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Nuclear Confidence Building in South Asia

Clifford E. Singer
Department of Nuclear Engineering and
Program in Arms Control, Disarmament, and
International Security
University of Illinois at Urbana–Champaign

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Clifford E. Singer
Department of Nuclear Engineering and
Program in Arms Control, Disarmament, and International Security
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Abstract

An analysis made here of fissile materials production cutoffs and more ambitious nuclear materials control measures for South Asia highlights the importance of concentrating near term research efforts on more modest confidence building measures. Options for furthering such nuclear confidence building measures are examined in the context of a review of recent literature on South Asian nuclear programs. A preliminary analysis of limitations on the likely demand for commercial reactor fissile fuels in South Asia suggests that there is a pressing need for a complete quantitative study of future South Asian fissile fuel supply and demand, with and without assuming free access to international markets. If properly carried out with adequate involvement by South Asian personnel, the pursuit of such a study would open valuable lines of communication; and it could contribute to developing international understanding concerning the production, reprocessing, and dispositioning of plutonium. An analysis was also made of prospects for cooperative development of high energy neutron sources for possible future use in the monitoring of nuclear wastes and/or fuel. Particular technical attention was paid to an analysis of computational simulation codes for a promising plasma source. Improvement of the available simulation techniques was identified as an especially promising area for an initial small scale international collaboration.

Section One
Introduction

The purpose of this report is to describe some of our recent work relevant to the military nuclear potential of Pakistan and India. Since neither of these countries officially has a nuclear weapons program, the distinction between civilian and military nuclear potential is even less clear in South Asia than the often blurred lines drawn elsewhere. For this reason, we will begin with a survey of public domain information on overall South Asian nuclear capabilities. While briefer surveys have been published, an adequate survey of the available recent public domain literature is both a generally needed resource and a prerequisite for our own studies.

We then proceed to discuss in some detail several types of possible initiatives aimed at building confidence that nuclear war involving South Asian countries will be avoided. We recognize that internal and domestic political situations make it highly unlikely that India and Pakistan will sign the nuclear Nonproliferation Treaty (NPT) in the foreseeable future.[1] Thus, we concentrate on other potential regional, bilateral, unilateral, and/or nongovernmental initiatives. We also recognize that major bilateral agreements between India and Pakistan in this area are unlikely in the near future, despite Pakistan's official interest in such agreements.[2] This is in part due to the situation in Kashmir.[3] Other cultural and political considerations affecting the prospects for nuclear confidence building will also be briefly described in our discussion of the feasibility of various initiatives. Thus, we shall concentrate on relatively modest and/or long-term possibilities. This approach harmonizes with our view that growing South Asian military nuclear capabilities don't constitute a crisis. Rather, they constitute a potential problem, primarily due to the remarkable vulnerability of indigenous populations to the consequences of even "limited" nuclear war.[4] Along with the potential international effects of the threat or actual use of South Asian nuclear weapons, this vulnerability makes it important for all interested parties to continually help minimize the possibility of the use of nuclear weapons in a crisis involving one or more South Asian countries.

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[1]. See "Roa Firm on Nuclear Stand as U.S. Prepares for Visit," *India Abroad*, 13 May 1994, p. 1; A. Haniffa, "U.S. Stresses Tough Policy," *India Abroad*, 13 May 1994, p. 10; A. Easwaran, "Nuclear Role Urged to Avoid Blackmail," *India Abroad*, 2 September 1994; J. F. Burns, "India Rebuffs U.S. Effort to Slow Nuclear Arms Race with Pakistan," *New York Times*, 26 March 1994, p. A1; S. P. Cohen, "Policy Implications," in *Nuclear Proliferation in South Asia*, S. P. Cohen, ed. (Boulder, Colo.: Westview, 1991), p. 338; I. Gopalakrishnan, "Atom Policy Stands, Rao Says," *India Abroad*, 13 May 1994, p. 10; M. R. Gordon, "South Asian Lands Pressed on Arms," *New York Times*, 23 March 1994; T. N. Srinivasan, "Nuclear Power and Economic Development: India," in *Strategies for Managing Nuclear Proliferation*, D. L. Brito, M. D. Intriligator, and A. E. Wick, eds. (Lexington, Ky.: Lexington Books, 1983); and P. Villaros, *South Asia: The Evolving Context*, Paper 14/3, Programme for Promoting Non-Proliferation, Kandy, Sri Lanka, 4–7 November 1993.

[2]. Reuters, "Pakistan Offers Joint Nuclear Arms Ban," *India Abroad*, 2 September 1994, p. 20.

[3]. UPI, "India Rejects Pakistan's Proposal on Kashmir Plebiscite," 19 January 1994.

[4]. S. Rashid Naim, "Aadhi Raat Ke Baad (After Midnight)," in *Nuclear Proliferation in South Asia*, S. P. Cohen, ed. (Boulder, Colo.: Westview Press, 1991), p. 23.

A primary focus of our comments concerns practicability. A practicable initiative must be feasible in up to three senses. If it involves international agreements and/or assistance, then there must be international mechanisms for its implementation; and it must be compatible with the foreign policies of the countries involved. Whether or not it has an international dimension, it must obviously be compatible with the domestic politics and culture of any consenting country. With many of the more substantive possible initiatives involving nuclear capabilities, there is also the question of technical feasibility. Thus, international, domestic, and technical feasibility will all be discussed as appropriate.

It may well be that there is presently no overlap between the sets of internationally, domestically, and technically feasible nuclear confidence building measures involving formal agreements which include Pakistan and/or India. This is, however, unlikely to remain the case indefinitely. Sources of international discord wax and wane. However, technical capabilities are evolving in a direction which highlights the consequences of nuclear war and the eventual pointlessness of continually building additional nuclear weapons specific capability.

The best mechanisms for laying the groundwork for future cooperation and/or consensual restraint are not all immediately obvious. However, one thing that *is* readily achievable in this regard is increased interpersonal contact between former, present, and future actors in the determination of what is internationally, domestically, and technically feasible. The personnel participating in the presently reported contract research have been active in the first two of these areas for some time. Here, therefore, we concentrate primarily on the need for more interpersonal interactions involving technically trained people. There are three areas we find to be of particular interest in this regard. The first area concerns nuclear fuel cycles. Perceived needs for enriching and/or reprocessing fissile nuclear material for future energy production can have an impact on the production of weapons-usable isotopes. It will be argued that attempts to build coordinated international views of fuel cycles and energy security throughout the world can be useful. A purpose of such studies would be to help all concerned parties differentiate between commercial and military incentives for developing militarily useful nuclear capability. The second area concerns technologies for keeping track of fissile and other militarily relevant isotopes. Questions about capabilities for use of such technology in South Asia are likely to continue be raised in connection with discussions of technical feasibility of possible future confidence building measures involving the nuclear capabilities of Pakistan and/or India. The third area involves integrated approaches to monitoring for shipments of nuclear weapons materials in or out of particular facilities. The ability to accomplish this at acceptable cost could conceivably be necessary for certain types of future confidence building measures involving South Asian countries. Dialogues involving South Asian experts in one or more of these areas are likely to be an essential prerequisite for execution of some of the more substantive proposals where technical feasibility is held to be a relevant issue. For these reasons, a central immediate action item recommendation of this report will be expansion of international exchanges involving technically trained South Asian personnel. Specific candidate projects for achieving this will be examined.

Section Two
South Asian Nuclear Facilities

The purpose of this Section is to report in depth on recent public domain information about South Asian nuclear programs. We begin with a general overview of South Asian nuclear facilities and capabilities, go on to a more detailed description of reports on the operating history of facilities, and conclude with a review of various author's inferences about South Asian military nuclear capabilities.

We begin the overview with the more straightforward Pakistani program. By concentrating on uranium enrichment, Pakistan has developed a fairly certain military nuclear capability, the extent of with depends primarily on the operating history of its enrichment centrifuges. There is apparently no quantitatively reliable public domain information about this operating history. Thus the total achieved enrichment (generally measured in "separative work units" is not public domain knowledge. Neither is the amount that may have been enriched to nuclear explosive levels of over 20 percent U–235. The most that can be reliably deduced using public domain knowledge is the amount of highly enriched material which could have been made in principle, given various reasonable assumptions about centrifuge numbers, configurations, and operating history. Pakistan has also developed plans for nuclear reactors which could eventually be militarily relevant.

The situation in India is far more complex, for a variety of reasons. First, optimization of India's commercial nuclear reactor operation for power production yields "reactor grade" heavily irradiated plutonium. The isotopes heavier than Pu-239 in this material reportedly make it an unattractive weapons material for a country which has the capability to manufacture substantial amounts of more lightly irradiated plutonium.[5] From the point of view of military capability, India is fully self-sufficient in plutonium capability. It has c. 1.7 GW_e (billion watts electric) of unsafeguarded power reactor capacity installed, 1.1 GW_e under construction, and an additional 0.5 GW_e at Tarapur, which it has said should be exempt from safeguards.

India also has seven heavy water plants of significant capacity in six different provinces, and "exported 100 tons of heavy water worth $23 million to South Korea" in April of 1994. These plants include an interesting if potentially problematic facility at Hazira—the first indigenous Indian plant to use a hydrogen–ammonia exchange process. India's Public Accounts Committee "estimated the cost of heavy water production would be Rs 13,800/kg ($400/kg in a 1993 report)."[6] Its Department of Atomic Energy "had told the committee that production at its Tuticorin plant costs around Rs4120/kg ($120/kg) but did not provide detailed production costs, information on installed capacity or production records for the last five years of operation." Thus, the price of India's current self-sufficiency in heavy water production remained to be definitively documented.[7] By way of comparison, the Indian Department of Atomic Energy's 1991–92 Annual Report showed c. 13% of $2x10^{10}$ Rs spent on heavy water projects vs.

5. J. C. Mark, *Reactor-Grade Plutonium's Explosive Properties* (Washington, D.C.: Nuclear Control Institute, August 1990).

6. "D_20 Programme Called to Account," *Nuclear Engineering International,* (May 1993): 11.

7. "Fire at Baroda," *Nuclear Engineering International,* (August 1994): 16.

just over 50% on nuclear power projects, c. 10% on the Nuclear Fuel Complex, and 7.5% for the Bhabba Atomic Research Center.[8] Substantial cuts were expected in 1992.[9]

In Trombay, north of Bombay, India has 0.14 GW_t (billion watts thermal) of "research reactor" capacity which has been used to support the construction of a nuclear explosive. It also has a fast breeder test reactor designed for .04 MW_t and thorium irradiation in the southeast coastal province of Tamil Nadu, which was shut down in 1987 for two years but subsequently restarted.[10] It has fuel reprocessing plants and in three different locations and three fuel fabrication plants in operation or under construction.[11] It has adequate supplies of uranium ore to operate for many decades all nuclear plants present in design, construction, or operation. The geographical distribution of India's nuclear facilities makes it highly unlikely that its ability to make additional weapons grade plutonium could be directly eliminated for a significant time by an isolated natural disaster or attack. India's nuclear infrastructure also appears sufficient to avoid significant interference with this ability by international sanctions focused narrowly on nuclear technologies. India's internal politics also appear to make it highly unlikely that modestly more broadly based international sanctions would have much effect on its ability to manufacture weapons grade plutonium, even in the hypothetical event that a sufficient number of other countries would convince themselves that this was both desirable *and* practicable.

India's military capability to manufacture fissile materials (and potentially even naval propulsion reactors)[12] is substantial. However, the contribution of its nuclear program to its electrical power consumption is modest, despite the fact that it consumes a substantial fraction of India's budget for "advanced" technology. This puts India at a crossroads where it is particularly interesting to make a careful examination of its nuclear program, especially its breeder reactor research program.

Indian scientists and engineers also provide an important part of the domestic base for its nuclear programs, with technical breadth in the fission area here evidenced by a few example articles from the international literature.[13]

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8. "India—Annual Report 1991–92," *Nuclear Energy*, 32 (1993): 73.

9. "Nuclear Budget Cut," *Nuclear Engineering International*, (March 1992): 52; "Nuclear Wins in Budget Allocation," *Nuclear Engineering International*, (March 1992): 8.

10. "India's FBR Programme Faces New Delays and Abandons New Fuel Changes," *Nuclear Engineering International*, (February 1991): 4.

11. "Tarapur Stalled by Resource Crunch," *Nuclear Engineering International*, (November 1994): 3.

12. N. M. Naik, "High-Level Expert Confirms India Developing Nuclear Submarine," Associated Press, 10 December 1994.

13. See C. Ganguly, U. K. Viswanathan, and K. S. Balakrishan, "Study on the Irradiation Embrittlement of a Microalloyed Ferritic Steel," in *Effects of Irradiation on Materials, Process*, 16th International Conference, p. 186; M. S. Kulkarni, P. Ratna, S. Kannan, and T. V. Venkateswaran, "A Data Logger for Personnel Monitoring TLD Readers," *Nuclear Institutional Methods in Physical Research* A334 (1993): 512; A. K. Ghosh, V. V. Raj., and A. Kakodkar, "A Scheme for Passive Isolation of the Containment of a Reactor," *Nuclear Safety* 34 (1993): 76; B. Raj, D. K. Bhattacharya, and P. Rodriguez, "Development of In-Service Inspection Techniques for Nuclear Power Plants in India," *International Journal of Pressure Vessels and Piping* 56 (1993):183; C. Ganguly, P. V. Hedge, and G. C. Jain, "Fabrication of $(Pu_{0.55}U_{0.45})C$ Fuel Pellets for the Second Core of the Fast Breeder Test Reactor in India," *Nuclear Technology* 105 (1994): 346; B. Mahalakshmi, and Mohanakrishnan, "Analysis of Radially Heterogeneous ZPPR-13A Benchmark for Investigating the Spatial Dependence of the Calculated-to-Experimental Ratio for Control Rod Worths," *Nuclear Science Engineering* 115 (1993): 341; V. J. Katti, Y. R. S. Saradhi, S. N.

TABLE 1 Pakistani Nuclear Power Reactors

Name	*Location*	*Type*	*Power*	*Enriched*	*Critical*	*Supplier*
Kanupp	Karachi	PHWR	.125 GW_e	no	1971	Canada
Chasma I	Chasma	LWR	.9 GW_e	low	[$\geq$ 1997]	China
PARR-1	Karachi	research	.010 GW_t	20 %	1965	U.S.
PARR-2	Karachi	research	27.0 kW_e	high		China

Pakistani Facilities

An overview of some of Pakistan's nuclear reactors is given in Table 1.[14]

The Kanupp pressurized heavy water reactor (PHWR) is a continuously fueled heavy water moderated CANDU reactor. This is safeguarded, despite the fact that Pakistan supplied the fuel from Chasma for the Kanupp plant after 1990. The Chasma light water reactor (LWR) would have been unsafeguarded if Pakistan had developed it without external assistance. It has been reported that a contract for completion of this reactor has been signed an begun implementation with China.[15] This reactor should be similar to the Chinese pressurized water reactor that went on line in December of 1991 at Qinshan in Zheijiang Province.[16] The PARR-1 reserach reactor went recritical in 1991 on 20% enrichment with an upgrade from .005 GW_t to .01 GW_t.[17] The Chinese-supplied PARR-2 light water research reactor (LWR) was safeguarded under an agreement between Pakistan and the International Atomic Energy Agency (IAEA) signed in December of 1990.[18] Thus, none of these facilities presently gives Pakistan unsafeguarded access to plutonium. In 1978, France withdrew cooperation on a reprocessing facility designed for 100 metric tons per year of spent fuel at Chasma. An order of magnitude smaller scale French-supplied reprocessing plant underwent cold tests at Rawalpindi in 1982. (A settlement of a $118 million dispute over French withdrawal from Pakistani reprocessing programs was reported in 1992).[19] There is also an experimental scale British-planned reprocessing facility at the Rawalpindi complex.

Pak, D. C. Banerjee, and R. Kaul, "Application of Remote Sensing Techniques for Nuclear Power Project Site Selection in India," *International Journal of Remote Sensing* 14 (1993) 3291. See, however, India's FBR Programme Faces New Delays, p. 4.

14. Jon Neuhoff and Cliff Singer, "The Verification and Control of Fissile Material in South Asia," in *Towards a Nuclear Verification Regime in South Asia*, Los Alamos National Laboratory subcontract 9-XC9-C4353-1 final report (1990), p. 165; condensed in *Nuclear Proliferation in South Asia*, S. P. Cohen, ed. (Boulder, Colo.: Westview Press, 1991), p. 207; F. W. Krüger, "Adapting Planning to Conditions in Developing Countries," *Nuclear Engineering International* (May 1993): 25; "Datafile: Pakistan," *Nuclear Engineering International*, (May 1991): 52.

15. F. W. Krüger, "Adapting Planning to Conditions in Developing Countries," *Nuclear Engineering International*, (May 1993): 25; "Civil Construction Began for Pakistan's Chasma Plant," *Nuclear News*, (February 1993) p. 52.

16. "Deal Closed with China for 300 MWe PWR Import," *Nuclear News*, (February 1992) p. 40.

17. "PARR's New Lease of Life," *Nuclear Engineering International*, (December 1991) p. 3.

18. "Pakistan Safeguards," *Nuclear Engineering International*, (1991) p. 3.

19. "France and Pakistan in Accord on Compensation," *Nuclear Engineering International*, (March 1992) p. 7.

Pakistan also has a 13 tonne/year heavy water production plant at Multan, and an additional heavy water facility at Karachi. (There are also reports of German technology for tritium extraction having been transferred to Pakistan.)

Indian Facilities

Table 2 contains a summary of the Indian nuclear program as of the date of compilation on 30 April 1994.[20] As in Table 1, the total gigawatts of thermal power (GW_t) for is about three times the electrical production power (in GW_e) reported for electrical power production reactors. India maintains that the boiling water reactors (BWR's) from U.S. suppliers should no longer be safeguarded. For the Indian products, square brackets in Table 2 indicate reactors reported as planned in April 1990 but not as under construction in April 1994. Parentheses give expected operation dates reported in 1990, and "delayed" indicates that these dates passed without a report of reactor operation in 1994. The notation 1995* indicates announced commercial operation for Kakrapar II in 1995. Trombay means the Bhabba Atomic Research Center (BARC) north of Bombay (where an additional 400 MW_t research reactor was reportedly decommissioned in 1983). Kalpakkam means the laboratory in Tamil Nadu, where U-233 breeding from thorium has also been investigated in three research reactors, one of which had a thermal power of 30 kW.

Several types of potentially serious construction or operations problems have occurred in Indian nuclear electric power plants. The most recent was the collapse of 10% of the containment dome during construction of the Kaiga I plant in Karnataka on 13 March 1994.[21] In March 1993, a turbine building fire occurred at Narora I in Uttar Pradesh,[22] which eventually resulted in two-three week turbine inspections throughout most of India's nuclear power plants.[23] A third problem is the possible reduction in plant lifetime due to average of 200 shutdowns per year for the Madras and Narora plants, reportedly due to fluctuations in power demand on the electrical grid. In general, radiation exposure to workers considerably higher than the world average has resulted in part from leaks of radioactive water. One of India's 0.22 GW_e nuclear plants is running at one third of rated capacity after several years of shutdown in the 1980's for repair of a cracked endshield. Also, two 0.22 GW_e plants in Kalpakkam are limited to 75% capacity due to problems with the "moderator's distribution system. Not all of these problems are specific to nuclear power plants. Moreover, their existence in themselves says nothing substantial about India's ability to produce substantial amounts of plutonium (albeit

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20. J. Neuhoff and C. Singer, "The Verification and Control of Fissile Material in South Asia," in *Towards a Nuclear Verification Regime in South Asia*, Los Alamos National Laboratory subcontract 9-XC9-C4353-1 final report (1990), p. 165; condensed in Nuclear Proliferation in South Asia, S. P. Cohen, editor (Westview, 1991) 207; "U-233 Reactor Goes Critical," *Nuclear Engineering International*, (1991) p. 6; M. R. Balakrishan, "Looking at Fast Breeder Fuel with India's Kamini Reactor," *Nucler Engineering International*, (February 1991) p. 50; "World Survey," *Nuclear Engineering International*, (June 1993) p. 21.

21. "Containment Collapses at Kaiga," *Nuclear Engineering International*, (July 1994).

22. "Narora-1 Stabilized after Fire, Blackout," *Nuclear News*, May 1993, p. 53; "Narora 1 Turbine Hall Gutted by Fire," *Nuclear Engineering International*, (June 1993) p. 2.

23. "Turbine Inspections Will Idle Most of India's Reactors," *Nuclear News*, (August 1993) p. 87.

TABLE 2 Indian Nuclear Reactors

Name	*Province/(Site)*	*Type*	*Power*		*Critical*	*Supplier*
Tarapur I	Maharashtra	BWR	.15	GW_e	1969	USA
" II	"	"	.15	"	1969	"
" III	"	PHWR	.47	"	[1997]	India
" IV	"	"	"	"	[1998]	"
Rajasthan I	Rajasthan	PHWR	.207	"	1972	Canada
" II	"	"	""		1980	India
" III	"	"	.22	"	(1994)	"
" IV	"	"	""		(1995)	"
Madras I	Tamil Nadu	PHWR	""		1983	"
" II	"	"	""		1985	"
Narora I	Uttar Pr.	PHWR	""		1989	"
" II	"	"	""		c. 1990	"
Kakrapar I	Gujarat	PHWR	""		1992	"
" II	"	"	""		1995*	"
" III	"	"	""			"
Kaiga I	Karnataka	PHWR	""		(1994)	"
" II	"	"	""		(1995)	"
" III	"	"	""		[1998]	"
" IV	"	"	""		[1999]	"
Aspara	(Trombay)	PWR	.001	GW_t	1956	UK
Cirus	"	PHWR	.04	"	1963	Canada
Dhruva	"	"	.1"		1985	India
FBTR	(Kalpakkam)	Pu breed	.42	"	1985	India
Purnima 3	(Trombay)	U-233	.000	"	1990	India

with most except "research reactor" material[24] unsuitable except as a last resort for a nuclear weapons program unless one assumes[25] weapons-grade rather than reactor grade burn-up continues indefinitely after initial reactor operation.) The existence of these problems may be relevant to the question of the commercial value of plutonium, but a more detailed study of their implications for future fuel demand in India would be required before specific conclusions about this could be drawn.

Much of what has been written on military nuclear capabilities in South Asia has been framed in the context of arguments for and against India and/or Pakistan signing the Nonproliferation Treaty. Accepting the reality of both countries' nuclear weapons capability[26] and focusing on future possible confidence building measures frees one from increasingly fruitless debates over the history of how this capability was acquired. It is still useful to have as accurate information as possible about the extent of these capabilities, since this may have some impact on the range of confidence building measures which is potentially practicable. However, there is no need in this context either to exaggerate or underplay the nuclear weapons capability of either country. For that reason, our review here concentrates primarily on carefully referenced documentary information potentially relevant to these capabilities.

24. B. Chellaney, "The Challenge of Nuclear Arms Control in South Asia," *Survival* 35 (1993): 121.

25. T. W. Wilson, "Shiva and Allah: Nuclear Futures for India and Pakistan—Transforming the South Asian Power Balance," The Wilson Center Asia Program *Occasional Paper* 28 (1986).

26. B. Chellaney, "The Challenge of Nuclear Arms Control in South Asia," Survival 35 (1993): 121; M. Manoharan, "India, U.S. to Cooperate on N-Power Safety," Reuters, 14 July 1994.

Section Three
Potential Confidence Building Measures

A more general discussion of adding South Asian nuclear confidence building measures to that already in place[27] has been presented in a companion report and previous work by S. Burns.[28] Our briefer discussion here is meant to provide a complementary view which focuses rapidly onto to specific measures that can be profitably be pursued at the research level in the near term. The measures of interest here can be broadly classified into five different categories. First, there are essentially political initiatives without immediate technical implications. These include third party diplomatic efforts, regional conferences, statements concerning restrictions on use of nuclear weapons, notification of certain activities, etc.. These are left for others to discuss. The second category involves nuclear test bans. This is beyond the scope of the present discussion, and is presumably being actively researched by others in connection with ongoing negotiations for a comprehensive test ban. The third category involves controls on production of special nuclear materials, including plutonium, enriched uranium, and/or tritium. South Asia presents some unique problems and opportunities in this area, as discussed in some detail below. The fourth category involves control on the use and/or location of special nuclear materials, a problem which also raises interesting questions in the South Asian context. The fifth category involves exchange of technical experts and/or information.[29] Proposals include enhanced telecommunications, provision of devices (or their design) for preventing unauthorized weapons detonation, controls on deployment of nuclear delivery systems, foreign support for civilian nuclear programs, exchange of experts and/or joint research programs on technical issues, site visits, and provision of verification technologies. Some of these are likely to be more useful than others in the immediate South Asian context. Here we simply outline some of these possibilities, deferring detailed discussion to Section 4 and the Appendix and Addendum to this report.

Controls on Production of Special Nuclear Materials

A deceptively simple-sounding proposal is for a prompt cut-off in the production of isotopes for potential use in nuclear weapons in South Asia. In the context of the U.S. program, we know precisely what this means. Previous programs for the production of highly enriched uranium, plutonium reprocessing, and tritium production would simply not be restarted. Since the U.S. has large reserves of highly enriched uranium, no plans to burn plutonium in commercial reactors, and no commercial tritium production reactors, a halt to these programs means no capacity to produce additional nuclear weapons isotopes. This can occur with no impact on civilian industry other than loss of hoped for contracts, and with no impact on nuclear weapons programs other than a possible distant problem in making up for decaying nuclear weapons' tritium (if tritium production is ever also controlled). If a recent agreement with Russia on plutonium production is

27. "India and Pakistan Have Exchanged Nuclear Site Lists," *Nuclear News,* February 1992.

28. S. M. Burns, "Stabilizing the Option: Deterrence, Confidence Building, and Arms Control in South Asia," *U.S. Department of Energy Contract No. 94-47DH-011 Report* (March 1995); S. Burns, "Preventing Nuclear War between India and Pakistan," *Friday Times,* 29 March-4 April, p. 11.

29. M. Manoharan, "India, U.S. to Cooperate on N-Power Safety," Reuters, 14 July 1994.

carried out, the situation is almost this simple with respect to the former Soviet Republics. If verification of fissile nonproduction is ever needed, it should be relatively straightforward to verify that previously used plants have not been restarted. Clandestine start-up of new facilities on anything but a scale of production with trivial impact on existing stockpiles could also be difficult to achieve in the face of present domestic attitudes and international detection capabilities in the readily foreseeable future.

The South Asian context in this respect is very different! Pakistan says it is interested in uranium enrichment for its future commercial power program. Continued enrichment could also have a substantial impact on the number of nuclear weapons Pakistan can have available. India has a plutonium breeder program, and may be interested in reprocessing of plutonium from PHWRs in the name of energy security. India does not necessarily draw the same distinctions between commercial and weapons grade plutonium as are used elsewhere. To our knowledge, moreover, India has not released complete production statistics on the plutonium isotope distribution of the material it has been producing and reprocessing. The situation with respect to tritium is also more complicated for a country relying on heavy water moderated reactors. This is because tritium is an operationally inconvenient by-product of reactions of reactor neutrons with deuterium in the heavy water, and technology has been developed for removing the tritium. Normal operation of GW_e levels of PHWRs can supply the tritium necessary to continuously replenish a substantial number of fission-boosted nuclear weapons.

These particular aspects of the South Asian situation raise a number of political and technical concerns about proposals to cut off production of weapons-usable isotopes. Dealing with these concerns is likely to require avoid retriggering of several Indian objections to the more inclusive Nonproliferation Treaty. First, for the foreseeable future, previously produced plutonium would probably need to lie beyond the scope of any verification methods used. Second, India might well insist on the ability to reprocess commercial-grade plutonium without interference, at least in the immediate future. This raises a particular technical problem concerning the first fuel elements expelled from a PHWR after its first criticality. These elements may be of quite low irradiation, and thus have very high Pu-239 content. A key technical question may lie in agreeing on methods for tracking the fate of such elements. Parallel arrangements in other countries starting up PHWRs with push-through fueling elements might be required. India may insist on no oversight of its tritium handling operations, or on parallel arrangements in other countries using heavy water reactors.

Even if Pakistan is eventually willing to cooperate with a cut-off in the production of highly enriched uranium, it may want to delay related verification measures until some time after making an agreement to participate eventually. This could be to allow for the possibility of producing some highly enriched uranium in the interim if it felt this necessary, to clear the process stream from older activities for commercial or national security reasons, or to configure the process stream to protect perceived commercial or national security interests.

Use or Location of Special Nuclear Materials

Controls on the use and/or location of special nuclear materials in South Asia present a much broader range of political and technical problems. A complete and monitored declaration of inventories is a sufficiently highly unlikely starting point that it is only touched upon here. Restricting special nuclear materials from a certain limited areas is the most technically straightforward task, albeit with limited strategic utility. An example would be controls on the storage of weapons-usable materials on certain air bases and/or rocket launch facilities. This would essentially be a symbolic confidence building measure, since such materials could be rapidly transported to such a facility once a policy decision were made to do so. However, technology for initial inspection and portal monitoring for such an agreement is relatively well developed. The most vexing fundamental technical question might concern limits on shielding of fissile materials, both for the initial implementation of such an agreement and flow of materials through the facility portals. A technically simpler (but politically more complicated) task would be limiting the flow of weapons-usable materials out of certain possible storage sites. Assuming a reasonable agreement on definition of the facilities' boundaries, monitoring, and limits on shielding for transports across the boundaries, the technology for limiting the outflow of fissile materials could be developed. However, such an arrangement could be of limited political utility without an initial inventory and/or controls on location of fissile materials at other sites.

A much more challenging task would be excluding weapons-usable isotopes from all but a particular number of sites. To make this really useful would require one or both of two difficult tasks. One would a reasonably accurate initial inventory, correlated with production history well enough to verify that the isolation of this inventory is of some use in confidence building. The other would be some combination of challenge inspection and/or whistle-blowing facilitation for disclosure of activities outside the scope of an agreement. The problem of planning for the possibility of challenge inspections across South Asia is formidable. Correlating initial inventory with production history could be an interesting technical exercise, if the enormous political problems confronting such a concept could ever be overcome. This report will eschew discussion of such problems in favor of the more limited and preliminary types of confidence building measures just outlined.

Exchange of Experts

The exchange of technical experts has a long history in the twilight of the Cold War, and arguably laid some of the groundwork for progress in dealing with the nuclear detritus of that era. This precedent makes such an exchange in the South Asian context an interesting idea in the abstract. What is needed to convert this to more practical form is a particular set of proposals concerning the projects that technically trained personnel could work on together. Here we examine three such possible projects that are particularly pertinent and practical for such exchanges. These concern, respectively, the motivation and means for India and Pakistan to proceed with confidence building measures concerning special nuclear materials.

One project where international cooperation is likely to be essential for optimal success is a study of the regional commercial value of plutonium reprocessing in the post-Cold War era. Various developments in the past two decades have had a profound impact on some analysts opinions concerning the global commercial value of plutonium reprocessing.[30] These include saturation in growth of the nuclear power industry in industrialized countries, a relatively modest growth elsewhere of this industry (concentrated primarily in Asia), the development of a large surplus of enriched uranium and uranium production capacity, and additional experience with the production cost of plutonium handling and breeding. For example, the results of these trends have recently led a Rand Corporation study to the conclusion that reprocessing plutonium from U.S. nuclear power reactors will be uneconomic for the foreseeable future.[31] However, recent work does not adequately address longer term energy demands nor special circumstances which may be invoked in discussing South Asian markets. To convincingly reassess the commercial value of plutonium reprocessing in South Asia requires two things. First, the extent to which Pakistan and/or India might be excluded from open buying on the world uranium market needs to be examined. Their domestic nuclear and conventional electricity supply and demand situations need to be examined carefully in this context, as well as in the context of what has been learned over the past few decades in the rest of the world. Second, South Asian technical experts would need to be involved in such a study if the results are to speak to and be listened to by a South Asian audience. Provided the choice and editorial freedom of the authors of such a study were sufficiently unfettered, such a study could have enough credibility to have some appreciable impact on commercially-related impediments to South Asian confidence building measures relevant to nuclear reactor and fuel cycle operations.

Another area where exchanges of experts could be desirable is in the development of technologies which might eventually be useful for confidence building measures in South Asia. Any of a number of such technologies could provide a vehicle for such a project. However, the use of high flux and/or energy neutron sources for detection of isotopes relevant to various confidence building measures is of particular interest in the South Asian context. This methodology is often not particularly appropriate for verification of U.S.–Soviet nuclear arms control initiatives, because it could potentially reveal some information about design of the world's most compactly destructive nuclear explosives. It is also precluded for historical reasons from routine use by the International Atomic Energy Agency in support of the Nonproliferation Treaty. However, it is a particularly powerful methodology for nondestructive investigation of special isotopes *and the shielding which might obscure their presence.* Although still potentially pertinent, neither of the problems limiting the use of this technology elsewhere are necessarily universally relevant in South Asia. Moreover, there is substantial scope for the unclassified development of such technologies for use in management of radioactive wastes, well logging, detection of conventional explosives, and a number of other applications. Therefore, a joint project with U.S. and South Asian scientists to further develop this technology could be of substantial mutual benefit.

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30. D. E. Sanger, Japan, "Bowing to Pressure, Defers Plutonium Projects," *New York Times,* (22 February 1994) p. A2; B. G. Chow and K. A. Solomon, *Limiting the Spread of Weapon-Usable Fissile Materials,* (Santa Monica, Calif.: Rand, 1993); J. P. Holdren, C. M. Kelleher, W. K. H. Panofsky, P. M. Doty, A. H. Flax, R. L. Garwin, D. C. Jones, S. M. Keeny, J. L. Lederberg, M. M. May, C. K. N. Patel, J. D. Pollack, J. D. Stenibruner, R. H. Wertheim, J. B. Wiesner, J. Wyngaarden, J. L. Husbands, M. Bunn, L. Lewis-Oliver, M. Oliva, and L. E. Peterson, *Management and Disposition of Excess Weapons Plutonium,* (Washington, D.C.: National Academy of Sciences, 1994).

31. B. G. Chow and K. A. Solomon, *Limiting the Spread of Weapon-Usable Fissile Materials,* (Santa Monica, Calif.: Rand, 1993).

A third project with particular potential for useful international exchanges involves a detailed examination of a particular trial confidence building initiative. The example considered here is a study of the problems of monitoring a particular pair of South Asian facilities for transshipment of fissile materials. While more politically ambitious than the background studies mentioned above, such a study would still be much smaller in scope than more sweeping proposals for production cut-offs or other nation-wide monitoring of nuclear programs.

Section Four
Practicability: International, Domestic, and Technical

As noted above, any externally promoted initiative aimed at nuclear confidence building in South Asia must be practicable in three senses to be useful. First, it must not require infeasible international agreements or financial arrangements. Second, it must be domestically acceptable in the pertinent South Asian country or countries. Third, it must be technically practicable. It should be possible to tailor all three of the projects examined here to meet these requirements.

Fuel Cycle Studies

A study of the likely role of fuel reprocessing in future South Asian electricity production would best include experts from the area in both economics and nuclear engineering. A small joint U.S. and South Asian team could survey the existing literature[32] and also

32. T. N. Srinivasan, "Nuclear Power and Economic Development: India," in *Strategies for Managing Nuclear Proliferation*, D. L. Brito, M. D. Intrilgator, and A. E. Wick, eds. (Lexington, Ky.: Lexington Books, 1983); D. E. Sanger, Japan, "Bowing to Pressure, Defers Plutonium Projects," *New York Times*, (22 February 1994) p. A2; B. G. Chow and K. A. Solomon, *Limiting the Spread of Weapon-Usable Fissile Materials*, (Santa Monica, CA: Rand, 1993); D. Albright, F. Berkhout and W. Walker, *World Inventory of Plutonium and Highly Enriched Uranium 1992*, (Oxford: Oxford University Press, 1993); P. M. and J. James Finucane, "Plutonium as an Energy Source, Quantifying the Commercial Picture," *IAEA Bulletin* 35 (#3, 1993) p. 88; *Organization for Economic Cooperation and Development (OECD), Projected Costs of Generating Electricity Update 1992*, (Paris: OECD, 1993); Jasjit Singh, "A Pitfall of Divergence for Nonproliferation Policy," *India Abroad*, (13 May 1994) p. 2; House of Commons Energy Committee, *Fourth Report, Session 1991-92*, (London: HMSO, 1992); S. Subak, P. Raskin, and D. Von Hippel, *National Greenhouse Gas Accounts*, (Boston: Stockholm Environment Institute, 1991); J. Anderer, J. McDonald and N. Nakicenovic, *Energy in a Finite World*, (Cambridge, MA: Ballinger, 1981); International Energy Agency, *World Energy Outlook to the Year 2010*, (Paris: OECD/IEA, 1993); World Bank, *World Population Projections, 1992-1993 Edition*, (Baltimore: Johns Hopkins University Press, 1992); World Energy Council, *Energy for Tomorrow's World*, (New York: St. Martin's Press, 1993); Dostrovsky, *Energy and the Missing Resource*, (Cambridge, MA: Cambridge University Press, 1988); K. Ahmed. *Renewable Energy Technologies: A Review of Status and Costs of Selected Technologies*, (Washington, D.C.,: World Bank, 1994); World Energy Council, *Renewable Energy Resources: Opportunities and Constraints 1990-2020*, (London, 1993); R. P. Omber and C. E. Wlater, *Disposition of Plutonium form Dismantled Nuclear Weapons: Fission Options and Comparisons*, University of California Rep. UCRL-ID-113055 (Springfield, VA: National Technical Information Service, 1993); *Projected Costs of Generating Electricity, Update 1992*, Organization for Economic Cooperation and Development/International Energy Agency, (Paris: OECD, 1993); D. J. Holland, "Costs and Risks of Plutonium and Highly Enriched Uranium in Civil Nuclear Programs," (Washington, D.C.: Nuclear Control Institute, 1990); L. C. Hebel, "Limiting and Reducing Inventories of Fissionable Weapons Materials," (Palo Alto, Calif.: Stanford

develop energy production scenarios which are parameterized by various rates of economic development, various degrees of access to international markets for nuclear fuel, and by various governmental policy options.[33] The implications of such scenarios for the commercial value of reprocessing and possibly breeding fissile fuels in South Asian countries could then be assessed, and also perhaps integrated using appropriate statistical risk–benefit methodology.

A particularly important factor in understanding the likely growth in demand for fissile fuels for commercial reactors in South Asia concerns the availability of capital.[34] Many previous models of global and regional energy economies may have given inadequate attention to this factor. Often, the driving factor in such studies is the concept of per capita demand for use of energy and/or electricity. More sophisticated studies have considered the possibility of alteration of this demand by improved by substitution of different energy sources for one another, conservation, and/or regulatory effects on pricing. Underlying all of these approaches is often the implicit assumption that supply will (or at least should) meet the per capita demand so estimated.

The fate of India's plans to build two 1000 MW_e reactors in the south illustrates how availability of capital can have a significant impact. Originally, these were to be imports of VVER reactors from the Soviet Union. However, contract negotiations moved slowly, "in part because of disagreements over financing terms." Still, in 1991 Indian Atomic Energy Commission Chair P. K. Iyengar said that "work on the site in Tamil Nadu would begin later this year, and that the plant would be complete in 1998."[35] In the end, Russian financing could not be arranged, and India considered seeking additional financing on the open market [36] and from Tamil Nadu (27% financing) and neighboring states (22% financing together) for reactor construction of a single 0.5 GW_e indigenous heavy water reactor [37] of the type to be first sited at Tarapur,[38] resources permitting.[39]

Demands for capital could be a significant factor in India's nominally imminent decision on whether to build a 500 MW_e fast plutonium breeder prototype. Commitment to this project would almost inevitably divert resources from investment in research, development, and/or production of additional energy supplies by other means. This decision is only one piece of the whole plutonium–uranium puzzle in South Asia

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University Center for International Security and Arms Control, 1991); "India Invites Private Investors," *Nuclear Engineering International*, (October 1992) p. 14.

33. J. Anderer, J. McDonald and N. Nakicenovic, *Energy in a Finite World*, (Cambridge, MA: Ballinger, 1981); *World Energy Outlook to the Year 2010*, International Energy Agency, (Paris: OECD/IEA, 1993).

34. "India Invites Private Investors," *Nuclear Engineering International*, (October 1992) p. 14; S. K. Chatterjee, "India's Nuclear Power Programme and the Resource Crunch," *Nuclear Engineering International*, (September 1993) p. 61; "Indian Nuclear Projects May Be Put on Hold," *Nuclear Engineering International*, (October 1994) p. 3; G. S. Bhargava, "Nuclear Power in India: The Costs of Independence," *Energy Policy*, 20 (1992) p. 735.

35. "India Expects to Start Work this Year," *Nuclear News*, (April 1991).

36. "Confusion at Koodankulam," *Nuclear Engineering International*, (August 1992) p. 7.

37. "Koodakulam: Kerala State Joins In," *Nuclear Engineering International*, (January 1993) p. 7; "Koodankulam Shrinks Again, to 500MWe," *Nuclear Engineering International*, (June 1993) p. 6.

38. "On Line, off Line, in India," *Nuclear Engineering International*, (April 1994) p. 8.

39. "Indian Nuclear Projects May Be Put on Hold," *Nuclear Engineering International*, (October 1994) p. 3; "It's Business, not Religion," *Nuclear Engineering International*, (June 1994) p. 16; "Tarapur Stalled by Resource Crunch," *Nuclear Engineering International*, (November 1994) p. 3.

and neighboring countries. Still, in a nuclear energy sector of the scope of India's, described in detail above, it is no small matter.

The debate on proceeding with a fast breeder program in India has been succinctly summarized in a qualitative fashion by V. Menon.[40] The initial breeder program is meant to produce fuel for the second of three stages of fissile material use in India: (1) natural uranium, (2) plutonium (first via reprocessing of uranium burner fuel, to initially fuel breeder reactors), and (3) U-233 from thorium. That India would even consider breeding U-233 from thorium may be a legacy from an era where rapid and fairly sustained exponential growth of nuclear electricity supplies was forecast throughout the world. A 1991 estimate quoted 70,000 metric tonnes (70 kt) of Indian uranium reserves as "modest," and noted an estimated 360 kt domestic reserves of thorium. Some U-233 has been produced in research reactors; and recently thorium has been added as an efficient neutron absorber in an initial heavy water reactor fueling).[41] However, India's Fast Breeder Test Reactor, initially designed to include tests of U-233 breeding, has had a number of problems recently critically reported in the Indian press by V. Menon.[42] Menon also gave a succinct qualitative summary of recent events which he says call the whole Indian breeder program into question.

> Recent international events, however, undermine the very basis of the three stage Indian nuclear power programme. With the demilitarisation of the Eastern Bloc, vast quantities of low enriched uranium are now available in the international market-place. Under International Atomic Energy Safeguards there's no reason why the enriched uranium should not be treated as a commercially negotiable commodity. If such deals come through, the entire rationale for the near term implementation of fast reactors in India or anywhere else will be stood on its head.

As in other countries, the director of the institution where breeder research is centered (in this case the Indira Gandhi Centre of Atomic Research) wants to continue the program. Menon noted, however, that the "Nuclear Power Corporation itself is starved of funds with the Government refusing to give it money. All attemps to expand its meagre installed base of 1,720 MW through joint ventures have failed to take off." Menon concluded that this leaves the Indian Department of Atomic Energy in the following situation: "In other word, they can design and run paper reactors. And the DAE's dream project (the Prototype Fast Breeder Reactor) will remain a mirage."

It should be noted that, in reality, the effect of deenriched highly enriched uranium being sold as commercial fuel can only have a transient effect even on the international uranium market (albeit for a decade or more). Moreover, while the subsequent announcement of a Chinese supplier of enriched uranium for Tarapur indicates that India may be able to sidestep other's demands for full scope safeguards, future access to international markets is likely on economic competition grounds but not absolutely guaranteed. Nevertheless, Menon's article does raise in a domestically visible way

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40. V. Menon, "Fast Breeder Reactors Moving at a Snail's Pace," *India Today*, (30 November 1994) p. 66.

41. "Thorium Is Being Used in the First Core at Kakrapar-1," *Nuclear News*, (August 1992) p. 76; "India Prepares for Its First Load of Thorium Fuel,"*Nuclear Engineering International*, (August or September 1992) p. 14.

42. V. Menon, "Fast Breeder Reactors Moving at a Snail's Pace," *India Today*, (30 November 1994) p. 66.

questions about how serious the Indian uranium fuel supply problem could plausibly become on the 25 to 50 year timescale for development of alternatives to domestic uranium supplies, even if India continues to rely primarily on this source using natural uranium burners for any expansion of its nuclear power program. Even if a decision on the underlying logic of the Inidan breeder program gets finessed by an appeal to the inadequacy of available funds, the question of the degree of future of reprocessing and fuel fabrication of plutonium from ordinary uranium burners will remain. Thus, a more quantitative analysis is still needed.

A "straw man" example of a quantitative analysis of the situation concerning the domestic Indian uranium supply is given on the following page in Table 3. Table 3a shows estimates of Reasonably Assured Resources (RAR), Category I ("low-cost") Estimated Additional Resources (ERA-I), and Speculative Resources (SR) for India.[43] Speculative Resources are expected on general geological evidence (a) "along a 64 km long middle Proterozoic Vempalle limestone belt in the Cuddapah basin, Andhra Pradesh;" (b) "in upper Cretaceous fluviatile Mahadek sediments in Meghalaya;" (c) "in quartz-pebble conglomerates at the base of the younger greenstone belts of Karantaka;" and (d) "in the Chhotanagpur gneissic complex of Sargula in the State of Madhya Pradesh." India has spent ca. $14 million per year on uranium exploration (e.g., for 1988 to 1991), and recent finds[44] have improved the resource picture a bit from that listed in the figures in Table 3a.

Table 3b shows an example fuel supply usage with half of a nominal target of 30 GW_e installed at the end 2020. In this example, ca. 33 kt of an initial 85 kt is used by 2020. This is without any imports or reprocessing of irradiated fuel, much less a plutonium fast breeder or thorium breeder program. It should be cautioned, however, that actual installed capacity at half the nominally desired target is a rough estimate, even for past performance. While the present state of financing and construction[45] makes it fairly clear that a suggestion enunciated in 1991 of 10 GW_e for "the turn of the century"[46] will not be met by at least about a factor of two, a much more careful probabilistic analysis would be needed to make well defined statements about the more distant future. Such a study would need to account for various possibilities for the availability of capital assets for more (or less) rapid installation of nuclear generating capacity.

Even if the decision for a 500 MW_e fast plutonium breeder is not fully carried through, as has been the case in other countries, the question of the extent that India (and Pakistan) will carry through with plutonium reprocessing also still needs careful examination. Recent studies have called into question whether constructing facilities for the safe reprocessing, fabrication, transport, and storage of plutonium in commercial reactor fuel will be a commercial viable enterprise in the U.S. for quite a long time.[47]

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43. Organization for Economic Cooperation and Development (OECD) and the International Atomic Energy Agency, *Uranium 1991 Resources, Production and Demand*, (Paris: OECD, 1992).

44. "India Finds New Uranium Deposit," *Nuclear Engineering International*, (November 1991) p. 4.

45. "Indian Nuclear Projects May Be Put on Hold," *Nuclear Engineering International*, (October 1994) p. 3.

46. S. L. Kati, "The Indian Experience—A Utility Perspective," *Nuclear Engineering International* (June 1991) p. 38.

47. J. Anderer, J. McDonald, and N. Nakicenovic, *Energy in a Finite World*, (Cambridge, MA: Ballinger, 1981); L. C. Hebel, "Limiting and Reducing Inventories of Fissionable Weapons Materials," (Palo Alto, CA: Stanford University Center for International Security and Arms Control, 1991).

However, differences in radiation protection,[48] reactor security, and financing lead to a somewhat different set of considerations about expanding existing reprocessing facilities

TABLE 3 Indian Fuel Supply

3a India Uranium Supply Rough Nominal Model: Estimates of Reserve Resources

RAR	*EAR-I*	*SR*	*Total*
50.61	15.54	18.72	84.87

3b Estimate of Reserve Usage

Begin Year	*Indian GWe*	*Annual Use ktonne*	*Total*
Pre-1991			84.87
1991	1.7	0.26	84.6
1992	1.7	0.26	84.4
1993	1.8	0.27	84.1
1994	1.9	0.29	83.8
1995	2.0	0.30	83.5
1996	2.5	0.38	83.1
1997	3.0	0.45	82.7
1998	3.5	0.53	82.2
1999	4.0	0.60	81.6
2000	4.5	0.68	80.9
2001	5.0	0.75	80.1
2002	5.5	0.83	79.3
2003	6.0	0.90	78.4
2004	6.5	0.98	77.4
2005	7.0	1.05	76.4
2006	7.5	1.13	75.3
2007	8.0	1.20	74.1
2008	8.5	1.28	72.8
2009	9.0	1.35	71.4
2010	9.5	1.43	70.0
2011	10.0	1.50	68.5
2012	10.5	1.58	66.9
2013	11.0	1.65	65.3
2014	11.5	1.73	63.6
2015	12.0	1.80	61.8
2016	12.5	1.88	59.9
2017	13.0	1.95	57.9
2018	13.5	2.03	55.9
2019	14.0	2.10	53.8
2020	14.5	2.18	51.6

Notes: Total Use (ktonne U) = 33.2; market price ($G/ktonne) @ .022; total cost ($G) = 0.73.

to a commercial role. Recent Indian reports of progress[49] on the capability to produce mixed plutonium and uranium oxide fuel (MOX) to avoid safeguard requirements for fueling the Tarapur light water reactor complex may have already had some impact on

48. “Datafile: Pakistan,” *Nuclear Engineering International*, (May, 1991) p. 52; “Radiological Improvements in India,” *Nuclear Engineering International*, (November 1991) p. 4.

49. “Domestic MOX Fuel to Be Used at Tarapur,” *Nuclear News*, (July 1993) p. 46.

the fuel supply question. In the end, Kirghizia offered[50] and China agreed to supply fuel, the receipt of a shipment of which for processing in India was announced at the beginning of 1995.[51] This finessed the announced plan for a commercial MOX fabrication and burning demonstration (or use of domestically enriched uranium[52] without obligating the U.S. or France to back down on previous objections to supplying the fuel without broader application of safeguards.[53]

An interesting "footnote" at the bottom of Table 3b is the total $0.73 billion cost of the an initial purchase of the indicated uranium consumption at recent international market prices of c. $10/pound ($22/kg). This total is substantially less than a realistic cost for a single plutonium breeder prototype. The amounts of fissile material involved are also substantially less than the amount of fissile material in a minimum estimated surplus of Soviet enriched uranium which is planned for deenrichment and "dumping" on the market on the next decade or so. In the context of the particular assumptions made in constructing Table 3b, the "problems" of current uranium "oversupply" and Indian fuel supply security could thus *in principle* both be addressed by stockpiling a plant generation's worth of material, either as part of an international agreement or instead of pursuing a plutonium breeder program.

In practice, of course, life is not so simple as just described. In practice, there are perceptions, and a possible reality, of higher installed future nuclear generating capacity. It should be kept in mind that India's nuclear program currently supplies only 2% of its generating capacity (with very small percentages also in Pakistan as well as in other large countries: China, Brazil, and Mexico).[54] Within plant lifetimes, there is thus certainly the potential for larger nuclear capacity installation rates than shown in Table 3b, especially in noncoal-producing regions if there is an unexpectedly dramatic increase price of fossil fuel imports. In practice also, negotiation of agreements for the bulk purchase and long term storage of a fuel stockpile of the indicated magnitude is not particularly likely. Extended negotiations on such a purchase could be expected to be met with a variety of domestic objections concerning financing terms, assurance of delivery, storage costs, national prestige, and/or the impact of resulting uncertainties on the domestic plutonium reprocessing program.

Pakistan's projected uranium requirements are more modest than India's, and its resources are comparatively substanital. Pakistan has worked on a solution mining technique for recovering low grade ores or use where underground tunnels is infeasible, such as the Bannu Basin and the Sulaiman Range. A pilot plant has been constructed in an area bordering the North West Frontier Province.[55] A complete study of the commercial value of plutonium in South Asia should also cover Pakistani electricity production, mining, enrichment, reprocessing, and access to Chinese an international market supplies with allowance for the possibility of limited rather than full scope safeguards.

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50. "World Survey," *Nuclear Engineering International,* (June, 1993) p. 21.

51. B. Chellaney, "Indian-Chinese Deal Startles Analysts," *Washington Times,* (11 January 1995); "India Defends Purchase of Enriched Uranium from China," *Agence France Press,* (10 January 1995).

52. "MOX, Enrichment both Said to Be Feasible," *Nuclear News,* (September 1993).

53. "France is Ready to Halt Fuel Shipments to India," *Nuclear News,* (August 1993) p. 22.

54. M. A. Khan, "Fifty Years of Nuclear Energy in the Third World," *Nuclear News,* (November 1992) p. 75.

55. "PAEC Technique Eases Uranium Recovery," *Nuclear Engineering International,* (1991) p. 4.

TABLE 4 Karachi Nuclear Plant Load Factors

Year	*Load Factor (%)*
1973	38
1974	49
1975	46
1976	40
1977	28
1978	19
1979	3
1980	7
1981	19
1982	7
1983	19
1984	24
1985	22
1986	44
1987	26
1988	16
1989	6
1990	35

Another important consideration in the type of studies suggested here concerns "load factors," the fraction of rated power capacity which is actually delivered. This can be significantly affected by power grid availability (and operation procedures)[56] in countries where resources for maintaining grid availability are stretched thinly. Pakistan's load factors for the aging[57] Kanupp reactor through 1990, listed in Table 4, are reported to have also been affected by "the cutting-off of foreign nuclear supplies and technical assistance since the mid-1970s."[58] The average load factor during the period shown in Table 4 was only about 25%.

India's nuclear power plant load factors for the twelve months ending June 1994 ("FY95") were also substantially below the world average for pressurized water reactors of 72%.[59] These are shown in Table 5 along with the approximate date each reactor went critical. There is no clear pattern in this table indicating that break-in or aging problems are responsible for this discrepancy. Moreover, Canadian heavy water plants performed excellently in availability compared to U.S. light water plants when the Canadian industry was similarly recent. (More recently, this gap may have narrowed. For example, Canadian Bruce 7 and 8 plants had load factors of 71% and 73%, respectively—still much higher than the Indian average.) Another consideration[60] in load factors is possibly overoptimistic power ratings (e.g., of 2x0.235 GW_e vs. 2x0.22 GW_e for Kakrapur and Kaiga). These are modest compared to more substantial operational problems (e.g., due

56. R. Senthilnathan, "Nation's Signing of Nuke Convention in Doubt," *India Abroad,* (26 August 1994) p. 18.

57. J. Wood, "Life Extension for Pakistan's Kanupp," *Nuclear Engineering International,* (December 1991) p. 7.

58. "Datafile: Pakistan," *Nuclear Engineering International,* (May 1991) p. 52.

59. *Nuclear Engineering International,* (October 1994) p. 123.

60. "Can Nuclear Pay Its Way in India," *Nuclear Engineering International,* (December 1991) p. 53.

TABLE 5 FY95 Indian Nuclear Load Factors

Plant	*Load Factor (%)*	*First Power*
Rajasthan II	63	Nov-80
Madras II	48	Sept-85
Tarapur I	39	Apr-69
Narora II	29	Jan-91
Kakrapur I	24	Nov-92
Madras I	23	Dec-78
Rajasthan I	4	Nov-73
Narora I	0	Jul-89

to inlet manifold failure at Madras and calandria and shield wall leaks and turbine blade cracks at Rajasthan), but increasing experience with operations and repairs should also be taken into account.[61]

While not trivial, the issues just delineated are all subject to relatively straightforward analysis and modeling. The "straw man" illustration given in Table 3b suggests that a well done study of such issues guided by significant South Asian input on methodology and conclusions could help clarify some important issues concerning the commercial role of plutonium. Of course, plutonium reprocessing may proceed in any case on national security grounds in India and/or Pakistan. The purpose of a study of the commercial value of plutonium would be to supplement other studies of the need for it under various domestic and international circumstances, so that a more complete picture of the entire issue might eventually emerge. An advantage of pursuing such a study as a part of a program on confidence building measures is that no international agreements would likely be needed to conclude such a study, beyond standard visa processing. The funding requirements should also be relatively modest, and need not necessarily all come from U.S. government sources.

Detection of Fissile Materials

A study aimed at improving the quality and availability of nondestructive nuclear assay technologies could begin with one or two South Asian technical experts visiting U.S. facilities to engage in joint research. Of particular interest in this regard is the development and use of deuterium-tritium neutron sources (c.f. attached Appendix and Addendum). Existing sources and recent proposed improvements can provide a high and modulatable flux of various energy neutrons for noninvasive assay of a variety of materials. They are particularly suited to assay of uranium isotopes. However, they can also improve detectability of plutonium, nitrogen used in chemical explosives, and a variety of other relevant materials. Considerable valuable work remains to be done in this area. This includes research and development on cheaper and more reliable and convenient neutron sources. It also includes signal detection technology. A potential fruitful research area involving little or no costly hardware is characterization of the

61. S. L. Kati, "The Indian Experience—A Utility Perspective," *Nuclear Engineering International*, (June 1991) p. 38; "Can Nuclear Pay Its Way in India," *Nuclear Engineering International,* (December 1991) p. 53.

utility of the method in various configurations with various possible types of necessary, coincidental, or deliberate shielding of the material to be detected. (An appendix may be added evaluating the electrostatic ion confinement approach as a specific candidate for such research.)

Very substantial progress on such a project could be made in the context of standard visa and laboratory visitation procedures. Without some specific agreement with South Asian research laboratories, the participating South Asian personnel could be limited to scientists on the job market or in academic or industrial institutions. A resulting likely bias toward career entry scientists might be desirable in any case, provided that sufficient incentives were incorporated to return such scientists to relevant work in their countries of origin. Provided that a small number worked on ongoing research projects or project proposal development efforts, financial requirements for such an initiative should be quite modest.

Portal Monitoring

It should be relatively straightforward to arrange international participation in an abstract study of possibilities for portal monitoring at South Asian facilities. A study of a pair of relatively nonsensitive facilities, such as major international airports, might also not be too difficult to manage. Cooperation for detailed study of military or nuclear production or storage facilities might likely require extensive negotiations to arrange, however. Demonstration of interesting results from a more abstract or tangential case study would likely be needed before this could be accomplished.

Section Five
Conclusions

The overall conclusions to be drawn from the present report are cautious but hopeful. First and foremost, a survey of South Asian nuclear capabilities indicates that the point of aquiring ability to construct nuclear arsenals capable of devastating South Asian populations has been passed. This may be a disappointment for those who wished it would not happen and a denouement for those who have precicted or pressed for it, but from either point of view it is unavoidable. Except for the possibility of formalizing the status quo on nuclear testing with a comprehensive ban, there also appears to be little that can realistically be expected in the near future in the way of sweeping formal nuclear arms control agreements involving Pakistan or India.

On the other hand, an all out nuclear arms race in South Asia has so far been avoided. India and Pakistan have also initiated some limited confidence building measures. That one or both countries will adopt a policy of nuclear sufficiency without order of magnitude increases in military nuclear capability appears to be conceivable. Both societies are also sufficiently open that dialogue with those educated in policy and technical areas is possible to a significant degree. It seems reasonable, therefore, to expect that it might be well worthwhile to take modest steps towards facilitating any desire these countries might develop in the area of nuclear confidence building measures in the future. What seems most practicable at the present time is exchanges of personnel and information relevant to this end. The three specific projects outlined above are specific examples of areas where this might be fruitful.

There are a number of guidelines which might be useful in this light. First, one of the primary purposes of exchanges of technical personnel is the development of internationally distributed expertise in arms control and confidence building measures. To this end, requirements or incentives for participants to return to active work in their countries of origin might be useful. For example, grants might include modest support dedicated to future support for travel, equipment, and/or salaries for relevant work completed in the country of origin after an exchange visit. It could also be useful if technical personnel involved in such exchanges *on both sides* could participate in activities aimed at building a better understanding of the international and South Asian political and cultural background in which the seeds of their work may grow or wither. A variety of foundation programs provide some useful if more limited models for both of these approaches.

One thing that is essential, in the author's view, to the success of U.S. sponsorship of any such endeavors is a thorough-going appreciation of the reality that the nature of any nuclear confidence building measures successfully adopted now lies essentially exclusively in the hands of Asian decision makers. There is, however, one abstractly conceivable U.S. policy initiative which appears to have a reasonable chance of having a substantial direct impact on South Asian approaches to management of nuclear weapons materials. This would involve a comprehensive initiative towards very limited and much more comparable nuclear weapons sufficiency on the part of all declared and undeclared nuclear weapons states, for example, over the course of the next century. It appears that such an initiative is unlikely to successfully compete for inclusion on the official agendas of all of the declared nuclear weapons states in the near future. It may, nevertheless, facilitate communications if the individual participants in exchange programs are prepared to face queries concerning this impasse. However, the scope of any officially sponsored near-term cooperation will necessarily be constrained by limits imposed by the lack of a mutual understanding by the participating governments concerning this global question. Despite these limits, it appears possible that substantial useful work can be done along the lines suggested in this report.

Appendix: An Evaluation of the Potential of a High Flux 14 MeV Neutron Source

This Appendix examines the potential for utility of developing expertise with 14 MeV neutron sources for possible eventual use in confidence building measures in South Asia. As noted in the main text of this report, using neutron sources[62] for active investigation of possible sources of special nuclear materials is of particular interest in South Asia for two reasons. First, the preexistence of modest but substantial amounts of various production facilities and grades of uranium and plutonium in South Asia may provide a particular challenge for nuclear confidence building measures. The existence of the strongest possible indigenous technology bases for detection of such materials would give policy makers in Pakistan and India maximum confidence that any technically feasible confidence building measures they would agree to could actually be implemented. Second, procedures established elsewhere[63] which limit the range of technologies used for detecting such materials have not yet taken root in South Asia. It is, therefore, still practical to consider the widest possible range of technologies for such purposes.

Use of modulatable high flux and energy neutron sources for nondestructive investigation of locations where storage of special nuclear materials is controlled would ideally be a part of a maximally effective set of available tools. A modulatable neutron generator is particularly useful for discriminating between sought-for materials and background signals from natural and/or man-made sources. A high flux source allows for rapid detection of small, distant, or moderately well shielded materials. Using a source which produces high energy neutrons allows for maximum flexibility. The source can be moderated near to thermal energies and/or collimated. Alternatively, high energy neutrons can be used for slightly improved penetration, and more significantly for measurement of particular isotopes in shielding materials by inelastic scattering. Some 14 MeV neutron instruments allow for depth measurements as well as horizontal and vertical scanning. (This is done by measuring the time delay between the alpha particle given off in the neutron-producing reaction and the signal produced by the neutron interacting with target materials.) Thus, these so-called “active” methods of nondestructive can be a useful complement to “passive” assay techniques for characterizing special nuclear materials and their surrounds.[64]

There is presently a variety of neutron sources available for use in active nondestructive assay measurements. Of particular interest here are sources which operate by accelerating deuterons towards a tritium-bearing solid target. While commercially available and

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62. H. H. Barschall, G. A. Bartholomew, C. B. Bigham, R. C. Block, R. M. Brugger, R. E. Chrien, S. Cierjacks, H. Conrads, J. S. Fraser, G. F. Knoll, M. A. Lone, C. A. Uttley, L. Walter, G. B. West, and W. L. Whitmore, *Neutron Sources for Basic Physics and Applications,* (Paris: OECD, 1982).

63. Monsanto Research Corporation, *Handbook of Nuclear Safeguards Measurement Methods, U.S. Nuclear Regulatory Commission Report NUREG/CR-2078,* (Springfield, VA: National Technical Information Service, 1983).

64. D. Reilly, N. Ensslin, H. Smith, Jr., and S. Krainer, eds. *Passive Nondestructive Assay of Nuclear Materials, U.S. Nuclear Regulatory Commission Report NUREG/CR-5550 and Los Alamos National Laboratory report LA-UR-90-732*, (Springfield, VA: National Technical Information Service, 1991).

relatively well characterized, such sources have a number of limitations. Chief among these for some applications are limited flux and a lifetime limited to some hundreds of hours. It can reportedly also be difficult to produce the most convenient sine-wave modulation of these sources. For extended operation where high sensitivity is needed, it might be useful to have a source without such limitations.

In principle, ion electrostatic confinement (IEC) devices can operate in a steady state or modulated mode for extended periods at high flux. An IEC device concentrates high energy hydrogen isotopes in a region surrounded by a grid charged up to several tens of kilovolts. The ions interacting in the central plasma undergo neutron-producing fusion reactions. Simple extrapolation of exploratory device yields operating with deuterium at lower power to deuterium–tritium operation at higher power suggest that about two orders of magnitude higher neutron fluxes should be achievable then for existing long-pulse sources using tritium immobilized in a solid. The intersecting ion streams in the IEC allow fusion reactions to be obtained with a substantially lower voltage than for a fixed tritium target. In principle, it should be relatively straightforward to sine-wave modulate the output of such a device at useful frequencies. Also, electrodes have been reportedly been operated in comparable devices for well over a thousand hours. Thus, a cheap and durable field-tested IEC with modest power supply requirements is conceivable.

Quite a few questions remain to be answered before one can assess the full potential of high energy neutron sources for eventual possible field use in South Asia. With respect to the IEC, these include the following. Will simple extrapolations to predict fluxes be reproduced by detailed simulation code modeling, which has been systematically calibrated against available experimental data? Will electrode lifetimes for modulated sources operating at high power actually significantly extend the field lifetime of available high energy neutron sources? Is the lower tritium inventory of such a source a significant advantage, or is this advantage neutralized by the fact that the plasma tritium is in a much more mobile form? Will neutron activation of the vacuum chamber be a significant concern for field operations? Is adequate shielding practical in a field system? Will the advantage of lower voltage requirements be more than lost in the additional complexity of pumping and control systems for an operating field source? Are alpha–neutron coincidence measurements practicable using a system where a high rate of alpha particles must be detected inside a relatively complex container? Can the entire system be developed to a reliable and readily maintainable package at a reasonable cost?

Probably the most central of these questions is whether existing simple flux extrapolations are essentially correct. If a final system were in fact to operate at lower fluxes than sources which are presently commercially available, then the IEC would likely be of considerably less interest. Our investigations of this question to date have been limited to determining whether work on this problem would be a practical project for international collaboration. To this end, we have written computer coding to reproduce results in the original published reference on this question, and have obtained and analyzing coding aimed at a detailed particle simulation of the ions in the device. This work has confirmed that the assumptions used in the available literature are inadequately accurate for such a determination. Modification or rewriting of coding for a more adequate treatment appears to be a tractable problem for a single scientist visiting on a one or two year exchange, but lies beyond the scope of the present study. Thus, this task is a possible candidate for a tractable international cooperation. A detailed summary of this work is included here as an addendum.

Experimental calibration of simulation models used to extrapolate IEC neutron fluxes would require a specific set of experiments run for this purpose. Adding a visiting scientist to an existing experimental team for a year or to in order to accomplish such experiments is also a possible candidate for international cooperation.

In order to guarantee a directly practical outcome for a group of participating South Asian scientists, it would be useful to run studies using existing 14 MeV neutron sources in parallel with attempts to develop better sources. Especially in connection with studies of an integrated portal monitoring exercise, it could be beneficial to correlate computational and laboratory studies of the use of commercial sources for nondestructive examination of special nuclear materials with various shielding configurations of interest. Small scale research reactor operations could provide a useful test bed for such studies, especially in establishments already familiar with the operation of relevant neutron and/or neutron-induced gamma measurements. A widely used neutron transport simulator (such as the “MCNP” code) would be a useful computational tool for such studies. One to three visiting scientists could usefully be employed in a pilot project of this type. Conducting such studies at an institution where graduate or undergraduate students from participating regions were present could also expand the pedagogical use of such reactors from more traditional areas related primarily to nuclear reactor operations.