear cooperation initiative than to its protagonists.
22. This figure includes the 6.59 MTU required for its initial loading plus the fuel consumed over 29 years.
23. NEA and IAEA, *Uranium 2003: Resources, Production and Demand*, 15. The 2005 edition, *Uranium 2005: Resources, Production and Demand*, assesses India's net reserves at a slightly higher total of 42,568 tons of uranium.
24. Admittedly, running a reactor at full power for 10 percent of the year would circumvent this specific problem, but would not change the broader conclusion argued here.
25. If the average discharge burnup is maintained at 1,000 MWD/MTU and a capacity factor of 0.73 is assumed, the fueling machines would have to operate at nearly seven times their normal intensity; if the average discharge burnup is reduced to 665 MWD/MTU on the assumption that the same capacity factors continue to obtain, the fueling machines would have to operate at more than ten times their normal intensity.
26. See, C. Ganguly, "Nuclear Fuel Complex—The Workhorse of DAE," *Nu-Power: An International Journal of Nuclear Power,* 18: 2–3 (2004).
27. It is worth noting in this context that not only would such an operating regime be infeasible—as discussed already—but it is also likely to be unnecessary: if the past record of weapons-grade plutonium production is any guide, using PHWRs in a full core mode to produce weapons-grade plutonium would sharply distend the Indian weapons stockpile to levels far beyond what any of its policy makers judge to be essential for national security.

The data in Table 5 suggests that if the eight PHWRs that India has withheld from safeguards were to be used solely for the production of weapons-grade materials, they would produce somewhere between 48,541 and 54,919 kilograms of weapons-grade plutonium, sufficient to produce some 8,090 to 9,153 simple fission devices. It is not commonly appreciated that although India's security managers cannot quantify their desired arsenal size publicly (and may not even be able to do so privately), they do believe in a doctrine of minimum deterrence not because it is the appropriate intellectual fancy, but because it comports most closely with the structures and the preferences of the Indian state. For more on this issue, see Tellis, *India's Emerging Nuclear Posture*, 259-296.

28. If the DAE, for example, uses half of the core to produce weapons-grade plutonium in a PHWR, electricity production would diminish by about 43 percent; if one-third of the core is dedicated to such production, electricity production diminishes by 28 percent; if even one-fourth of the core is allocated to the production of weapons-grade plutonium—the most realistic option, as subsequent discussion will indicate—the level of electricity production is reduced by more than 20 percent, clearly not a trivial diminution by any means.

29. The two research reactors referred to here are the CIRUS and Dhruva reactors until 2010, with two Dhruva-type facilities thereafter. It should also be remembered in this context that India has substantial stockpiles of unsafeguarded reactor-grade plutonium which is usable, though not ideal, for the production of nuclear weapons, given India's current device designs. For an extended discussion of this issue, see Tellis, *India's Emerging Nuclear Posture*, 497–498.

30. Thus, for example, if it were assumed that the Kaiga-1 and Kaiga-2 reactors were set aside for the full core production of weapons-grade plutonium (operating at a capacity factor of 0.73 and an average discharge burnup of 1000 MWD/MTU), in addition to the two research reactors allocated for the same purpose, the entire Indian nuclear estate would require some 22,910–23,060 MTU to run all these reactors for the remaining duration of their notional lives—again, a fuel requirement that lies well within the most conservative estimate of Indian natural uranium reserves of some 54,636 tons. If the two Kaiga reactors were used in this way, they would produce 8,554–9,678 kilograms of weapons-grade plutonium over the remainder of their active lives, sufficient for some 1,426–1,613 nuclear weapons over and above those already existing in India's arsenal. As discussed previously, the only circumstances when India's fuel requirements relating to its PHWRs begin to exceed the country's known reserves is when it is presumed that all eight unsafeguarded PHWRs would be committed to the full core production of weapons-grade plutonium over the duration of their notional lives. This scenario was discounted in the analysis for sound technical reasons. The same argument would also apply to the scenario involving two PHWRs allocated to the full-time production of weapons-grade materials, but the problems associated with refueling and diminished electricity production are disregarded in this instance to assess the sufficiency of India's indigenous uranium reserves.

31. OECD/IAEA, *Uranium 2003: Resources, Production and Demand*, 80, 99.

32. Rahul Tongia and V.S. Arunachalam, "India's Nuclear Breeders: Technology, Viability, and Options," *Current Science*, 75: 6 (September 25, 1998), 549–558.

33. World Nuclear Association, "Thorium," November 2004, available at www.world-nuclear.org/info/inf62.htm.

34. T.S. Subramanian, "A Debate over Breeder Reactors," *Frontline*, 15:25 (December 5–18, 1998).

35. Planning Commission, *Mid-Term Appraisal of the Tenth Five Year Plan, 2002–2007* (New Delhi: Government of India, 2004), 329–330.

36. OECD/IAEA, *Uranium 2005: Resources, Production and Demand*, 185–188.

37. World Information Service on Energy Uranium Project, "Uranium Mine Ownership—Canada," June 6, 2006, available at www.wise-uranium.org/uocdn.html. The data on Canadian deposits on this website refer to assays of triuranium octaoxide, which has been converted to uranium here for purposes of comparison.

38. In both examples, the amount of ore that must be mined to concentrate the quantities of uranium required to refuel the reactor will be larger than the values hypothesized here because the concentration process is never 100 percent efficient. If an efficiency factor of 80 percent were assumed, as is apparently the case at Jaduguda, the ore requirements in these two examples would increase to 62,500 metric tons and some 4,687 metric tons respectively.

39. J. L. Bhasin, Ashok Mohan, and K. K. Beri, "Expansion of Uranium Corporation of India Limited," available at www.dae.gov.in/ucilex.htm.

40. If the Gogi mine in Karnataka, for example, were to yield ore assays of 1 percent uranium per metric ton in commercial quantities and this entire ore stream was processed hypothetically at the Jaduguda concentration plant, the total output of this facility would exceed 5000 MTU per year, all other assumptions remaining the same.

41. The recent performance records of India's power reactors is discussed in T.S. Subramanian, S. Ramu and Suhrid Sankar Chattopadhyay, "Uranium Crisis," *Frontline*, December 31–January 13, 2006. That India's policy makers do not aim to produce the largest nuclear inventory possible is further confirmed by the fact that they have not reallocated uranium feedstock from their power to their research reactors, which they would have done, at the cost of further lowering the operating factors at their power plants, if maximizing the production of weapons-grade materials was their principal goal. The record in fact suggests that irrespective of the performance of India's nuclear power reactors, the production levels of weapons-grade plutonium in India since 1998 have remained more or less constant.

42. Subramanian, et al., "Uranium Crisis."

43. In case the significance of this fact is missed, the surplus in productive output of natural uranium feedstock represented by the 7,710 MTPD level of processing capacity would enable India to theoretically devote two 220 MWe reactors entirely to the full core production of weapons-grade plutonium (in addition to the two research reactors already committed to this purpose), yielding an additional 356 kilograms of bomb making material annually (or equivalently some 59 simple fission weapons annually), *assuming the refueling rate problem was wished away*. Alternatively, India could fuel about six 220 MWe reactors at one-fourth core levels to the production of weapons grade plutonium, in which case it could produce 268 kilograms of bomb making material annually (or equivalently some 45 simple fission weapons annually)—albeit at great stress on its refueling machines. All these calculations assume a 0.73 capacity factor and a 1,000 MWD/MTU equivalent. These data further prove that India's capacity to build a huge nuclear arsenal in principle over the secular period is by no means dependent on either direct access to, or the indirect benefits of substitution flowing from, imported natural uranium.

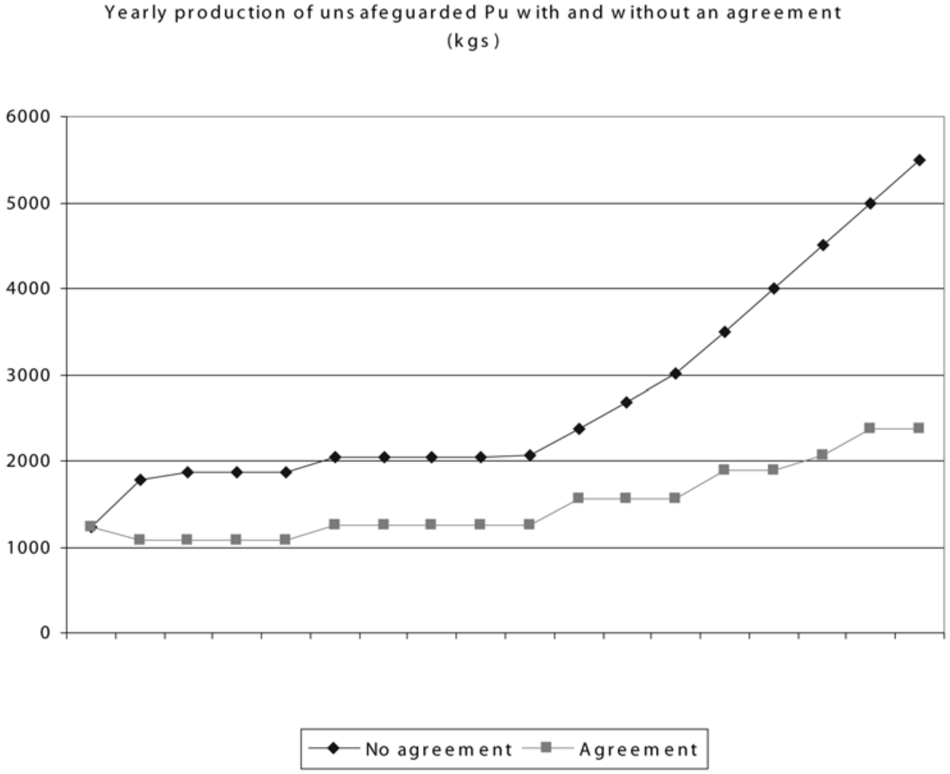
44. The budgetary allocations for uranium exploration, including drilling, have been continuously increasing in recent years. The chairman and managing director of the Uranium Corporation of India (UCIL), Ramendra Gupta, has asserted on the record that "money is not a constraint" as far as new exploration and new investments in uranium production is concerned. Noting that the government of India had allotted rupees 1,000 crores (approximately 200 million dollars) during the Tenth Plan (2002–2007) for deepening old mines, commissioning new mines and setting up new mills, Gupta exclaimed, "We are in an expansion mode. No reactor will be idle" for want of natural uranium fuel. See, Subramanian, et al, "Uranium Crisis." Even more significantly, the Chairman of the Atomic Energy Commission, Anil Kakodkar, recently announced that the DAE was actively exploring the hitherto heretical idea of inviting domestic and foreign private sector firms to participate in uranium exploration activities in India. "Plans for outsourcing uranium exploration," *Outsourcing Times*, March 20, 2006.

45. This phrase is borrowed from Ganesan Venkataraman, *Bhabha and His Magnificent Obsessions* (Hyderabad, India: Universities Press, 1994).

46. Because the PREFRE facility also reprocesses fuel from other safeguarded PHWRs, it will be brought under safeguards in "campaign mode," meaning that it will come under safeguards whenever safeguarded spent fuel passes through this facility. The third reprocessing plant at Trombay will continue to remain outside of safeguards because it remains dedicated to supporting the Indian nuclear weapons program.

47. As one of India's finest operations researchers, G. Balachandran, has pointed out, the U.S.-Indian civil nuclear cooperation agreement would actually have the effect of *reducing* India's stockpile of unsafeguarded plutonium over time in comparison to a scenario that posits no agreement between the two countries. On the assumptions that: (1) the Prototype Fast Breeder Reactor is commissioned in 2011; (2) one new 500 MWe

PHWR is commissioned each year from 2016; (3) one new 500 MWe fast breeder reactor (FBR) is commissioned each year from 2019; and (4) that two out of every three new PHWRs and FBRs are declared civilian, Balachandran's analysis provides the following graphic illustration of India's unsafeguarded plutonium inventory under the two scenarios referred to above.



Source: G. Balachandran, "The U.S.-India Civil Nuclear Cooperation Agreement and India's Strategic Weapons Programs," May 2006, unpublished manuscript.

48. Nunn, "Nuclear Pig in a Poke."

49. Sarosh Bana, "What Can't We Produce?" *Business India*, March 12, 2006, 49.

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ABOUT THIS REPORT

The calculations of plutonium production rates and uranium requirements used in this report are approximations based on generic estimates of the isotopic content of nuclear fuel as a function of burnup and assumptions regarding the thermal efficiencies of power reactors. These calculations should be good to one or perhaps two significant figures—but not to the four or five significant figures shown in the text and tables. These inelegant numeric representations have been retained, however, to enable the reader to understand the arguments and to compare the data in the text and tables as easily as possible. Reactor code calculations on detailed models of the various reactor cores would have provided more accurate estimates, but were not performed for this report. The box on "Civilian Nuclear Cooperation and U.S. Non-Proliferation Treaty (NPT) Obligations" is based partly on the U.S. Department of State's response to Congressional Questions-for-the-Record.

ACKNOWLEDGEMENTS

The author would like to thank Jason Ellis, Gregory Jones, Fred Mackie, Daniel Markey, George Perkovich, Faaiza Rashid, and Dhun Tellis for their valuable comments on this manuscript.

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